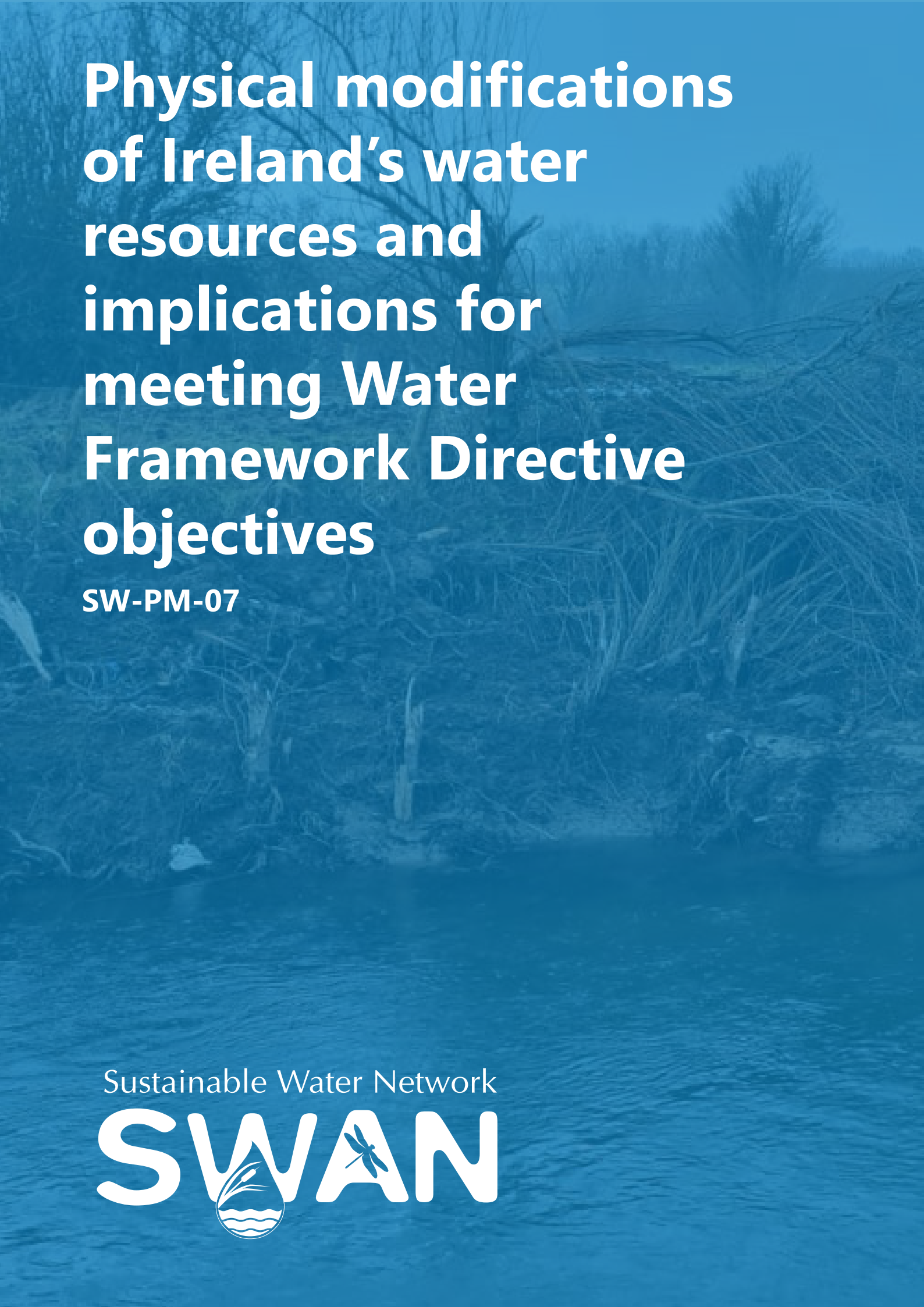
Physical modifications of Ireland's water resources and implications for meeting Water Framework Directive objectives

SW-PM-07



Sustainable Water Network

SWAN

Kenneth Irvine PhD and Konstantina Katsanou PhD,

Department of Water Resources and Ecosystems,
Delft IHE Institute for Water Education, Delft, Netherlands.

Eiven Curran, B.A., BL, M.Sc. (Econ), M.B.A., DipLegalStud.



Table of Contents

TABLE OF CONTENTS ..... **I**

ACKNOWLEDGEMENTS ..... **IV**

ACRONYMS ..... **V**

REPORT SUMMARY ..... **VIII**

Hydromorphology and the WFD viii
Indicators for WFD assessment ix
European Case Studies xiv
Legislation relating to hydromorphology in Ireland xv
Development and application of knowledge xvi
Stakeholders engagement xx
Irish Case Studies xxi
Legal Overview xxv
Recommendations xxviii

1 GENERAL INTRODUCTION **1**

1.1 Physical structure and the ecological integrity of water bodies 1
1.2 Hydromorphology and WFD 3
1.3 Assessment Methods 10
1.4 Monitoring for hydromorphology 16
1.5 Overview of main hydromorphological pressures on the European water bodies 19

2 HYDROMORPHOLOGICAL ASSESSMENT ON WATER BODY TYPES **27**

2.1 Methods for gathering literature to review 27
2.2 Surface water bodies: Rivers 28
2.2.1 Barriers and impoundments *31*
2.2.2 Water Abstraction *37*
2.2.3 Channelisation *37*
2.2.4 Dredging of sediments and removal of in-stream and riparian vegetation *39*
2.2.5 Flood protection *46*
2.2.6 Land-use and Floodplains *49*
2.2.7 Arterial drainage in Ireland *50*
2.2.8 Designation of HMWBs in Ireland *54*
2.2.9 Summary River Assessment *63*
2.2.10 Biological trait assessment *70*
2.3 Surface water bodies: Lakes 71
2.3.1 The pelagic zone *71*
2.4 Groundwater bodies and GDEs 73
2.4.1 Littoral zone *81*
2.4.2 Springs *85*
2.4.3 The management and assessment of GDEs *86*
2.5 Transitional and coastal water bodies 90
2.5.1 Transitional water bodies *93*
2.5.2 Assessment methods for transitional and coastal water bodies at European level *97*
2.5.3 Coastal water bodies *101*
2.6 European Case Studies employing ecosystem to mitigate hydromorphological pressures 102
2.6.1 Room for the River Project, The Netherlands *102*
2.6.2 Space for river and management in the Loire/Allier River, France *105*

2.6.3 Restoration of Skjern River, Denmark *110*
2.6.4 Nature Based Solutions and the Cityscape *116*

3 KNOWLEDGE DEVELOPMENT IN HYDROMORPHOLOGY THROUGH THE WFD 121

3.1 EU projects to support WFD implementation 121
3.2 Transposition and administration of WFD in Ireland 132
3.2.1 Legislation and overview of administrative structures for WFD implementation in Ireland *132*
3.2.2 Guidance and planning governing hydromorphological alterations *135*
3.2.3 Links of WFD with other EU legislation relevant to hydromorphology *136*
3.2.4 Programmes of Measures for a Protected Species *148*
3.2.5 Hydromorphology and its importance for other key EU Directives *150*
3.3 Development of hydromorphological management planning in Ireland 154

4 RIVER BASIN PLANNING AND HYDROMORPHOLOGY 165

4.1 River Basin Management Plans 165
4.1.1 RBMP Water Action Plan (WAP) (2022-2027) *172*
4.1.2 HMWBs, Land drainage and Land-use (see also Section 2.2.7) *181*
4.1.3 Mitigation of the negative impact of constructions in or near water bodies *184*
4.1.4 Invasive species *185*
4.1.5 Links to climate change in the third cycle Water Action Plan *186*
4.1.6 Water Dependent Habitats and Species, and Appropriate Assessment *187*
4.1.7 Conclusion, third cycle RBMP and hydromorphology *187*
4.2 Hydromorphology Stakeholders Consultation Meeting 189

5 APPLICATION: IRISH CASE STUDIES 194

5.1 Irish Rivers 194
5.1.1 Shannon River *194*
5.1.2 River Lee *204*
5.1.3 River Liffey - Poulaphouca Reservoir *208*
5.1.4 River Erne *210*
5.2 Coastal and transitional: Irish case studies 214
5.2.1 Tacumshin Lake *214*
5.2.2 Waterford Port Dredging (2018-2026) *215*
5.2.3 Bantry Bay *217*
5.3 Urban Flood Relief Schemes 217
5.3.1 Qualifying schemes and conditions *218*
5.3.2 Clonakilty Flood Relief Scheme *219*
5.3.3 The River Deel and Crossmolina Flood Relief Scheme *223*
5.3.4 Blackpool Flood Relief Scheme *225*

6 LEGAL OVERVIEW 246

6.1 Overview of chapter 246
6.2 Water Framework Directive provisions 247
6.2.1 The WFD and Weser (Case C 461/13) *250*
6.2.2 Implementing the WFD in Ireland *253*
6.3 Planning and Development Acts 257
6.3.1 Planning and WFD *260*
6.4 The WFD and interface with the Nitrates Directive and the Floods Directive 265
6.5 Environmental assessments and WFD 274
6.5.1 Birds and Habitats Directives *274*
6.5.2 Conflicts between the Habitats Directive and WFD *276*
6.5.3 The Strategic Environmental Assessment Directive (SEA) *277*
6.5.4 Environmental Impact Assessment Directive *279*
6.5.5 Assessment of challenges with respect to WFD implementation *284*

7 RECOMMENDATIONS 292
7.1 Hydromorphological Assessment 292
7.2 Barriers 293
7.3 Water Abstraction/ Climate Change 293
7.4 Channelisation, dredging, sand and gravel extraction, and sediment management 294
7.5 In-stream and riparian vegetation 294
7.6 Flood Protection and Nature Based Solutions 294
7.7 Land-use 295
7.8 HMWBs and AWBs 295
7.9 Lakes 296
7.10 Groundwater bodies and Groundwater Dependent Ecosystems (GDEs) 296
7.11 Transitional and coastal water bodies 297
7.12 Legislation relating to hydromorphology in Ireland 297
7.13 River Basin Management Plans and Programmes of Measures 298
7.14 Stakeholders' input 299
8 REFERENCES 301
ANNEX I: RESULTS FROM THE STAKEHOLDER QUESTIONNAIRE 353
ANNEX II: REPORT OF THE STAKEHOLDERS' WORKSHOP 375

Acknowledgements

During the writing of this report and the extensive collation of material, we have read and reviewed many papers, reports and websites. This has drawn on the knowledge and experience of several people working in areas that could be considered falling within the broad sphere of hydromorphology, or in science and policy relevant to placing the topic in an applied context. We also engaged in much stimulating discussion and would like to especially thank Kasper Spaan, Beleidsadviseur Klimaatadaptatie of RESILIO for outlining the city greening initiatives of the Netherlands, and Martina Bussettini of Ecologic for her deep insight to hydromorphology and the EU Water Framework Directive. We thank Harriet Emerson for her skilful management of an on-line hydromorphology workshop with Irish stakeholders. Many insights on Nature Based Solutions were provided through an earlier attendance at a workshop in preparation of a World Development Report on the topic. Tom O'Connor and Ashley Glover provided stimulating conversation on the management and policy in Ireland, and Chris Moody gave up considerable amount of time and generosity in providing material for the case study on the Bride River, Blackpool. We thank the Irish Government Expert Working Group on hydromorphology for discussion and feedback on a previous draft of this plan and based on the draft third cycle River Basin Management Plan. Finally, we are grateful to Elaine McGoff and Sinéad O'Brien for reading and commenting on earlier sections of the draft report. We are especially appreciative of Sinéad for her patience as the report grew in size, and for her management of the project for the Sustainable Water Network (SWAN).

Acronyms

AA	Appropriate Assessment
ACRES	Agri-Climate Rural Environment Scheme (ACRES)
AEOS	Agri-Environment Options Scheme
AEP	Annual Exceedance Probability
AIE	Access to Information on the Environment
AMBER	Adaptive Management of Barriers in European Rivers programme
ARCs	Activities Requiring Consent
ASSAP	Agricultural Sustainability Support and Advisory Programme
AWBs	Artificial water bodies
AQUACROSS	AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies programme
BOD	Biological Oxygen Demand
BQE	Biological Quality Element
CAP	Common Agricultural Policy
CCMA	County and City Management Association
CEMP	Construction Environmental Management Plan
CEN	European Committee for Standardisation
CFRAM	Catchment Flood Risk Assessment and Management Programme
CIS	Common Implementation Strategy
CJEU	Court of Justice of the European Union
COFORD	National Council for Forest Research and Development
COP	Convention of the Parties
COSAINT	Cattle Exclusion from Water courses: Environmental and Socio-economic Implications programme
CRU	Commission for Regulation of Utilities
DAFM	Department of Agriculture, Food and Marine
DCI	Dendritic Connectivity Index
DD	Drainage District
DECC	Department of the Environment, Climate and Communication
DELGH	Department of the Environment, Local Government and Heritage
DETECT	Disentangling the Effects of multiple Stressors on the Ecology of Water Bodies programme
DHPLG	Department Housing, Local Government & Heritage
DMNR	Department of the Environment, Climate and Communications
DPSIR	Drivers, Pressures, Impact, State, Response model
DSFI	Danish Stream Fauna Index
EBM	Ecosystem Based Management
EC	European Commission
EcA	Ecological Assessment
EIAs	Ecological Impact Assessment
ECRR	European Centre for River Restoration
EDM	Environmental Drainage Maintenance
EEC	Estuary Environment classification
EFI	European Fish Index
eFlows	Environmental Flows
EHI	Estuarine Health Index
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EIS	Environmental Impact Statements
EPA	Environmental Protection Agency Ireland
EREP	Environmental River Enhancement Programme
ESB	Electricity Supply Board
EQO	Environmental Quality Objectives
FEPS	Forest Environmental Protection Scheme
FFGs	Functional Feeding Groups
FOWG	Swiss Federal Office for Water and Geology

FRMPs	Flood Risk Management Plans
GAP	Good Agricultural Practice
GBC	Groundwater Biodiversity Concern index
GDEs	Groundwater Dependent Ecosystems
GDTEs	Groundwater Dependent Terrestrial Ecosystems
GEP	Good Ecological Potential
GES	Good Ecological Status
GIS	Geographic Information System
GLAS	Green, Low-Carbon, Agri-Environment Scheme
GSI	Geological Survey of Ireland
GUS	Geomorphic Units survey and classification System
HHR	Hydrological-Hydromorphological Risk
HMWBs	Heavily Modified Water Bodies
HNV	High Nature Value
HQI	Hydromorphological Quality Index
HSE	Health Service Executive
HHYC	Impacts altering habitats due to hydrological changes
HMOC:	Impacts altering habitats due to morphological changes.
IBEC	Irish Business and Employers Confederation
ICZM	Integrated Coastal Zone Management
IFA	Irish Farmers Association
IFI	Inland Fisheries Ireland (previously Central Fisheries Board)
IPPC	Integrated Pollution Prevention and Control Directive (2008/1/EC)
IROPI	Imperative Reasons for Overriding Public Interest
IUCN	International Union for Conservation of Nature
IW	Irish Water
IWRM	Integrated Water Resources Management
LAWPRO	Local Authority Waters Programme
LHS	Lake Habitat Survey
LLFRS	Lower Lee Flood Relief Scheme
MEP	Maximum Ecological Potential
MImAS	Morphological Impact Assessment System
MQI	Morphological Quality Index
MS	Member state of the EU
NBS	Nature-Based Solutions
NAP	Nitrates Action Programme
NCEA	Netherlands Commission for Environmental Assessment
NCMC	National Co-ordination and Management Committee
NGOs	Non-Governmental Organisations
NHA	Natural Heritage Area
NIEA	Northern Ireland Environment Agency
NIS	Natura Impact Statement
NPF	National Planning Framework
NPWS	National Parks & Wildlife Service
NTIG	National Technical Implementation Group
NWRM	Natural Water Retention Measures
OPW	Office of Public Works
OSPAR	Oslo/Paris Convention (for the Protection of the Marine Environment of the North-East Atlantic)
PA	Physical Alteration
PAA	Priority Area for Action
PFRA	Preliminary Flood Risk Assessment
PIANC	World Association for Waterborne Transport Infrastructure
POM	Programme of Measures
RBAPS	Results Based Agri-environment Pilot Scheme
RBD	River Basin Districts
RBMP	River Basin Management Plan

REBECCA	Relationships between ecological and chemical status of surface waters programme
REFORM	REstoring rivers FOR effective catchment Management programme
REPS	Rural Environmental Protection Schemes
RESTORE	Restoring Europe's rivers programme
RHAT	River Hydromorphology Assessment Technique
RHS	River Habitat Survey
SACs	Special Areas of Conservation
SAGE	Schéma d'Aménagement et de Gestion des Eaux (Water Management and Management Schemes)
SEA	Strategic Environment Assessment
SERCON	System for Evaluating Rivers for Conservation
SI	Statutory Instrument
SNIFFER	Scotland & Northern Ireland Forum For Environmental Research
SOPs	Standard Operating Procedures
SPAs	Special Protection Areas
SPS	Single Payment System
SSNet	Managing the Small Streams Network project
SSSI	Sites of Special Scientific Interest
STAR	Standardisation of River Classifications: Framework method for calibrating different biological survey results against ecological quality classifications to be developed for the Water Framework Directive programme
SuDS	Sustainable Urban Drainage System
SWAN	Sustainable Water Network
TAGs	UK Technical Advisory Groups
TraC-MImAS	Transitional and Coastal Waters Morphological Impact Assessment System
TDS	Total Dissolved Solids
UCC	University College Cork
UKTAG	UK Technical Advisory Group on the Water Framework Directive
USEPA	United States Environmental Protection Agency
WFD	Water Framework Directive (2000/60/EC)
WPAC	Water Policy Advisory Committee
WWDR	UN World Water Development Report
WWTP	Waste Water Treatment Plant

Report Summary

Hydromorphology and the WFD

The Water Framework Directive 2000/60/EC (WFD) provided a new vision for the protection of European water resources and aquatic habitats. A fundamental element of the legislation is the recognition of the importance of hydrological regimes, connectivity of aquatic ecosystems, and the nature of the habitat within and adjacent to water bodies. These components that combine hydrology, hydraulics, and morphometry fall within the new integrated term of hydromorphology. The WFD requires policy measures to prevent or mitigate hydromorphological alterations. These measures apply to all water bodies defined in the Directive, including a class identified as water dependent habitats, such as vegetated wetlands. Good hydromorphological conditions provide an ecosystem structure of physical habitat for biotas such as fish, invertebrates and aquatic macrophytes commensurate with good ecological status.

This report reviews and summarises the key principles that underpin hydromorphology, its alteration, and importance within the WFD. The structure and ecological function of any water body is highly influenced by the physical nature of the water body and type-specific responses of biological quality elements (BQEs). For Europe's surface waters, including groundwater dependent terrestrial ecosystems, transitional, and coastal waters, many negative effects are already evident through physical modifications that have occurred.

In Annex V of the WFD, hydromorphological conditions are only explicitly described for high status water bodies, leading to an interpretation among some Member States that specific assessment of hydromorphological conditions and alteration is not applicable for good or less than good status for WFD classification. The European Commission WFD advisory ECOSTAT group has indicated that this may not be the case, and that hydromorphological assessment is required for each of the 5-class biological classifications and the requirement for assessment techniques that are responsive to hydromorphological alterations along the full gradient of status classes.

The hydromorphological quality elements mentioned in guidance produced by the WFD Common Implementation Strategy Group included a number of hydromorphological elements that could be monitored to detect “possible impacts or changes in state”, although not specific on what hydromorphological elements need to be monitored. The range of possible hydromorphological alterations is very extensive, extending to catchment processes and diverse locations that may be at considerable distance from a water body. Hydromorphological alterations and impacts can have profound interaction with other pressures. It can, therefore, be concluded that the scope of the meaning of hydromorphological pressures is all, or any, change from reference state that can affect the hydrological regime, continuity and morphology that threaten the ecological status of water bodies, including groundwater dependent ecosystems (GDEs).

Hydromorphological assessment can involve added complexity compared with seemingly more straightforward response of BQEs to pressures such as nutrients, organic matter, and acidity. Land-use policies including agriculture, forestry, urban development, ports and

harbours provide pressures that may lead to failure in achieving WFD objectives because of hydromorphological alterations and their interaction with other pressures.

Indicators for WFD assessment

BQEs sensitive to hydromorphological alterations are generally underused in water body classification. There is further need for understanding ecological mechanisms that link hydromorphology to BQEs, and development of indicators sensitive to hydromorphological alterations. While a large range of hydromorphological changes can alter the ecology of a water body, the majority of European countries use site-specific metrics of physical habitat rather than more ecologically relevant measures of hydrological and geomorphological processes.

A conceptual recognition of what constitutes hydromorphological pressures is not matched with application of indicators or common methodology. Guidance has been developed through the WFD Common Implementation Strategy (CIS) advisory group on hydromorphology and the European Committee for Standardisation (CEN) for general standardised approaches to biological and physical monitoring. Standard Operating Procedures (SOPs) are developed by individual Member States to guide monitoring. Key considerations for the management of water bodies and for the understanding and mitigation of hydromorphological alterations relate to 1) Barriers and Impoundments; 2) Water Abstraction; 3) Channelisation; 4) Dredging, sand and gravel extraction and removal of in-stream and riparian vegetation; 5) Flood protection; and 6) Land-use. While all of these pressures are common in rivers, they also apply to a greater or lesser extent in other water body types.

Barriers

Human-constructed barriers in rivers range from small weirs to mega-dams that completely alter the hydromorphology of large sections of rivers, other water bodies, and sediment outflow to coastal areas. Barriers particularly interfere with fish migrations and sediment mobility. Impounded water upstream of a barrier changes the nature of a water body. Managing flow regimes for environmental and social economic benefits is increasingly recognised as important. Managing for such environmental flows is a less dramatic mitigation than removal of dams, which is also occurring in many parts of the world. Removal of smaller barriers such as weirs is often seen as producing net ecological and social benefits.

Water Abstraction

Abstraction of water can have major effect on flow regimes, residence times of water bodies, and critical water availability for GDEs. Groundwater abstraction may affect groundwater discharge to rivers and impacts on riparian vegetation. Small individual abstractions can lead to large cumulative effects. For GDEs such as turloughs, 'local' abstraction may have far-reaching effects. Effective management of abstraction is a critical part of the WFD. Ireland enacted the Water Environment (Abstractions and Associated Impoundments) Act 2022. This requires the registration of any abstraction greater than 25 m^3 in a 24-hour period, and if no rate of allowed abstraction is prescribed, then there will be a need for a licence for abstractions of 2000 m^3 or more within a 24-hour period. Subsequently, a recent ruling (22nd November 2025) of the Court of Justice of the European Union European Court was that the Government of Ireland has failed to provide adequate controls on water abstraction.

Channelisation

The straightening of rivers, or channelisation, often results in extensively modified habitats, with effects on geomorphological and ecosystem functions, and disconnection with the riparian zones. Increasing the velocity of water in the channel leads to scouring and deepening of the stream bed. It can create a 'nick-point' at the upstream end, causing an erosive process that moves upstream. Scouring of the channel means that removal of finer bed sediment can create an armoured bed. Incising of the channel can lead to riverbanks becoming higher and often more unstable, resulting in erosion and sediment deposition downstream. In gentle flowing rivers, channelisation can increase siltation that can lead to in-stream sediment barriers and prolific weed growth. This leads to increased need for maintenance. In steeper topography, channelisation can increase in-stream power to such an extent as to negate any subsequent attempts at restoration.

Dredging, sand and gravel extraction, and sediment management

Channelisation, along with flood control and navigation maintenance, often require periodic dredging. This disturbs habitats and affects sediment dynamics. In many parts of the world, extraction of sand and gravel has major effects on river and other water bodies. This disturbance can range in scales from small artisanal works to industrial-scale licensed activities. While dredging of inland water bodies is likely a lesser, although often unknown, problem in Ireland, a main disturbance on river systems is from mobilisation of sediment during river maintenance and input of sediment from land-use. This can lead to sorting of sediment particles by size, and movement downstream of fine particles, increasing river turbidity, with potential to clog habitats. While sediment is mentioned in the WFD as important for continuity, so that sediment can "pass freely up and down rivers and laterally within the floodplain", specific focus on the importance of sediment dynamics for healthy ecosystems has been largely neglected in the implementation of the WFD. While essential for river and coastal geomorphology and associated habitats, it is also a pollutant in its own right. Sediment can be a matrix for adsorption to soil particles of other pollutants, including heavy metals and phosphorus.

Sediment mobilised from the catchment arrives in water bodies through a variety of hydrological pathways. Most suspended sediment is transported during storm events. In grassland agriculture, sediment mobility can be promoted by animals disturbing soil along hydrological pathways. Overgrazing by sheep in uplands, often combined with upland forestry, can lead to high loads of sediment to streams. Loss of soil from peatlands can be particularly harmful to ecological health of rivers because of the prevalence of particulate organic matter. This can be particularly prevalent in forested catchment during planting and felling of trees. Riparian buffer strips retain sediment, but the effective width and structure vary depending on the nature of the land-water interface. The importance of sediment in rivers calls for what the WFD terms "Supplementary Measures" for sediment transport management. This would include assessment and mitigation connected with infrastructures or other interventions in rivers and estuaries, dredging, siltation of riverbeds, erosion of beds and banks, receding deltas, and infilling of estuaries. There is a need for sediment budgets at the river basin scale.

In-stream and riparian vegetation

Woody debris and riparian vegetation are key elements for river and lake ecology. Woody debris is often viewed as something to be removed rather than a critical ecological resource. Its removal can change flow hydraulics, simplify ecosystem structure, reduce organic matter retention, and have an impact on bed and bank stability. Riparian trees and other vegetation provide ecological structure for both aquatic and terrestrial life and provide a natural physical roughness at the edge of stream or lake that reduces scouring of the bank. In small and mid-sized streams, channel and stream bed modifications are major morphological stressors on physical habitat quality. The removal of woody debris generally increases river flow velocity because of reduced boundary roughness and homogenises lake shore ecological structure. The importance of riparian vegetation has been underestimated in water body assessment and hydromorphology.

Flood protection

Flood protection using traditional hard engineering approaches can have profound effects on water body morphology, hydraulics and ecology. The need to assess and mitigate the impacts of hydromorphological alterations is a requirement of the WFD. Article 4.7 requires "assessment to determine whether the beneficial objectives served by the flood protection modifications or alterations cannot for reasons of technical feasibility or disproportionate cost be achieved by other means, which are a significantly better environmental option." Alternatives to traditional flood protection are increasingly applied across Europe. This introduces a larger discussion about the net value, costs and benefits, of flood defences. In Ireland, the Office of Public Works (OPW) is the responsible body for flood defence, operationalised through arterial drainage and urban flood defence. Surface water storage, through dams, embankments and retention ponds is a traditional approach to attenuating flood peaks. Generally, greater attention to water storage in the catchment and use of 'green infrastructure' is gaining traction for flood management, with associated benefits such as reduction in nutrient loads from land to water, and increased extent of wetland habitat beneficial for biodiversity. Some of these techniques are being employed in Irish flood management, but greater consideration of a more ecological approach to flood management is required. This applies also to the management of coastal and transitional zones. Loss of salt marsh and estuarine mudflats has major impacts on coastal habitats and the species that depend on them. Flood Protection Projects that derive from, or assist, with the implementation of the Flood Risk Management Plans (FRMPs) require assessment for their compatibility with WFD objectives.

Land-use

The management of water bodies cannot, and should not, be separated from that of the catchment. Lateral connectivity is critical for hydrological, and pollutant yields from land to water. Many European floodplains, including in Ireland, have been dramatically modified. Disconnection between the river and the land through altered floodplains has an impact on ecological processes. Changes in land-use patterns can increase or decrease water availability to surface waters, effected by changing surface run-off and groundwater recharge. In Ireland, the hydrological connectivity with, especially, rivers have been majorly altered through long-standing arterial drainage programmes, pre-dating the Arterial Drainage Act 1945. Currently, the OPW is responsible for the maintenance of about 11,500 km of rivers in collaboration with County Councils. The Arterial Drainage (Amendment) Act 1995 further allowed for flood protection for cities, towns and villages.

The Arterial Drainage Acts place a responsibility on the OPW not only to drain for enhancement of agricultural production, but to maintain all rivers, embankments and urban flood defences on which it has executed works since the 1945 Act in “proper repair and effective condition.” This raises fundamental questions about the designation of water bodies and proposed increased designations of Heavily Modified Water Bodies (HMWBs) within the arterial drainage network as part of the third cycle River Basin Management Plan.

HMWBs and AWBs

A water body can be designated as an Artificial Water Body (AWB) when created by human activity. An HMWB can be designated as such when physical alteration by human activity has substantially changed its character because of “significant and permanent modifications as a result of:

- navigation, including port facilities, or recreation.
- activities for the purposes of which water is stored, such as drinking-water supply, power generation or irrigation.
- water regulation, flood protection, land drainage; and
- other equally important sustainable human development activities.”

Where restoration measures cannot lead to good ecological status or where measures do not restore a water body to good ecological status, a target can be achieving good ecological potential, with measures to establish maximum ecological potential. There is a need to define the biological indicators commensurate with good ecological potential and the additional pressures within the HMWB or AWB that can prevent attaining good ecological potential. For HMWBs, methodology for designation and assessment of good ecological potential is still developing.

The designation of an HMWB is not permitted simply because there are modifications but requires that those modifications are of such significance that the water body cannot attain good ecological status, even with mitigation or restoration that would address the hydromorphological alteration. If restoration to good ecological status is difficult, mitigation is required to achieve the best attainable ecological state. There is no clear definition of what the ecological targets for particular water bodies may be, and this may require assessment on a case-by-case basis. Any revision of water body designation to increase the extent of HMWBs needs to be cognisant of the European Commission guidance on criteria for HMWB designation that: 1) *“*HMWBs should be water bodies that have undergone significant hydromorphological alterations such that the water body is substantially changed in character (WFD Article 2(9)); and 2) HMWB designation can only take place if the changes to the hydromorphological characteristics of that body which would be necessary for achieving good ecological status would have significant adverse effects on use or the wider environment.”

The Arterial Drainage Act 1945 provides clear potential conflicts with Ireland's obligation under the WFD and Nature Directives. As a matter of priority is a review of the Arterial Drainage Acts to align with Ireland’s climate and biodiversity ambitions, as recommended by the Oireachtas Joint Committee on Environment and Climate Action.

Other monitoring considerations

Monitoring and programmes of measures for lakes, GDEs, transitional, and coastal water bodies have attracted less attention than rivers. Main hydromorphological pressures on lakes relate to modifications of the littoral zone and alterations of residence time. The extent of hard embankments in Irish lakes is far less extensive than in many other European countries, although modifications to the riparian zone are common. Methods for the assessment of some of these have been developed. The Lake Habitat Survey (LHS) provides an overview of habitat quality, with a modified version, the Morphological Impact Assessment System (MImAS), used as the WFD hydromorphological assessment method for monitoring Irish lakes. Application of research linking BQEs to broad habitat assessment requires further consideration. Advances in assessing hydromorphological changes in lakes has been very variable across EU Member States, and generally not included specifically in national legislation. Effects of residence time and its impact on biological structure is an optional factor under Annex II and V of the WFD but not used in Ireland for WFD purposes.

Groundwater and surface water are mostly interconnected, with many rivers dependent on groundwater for their minimal (base) flow and affecting surface water conditions over very large scales. The surface hydrology of the topographical catchment is seldom the same as the hydrogeological catchment below the surface. In Ireland this is well illustrated by extensive unconfined aquifers. Changes in groundwater availability can have a huge impact on structure and function of connected ecosystems. The interaction between surface and groundwater can be particularly striking, especially in karst regions. In Ireland, 40% of total area is underlain by limestone, 20% has intense karstification, and karst systems cover 30% of Ireland's water supply.

Land-use changes and agricultural intensification, irrigation and drainage schemes may lead to hydrological changes to karst aquifers. The extensive karst systems contain the internationally unique turloughs ecosystems. Despite protection under the Habitats Directive, turloughs remain especially vulnerable to drainage and nutrient pollution, but often lack quantification of surface-groundwater interactions. Many other GDEs require further understanding to provide estimates of relevant threshold values of possible impact. The ecological importance of springs is often overlooked, while they also represent important cultural sites.

Hydromorphological alterations affect transitional and coastal ecosystems by changing the salinity, suspended sediments, water movement, and tidal balance. This can have significant effects on ecological status of fish, angiosperms, plankton, and benthic invertebrates. The BQEs angiosperms and benthic invertebrates are used mainly in the assessment of both coastal and transitional waters, with greater reliance on fish in transitional waters. Hydromorphology plays a major role in the hydrodynamics and sediment dynamics of transitional and coastal waters.

Transitional water bodies comprise a wide range of ecosystem types such as estuaries, fjords, lentic lagoons, river mouths and deltas. The boundaries between these are often not clear. There is still a considerable need to develop effective pressure-response methods for transitional and coastal waters. A lack of clear distinction between hydromorphological and biological/biogenic assessment suggests insufficient attention to either hydromorphological or biological elements, with an over-reliance on expert judgment for water body classification. Estuaries, one of the most productive ecosystems, are subject to a number of pressures, including land reclamation, port development and, in many parts of the world, sediment

depletion because of upstream barriers. There are only a few true lagoons in Ireland, with main pressures being discharge of sediments and fertilisers from agriculture. While there are many potential impacts on coastal waters, these are relatively of low pressure in Ireland. Most pressures arise from activities associated with ports and harbours as a result of hard infrastructure and maintenance activities, particularly dredging. Ireland employs a recently developed method, the Hydromorphological Quality Index (HQI) to assess hydromorphological alterations on transitional and coastal water bodies.

European Case Studies

The application of hydromorphology principles and mitigation of hydromorphological alterations are increasingly advocated and applied in water management. Almost all the rivers in central Europe require hydromorphological and ecological restoration. In the UK, up to 60% of all river channels assessed by the UK River Habitats Survey were classified as modified. In Ireland, the 30-40% of rivers failing to meet their WFD environmental objectives was attributed to hydromorphological alterations, although the nature of these alterations can be very variable. Restoration of water bodies has been a major activity in many European countries, although success can be variable. Success depends on a good understanding of the hydromorphology and putting in place effective engagement with landowners and other stakeholders. A series of case studies in the main report illustrate this.

In the Netherlands, the 'Room for the River' programme involved extensive consultations and a mix of old and new flood management practices that created a new paradigm in Dutch flood management that allowed land to flood at critical times to reduce wider flooding risk. A similar, but more extensive process, has provided space for flooding in the catchment of the Loire River, France. A shift in perspective over the last circa 30 years has taken the river's hydromorphology more into account, including interventions to alleviate flooding for providing more space for the river, and dam removals. It is also a highly relevant case study because of its scale, involving the entire river basin, and initiated a decade ahead of the WFD. A key element has been the commitment to a long-term plan and the involvement of multiple agencies and stakeholders. It has also provided a platform for research to better understand hydromorphological processes.

A major restoration project in Denmark was the Skjern River, a medium sized lowland river with a catchment area of 2,490 km² draining the western part of the Jutland Peninsula. In 1960 a drainage project was designed to provide agricultural land. Between 1962 and 1968 the meandering Skjern River was straightened and deepened. The disruption of connection between river and wetlands due to the presence of barriers led to the drainage of 4,000 ha of wetlands, meadows and heaths in the floodplain. Between 1999 and 2002, a restoration project aimed to restore 25 km of the river and the natural water levels. While the restored wetlands regained natural function and successful habitat rehabilitation and nutrient control, the expected results were not fully achieved. Disruption of hydromorphology can lead to long lasting impacts, even following restoration attempts. Designing restoration projects that aim for an imagined past or static reference state is usually flawed thinking.

Increasingly, there are rehabilitation programmes of urban rivers, and developing methodology for doing that across Europe. Urban green infrastructure, employing a range of techniques, including re-vegetation of impermeable surfaces, constructed wetlands, bioswales and green roofs can improve water availability during dry periods, reduce flood damage from extreme events, and improve water quality. Individual or combined techniques can contribute substantially to provisioning, regulating and cultural ecosystem services, and enhancement of biodiversity and its connectivity in cities. For established urban areas, an adaptive management and multisectoral approach bring many benefits. An example is the 'rainproof initiative' in Amsterdam that is developing the 'sponge effect' potential of the city using public and private spaces such as streets, gardens and rooftops. This is strongly aligned with the city's 'Green Space' policy, designed to enhance and promote the use and availability of urban parks and forests for multiple use, and to support meeting its 'Climate Proof' targets for 2050. It involves partnerships between public services and citizens. Experiences are shared with other municipalities in the Netherlands through a 'coalition of the willing'. Achievements are made through both technical innovations and enabling social processes. The scope for application of such local scale initiatives for Ireland is very obvious and can be achieved gradually as opportunities arise.

A major recent development in Europe has been the passing of the Regulation on Nature Restoration (Nature Restoration Law) of 2024 and its links to other policy instruments including international biodiversity commitments under the Kunming-Montreal Global Biodiversity Framework. Under the Restoration Regulation, Member Stated are required to set legally binding targets by 2027. This will include those targeted at freshwaters.

Legislation relating to hydromorphology in Ireland

In Ireland, the WFD was transposed into law by the *European Communities (Water Policy) Regulations 2003* (S.I. No. 722 of 2003) and amended by 2005 *Water Policy (Amendment) Regulations 2005* (S.I. No. 413 of 2005). *The European Communities Environmental Objectives (Surface Water) Regulations 2009* (S.I. 272, 2009) and the *European Communities Environmental Objectives (Groundwater) Regulations 2010* (S.I. 9, 2010) established the legal framework to implement the environmental objectives of the WFD in Ireland. S.I. 272, 2009 transposed the requirements of Articles 6 and 9 of the WFD into Irish legislation.

The WFD is linked to a number of other EU Directives in several ways. The Birds Directive (2009/147/EC) and Habitats Directive (92/43/EEC) (together known as the EU Nature Directives), and Environmental Impact Assessment Directive 2014/52/EU have direct importance for the management and prevention of physical modifications on Irish water bodies. The Industrial Emissions Directive (2010/75/EU) (that repealed the IPPC Directive 2008/1/EC) is relevant in that it has led to a more consolidated and integrated approach to the prevention of impact on water bodies from industrial activities, which could include hydromorphological alterations.

The interpretation of how the Birds and Habitats Directives apply to the WFD, and vice versa, is subject to some uncertainty, such that aligning quality among the Natura 2000 network with classification under the WFD remains an issue of potential confusion for overall site designations, monitoring and management. Article 4(1)(c) of the WFD applies to Protected Areas, defined as "areas designated for the protection of habitats or species where the maintenance or improvement of the status of water is an important factor in their protection,

including relevant Natura 2000 sites designated under Directive 92/43/EEC (1) and Directive 79/409/EEC*."*

Article 4(1)(c) of the WFD states that in making operational the programme of measures specified in RBMPs "Member States shall achieve compliance with any standards and objectives at the latest 15 years after the date of entry into force of this Directive, unless otherwise specified in the Community legislation under which the individual protected areas have been established*."*

There remains a lack of effective guidance both at EU and national level as to how Article 4(1)(c) of the WFD is to be applied in a practical way. Such clarification is now urgently required in Ireland where plans with significant potential impacts to water bodies such as the Nitrates Action Programme are subject to Appropriate Assessment under the Habitats Directive, but where there is little or no direct engagement with the requirements of Article 4(1)(c) of the WFD in respect of those same plans. Effects of climate change add an extra urgency to resolving this ambiguity.

Environmental Impact Assessment (EIA) plays a central role in the environmental legislation of almost every country to ensure that development projects do not present significant risk of adverse environmental impact. The EIA Directive was codified in Directive 2011/92/EU, which was subsequently modified by Directive 2014/52/EU. The Irish legislation to implement this Directive includes the EIA Regulations, *the Planning and Development Regulations 2001 (as amended),* and the Planning and Development Acts, 2000 (as amended). As is set out in more detail in Chapter 6 of this report, the numerous different legislative instruments governing activities with potential hydromorphological impacts is lacking in coherence and not consistent with the integrated ecosystem approach underpinning the WFD.

The Nitrates Directive (91/676/EEC) forms an integral part of the WFD and is one of the key tools in the protection of waters against agricultural pressures. It has led to the Nitrates Action Programme (now in its sixth cycle) which aims to protect surface and groundwater from nutrient pollution arising from agricultural sources, and the development of schemes for farm advice, that is currently the Agri-Climate Rural Environment Scheme (ACRES) supported by the Department of Agriculture, Food and the Marine (DAFM). Forestry and land and river drainage policies and practice have potential direct and negative impacts on water bodies. While the focus is largely on impacts from nutrient pollution, land and riparian zone management can lead to hydromorphological alterations, including increasing transfer of soil and nutrient from land to water.

Development and application of knowledge

The creation of knowledge from EU and Irish projects has greatly advanced the understanding of the impact and nature of hydromorphological alterations on water bodies. There are, however, deficiencies in the application of knowledge, and it is generally unclear how research project outcomes have been applied in River Basin Management Planning in Ireland. This is not a uniquely Irish experience.

Lateral links with land-use, and the catchment as a whole, are largely not considered specifically in monitoring and assessment. The consequence of this is that while hydromorphology is inherently an integrated concept, how it is featured in planning and management is far from integrated. This is not helped by the large number of actors responsible in some form or other for river basin management and its hydromorphology. It is

striking how individual state bodies with a fairly narrow remit are responsible for river flow and potential hydromorphological alterations.

Notable examples are the Electricity Supply Board (ESB), with responsibility for the management of major river systems, and the OPW prominence in arterial drainage and flood defence. Concepts such as environmental flows are not embedded in water body management, or, if used, are employed with an outdated approach. The remit of the OPW does include a greater responsibility for, and engagement in, mitigation of hydromorphological alteration of river works and coastal defences. This includes the requirement to conduct EIA and screening for the need of Appropriate Assessment for individual schemes, and a Strategic Environmental Assessment (SEA) for the rolling programme of arterial drainage. Nevertheless, the approach by the ESB and OPW in water management can lead to direct conflict with the objectives of the WFD and Habitats Directive, and difficulties of cross-compliance with different policy objectives.

Furthermore, effects of climate change (including the associated spread of invasive species) have not been considered sufficiently in the research or planning for river basin management in Ireland. Climate change effects on rivers and lakes are already apparent in Ireland. For all water bodies, this has important implications for the determination of reference state and ecological classification.

River Basin Management Plans and Programmes of Measures

River Basin Management Plans (RBMPs) are central to achieving the environmental objectives of the WFD. Ensuring consistent policy integration between the River Basin Management Planning process and other national planning processes remain a priority need. The RBMPs identify significant pressures that can lead to a risk of water bodies failing to meet WFD environmental objectives. In Ireland, agriculture, hydromorphological alterations, urban wastewater, and forestry are identified as the most common pressures. Ireland is now implementing its third river basin management plan, covering 2022-2027, that was put out for consultation from September 2021 to March 2022, and published in September 2024. Further details are provided in Chapter 4. For hydromorphology, the third RBMP Water Action Plan emphasises: 1) the importance of Integrated Catchment Planning, with a number of Sectoral Action Plans proposed and 2) proposed review and update of legislation relating to hydromorphology, including the Arterial Drainage Act 1945. Many of the measures needed to protect and improve hydromorphology and water quality can also deliver benefits for biodiversity and mitigate the effects of climate change.

In a recent assessment by the Environmental Protection Agency (EPA), slightly more than half (52%) of Ireland's water bodies are considered 'at risk' of not meeting mandatory environmental objectives by 2027. The third cycle Water Action Plan identifies "physical impacts on water bodies (for example, the interruption of river continuity due to river barriers, and drainage of lands and rivers)" as a major pressure that needs to be addressed. In its assessment of risk of failing to meet WFD environmental objectives, the third Water Action Plan identifies agriculture as the most common significant pressure.

Both physical alteration and excess silt have been identified as significant problems in many waterways. Sources of silt include maintenance dredging, land drainage works, river bank erosion, soil erosion from agricultural practices, including livestock 'poaching' and associated lack of buffer strips, forestry, construction activities and peat extraction. In the third management cycle, the Local Authorities Water Programme (LAWPRO) is tasked with

conducting assessments of water bodies with unknown pressures in 'priority areas for action' and will continue the implementation of measures from the second cycle.

On hydromorphology, the third cycle RBMP states that "recent technical advances mean that a comprehensive, robust and streamlined management regime can now be developed and implemented" to address the hydromorphological pressures identified. The Water Action Plan of the third cycle RBMP raises the expectation that this will be realised, but many of the proposed measures remain quite general. The third cycle Water Action Plan places an emphasis on stakeholder engagement. It will be a measure of the Irish Government's commitment to the WFD as to which stakeholders' voices are most listened to in striving to meet the new and ambitious targets of the new plan and achieve WFD compliance.

A new 'Controlled Activities for the Protection of Waters' regime is proposed to achieve the hydromorphological objectives, and "deliver multiple benefits for water, nature and biodiversity, and climate mitigation and adaptation." This provides the opportunity for a better integrated approach to catchment management, ideally that would be set out in legislation. A new administrative system reaching across policy and departmental boundaries is proposed.

The Water Action Plan specifies that "river channel alterations arising from agricultural activities are a significant pressure on the physical condition of river channels. Additional and/or enhanced measures are now urgently required." There is a number of interconnected issues, in relation to agricultural impact on hydromorphology. The most significant is likely to be arterial drainage. The prevailing official view appears that where a river water body has been designated as good ecological status over the last three EPA monitoring cycles (2013-2018, 2010-2015, 2007-2009) by virtue of its BQEs, there would be no need to consider a designation to HMWB. However, where a river water body has failed to reach good ecological status in an area subject to arterial drainage, and where the cause of that failure is uncertain, then designation to HMWB appears to be an option. A review and guidance for the designation of HMWBs is included in the Water Action Plan, with the follow up government consultation, outlined in Chapter 4.

As a climate action, the Government made a commitment of €8.8 billion to public water and wastewater infrastructure over a ten-year period up to 2027. While these plans likely refer to hard engineering, opportunities for re-wetting existing drained land can provide multiple benefits, but would necessitate important stakeholder engagements and, where appropriate, fiscal compensation. This is a potential and powerful measure to better align objectives of the WFD and Floods Directive. Recent, and projected, more frequent flooding in many parts of the country attest to the need for further and serious consideration of landscape management to alleviate flood risk. These issues are also influenced by wider scale debate and measures introduced through the recently agreed European Restoration Law.

In its Water Quality report (2019-2024) the EPA re-affirmed that diffuse emissions from agriculture are the primary source of the upward trend in nutrients in Irish rivers. Identifying land to water body hydrological pathways can be extremely important for management measures to reduce sediment run-off, which carries with it potentially high concentrations of sediment-bound phosphorus. Hydromorphological interventions such as sediment traps and use of well-placed constructed wetlands can greatly reduce risk of sediment loss to water bodies, while at the same time providing nature conservation benefits. There are substantial opportunities for hydromorphological benefits effected through the 'Green Architecture' plans linked to the new Common Agriculture Policy (CAP).

In the second cycle RBMP, a measure relevant to hydromorphology was that new legislation for sustainable management of water abstractions was introduced, through the Water Environment (Abstractions) Bill 2018 which sought to bring in a licensing system compliant with the WFD. The subsequent Water Environment (Abstractions and Associated Impoundments) Act 2022 raised concerns from Irish environmental NGOs that the Act is not, however, compliant with the WFD on the basis that the thresholds for the abstraction registration and licencing limits are too high, a view shared by the Court of Justice of the EU (CJEU) in its November 2025 ruling (Case C-204/24). The cumulative impact of unlicensed and unregistered abstractions below 25 m^3 in a 24-hour period in a drought situation could be detrimental to water quality and quantity. If abstractions are unknown, they cannot be regulated.

In the second cycle RBMP, a roadmap supporting EU Biodiversity Strategy objectives for restoring rivers to a free-flowing state was prepared. It included a programme of investment to better facilitate fish passage at Ardnacrusha /Parteen in the short term, and overall, to improve the ecology and environment of the Lower Shannon. A multi-agency steering group was formed to propose recommendations for improvements to fish passage in the Lower Shannon catchment and in other rivers. Pilot projects are proposed for implementation in the third cycle RBMP. The potential effects of barriers in Irish rivers are, however, far more extensive than in the Lower Shannon and those identified for specific action. The third cycle RBMP Water Action Plan outlines a restoration programme to mitigate the negative impact of existing constructions in or near water bodies, as a long-term restoration programme, with short-term removal and/or modification of barriers. Smaller barriers such as weirs can have negative impacts on river continuity and fish passage.

The third cycle RBMP Water Action Plan aims to progress amendments to the planning and development legislation to give effect to new guidance for planning authorities on physical planning and the WFD. There are plans for a reliance on the Local Authority Waters Programme (LAWPRO) and other competent authorities to manage WFD assessments as part of the statutory planning process, but the capacity to do so within the wider Local Authority structures is unknown. It is proposed that development of these guidelines and associated training will provide the planning authorities with a suite of tools to assist determination of potential impact on water bodies of planning decisions, from Development Plans to individual projects. These will facilitate “Avoidance of inappropriate development in or near water bodies that will pose a risk of not meeting the WFD’s environmental objectives or WFD protected areas” and “Provide practical steps, approaches and methodologies to ensure planning decisions, take account of risks and avoid or mitigate the adverse effects of inappropriate development on WFD objectives.” Furthermore, for urban areas, “Sustainable Urban Drainage objectives are evident in the majority of the City and County Development plans. However, the resultant outcomes currently seem to be focused upon engineering solutions rather than nature-based solutions.”

The EU Regulation (1143/2014) on *The Prevention and Management of the Introduction and Spread of Invasive Alien Species* has been in force since January 2015. The risks of invasive species establishment are linked to both water quality and quantity and, therefore, to hydromorphology. Invasive species such as the zebra mussel (*Dreissena polymorpha)* change the nature of the benthos, with consequences for ecological integrity. There are numerous other invasive species for which the third cycle RBMP Water Action Plan can implement the necessary strong management framework to mitigate their impact.

In accordance with European and national legislation, the Department Housing, Local Government & Heritage (DHLGH) is undertaking SEA and Appropriate Assessment of the Water Action Plan, carried out in parallel with the drafting of the plan. Forging consistent and robust linkages among different policy areas is a significant challenge, including how these are connected with Climate Adaptation Plans, Marine Spatial Planning, Flood Risk Management Plans, and Biodiversity Action Plans.

Stakeholders' engagement

Stakeholder engagement is considered by the Government of Ireland, the EPA and the LAWPRO to be important for the implementation of the WFD. The LAWPRO programme has dedicated stakeholder actions at local scales. A national water forum as a statutory body exists, but its influence on water management appears limited. Access to information from some agencies, can be particularly troublesome, despite Ireland being a signatory to the Aarhus Convention on *Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters.*

Hydrometric data of the OPW is, however, generally available in 'real time', and searchable for individual stations also over extended time periods. Much, and historic, WFD monitoring data is available from EPA at Catchments.ie, but requires a certain level of expertise to find. Access to other spatial data held by public bodies, such as Coillte and Bord na Mona often necessitates time consuming or costly procedures. This could be in breach of Directive (EU) 2019/1024 on open data and the re-use of public sector information, transposed into Irish law by S.I. No. 376/2021 - *European Union (Open Data and Re-use of Public Sector Information) Regulations 2021*.

As part of this current project, a putative matrix of 'Power Influence and Interest' of 30 stakeholders in relation to hydromorphological management was followed by a workshop attended by a cross-section of stakeholders. This provided a stimulating sharing of views. Generally, it was considered that there could be greater water literacy in Ireland, more emphasis needed on the catchment approach, and the important recognition that the water and landscape are interconnected. This includes a need for a focus on morphology as well as hydrology that can be of particular importance in upstream high quality water bodies. Moreover, the reference condition for hydromorphology needs to be better defined, especially owing to many old human-built structures.

The stakeholders considered that many hydromorphological pressures arise from land-use and agriculture, and how important it is to interact across sectors for common purpose. There was a consensus that hydrology and sediment load is crucial and that it connects with land-use. Assessing and managing cumulative pressures requires consideration of how a number of key variables interact and how that aids cross-sectoral decision making. This level of complexity has not yet been addressed effectively in River Basin Management Planning in Ireland. Moreover, it was considered that there appear little appreciation of future climate effects and the adaptation that will be necessary to manage those shocks. Other stakeholders were concerned about how measures for hydromorphological management could restrict economic activities and capacity for making decisions on appropriate land use. This resonates very much with recent dialogues and policy shifts over the EU Nature Law, 'Green Deal', and the EU Common Agriculture Policy (CAP).

Views expressed in the stakeholder workshop emphasised that stakeholder engagement needs to address concerns of anyone who has a stake in water management, including

hydromorphological issues. Early engagement is critical in highlighting unacknowledged or uncertain issues at local to national scales. Stakeholders have a wealth of relevant knowledge and experience that is important to be considered. They can provide access to information that will lead to more effective decision-making. Moreover, understanding issues and concerns provides an opportunity to reflect on what will, or will not, work. Often, however, stakeholder engagement is not effectively resourced, moderated or follows best practice.

Irish Case Studies

The project report includes a number of case studies on Irish water bodies and catchments. Overviews of hydromorphology considerations are provided for the Rivers Shannon, Lee, Liffey (Poulaphouca Reservoir), Erne and Inny. Hydromorphology management of coastal water bodies is illustrated by Tacumshin Lake, Waterford Port and Bantry Bay. Urban Flood Relief, while also featuring in the example of the River Lee, are further explored in a general overview of key issues and using examples of Clonakilty and River Deel (Crossmolina) Flood Relief Schemes.

River Shannon

The hydrological alterations that could have possible impacts or changes in state in the River Shannon cover the general themes of hydrological regime, river continuity and morphology. Specific potential impacts that can influence ecological classification include alteration of flow regime, sediment regime, water levels, impediment to fish migration and hydrological connectivity between main channel and floodplain. Very local potential impacts relating to riparian alterations for ports, harbours and jetties may be widespread, but overall, of low extent. Impacts from pressures of nutrient loadings and invasive species, while prevalent in the Shannon catchment, were not considered specifically in the review. Within the catchment, hydromorphological alterations have affected the main stem and many tributaries. Notable has been the Shannon hydroelectric scheme at Ardnacrusha, a milestone in Ireland's economic development, that also had a major impact on migration of fish to the upper Shannon and led to reduction of spawning sites in the Lower Shannon. A requirement for a minimum 'statutory compensation flow' of 10 m^3/s into the Lower Shannon Special Areas of Conservation (SAC) is far short of any idea of reference condition, and unlikely to represent a hydromorphological classification commensurate with WFD good ecological status. While once supplying almost 90% of national demand, Ardnacrusha now accounts for <3% of the country's electricity. From a hydromorphological perspective, the operating condition merits a critical review.

The Shannon Callows, between Lough Rea and Lough Derg, is exceptionally rich in birds and plant biodiversity because of seasonal flooding, but has seen much conflict in its management, and many proposals for drainage. As a prime ecological area, the callows are a protected SAC and Natural Heritage Area (NHA). A 'results-based' agri-environment pilot scheme (RBAPS) trialled between 2005-2018 provides an example of a result-based model for farming High Nature Value (HNV) farmland. Farming for hydromorphology can be incorporated into this. Calls for drainage and dredging continue, but with respect to the flooding of the River Shannon, it is perhaps best to accommodate the natural dynamics of the river and find other mechanisms for addressing concerns about the flooding of land.

In 1956 a report by the Corps of Engineers, a body renowned for large scale engineering and water management schemes, concluded: "The problem of Shannon River flooding has been the subject of much study over the past 150 years. Because of the flat terrain through which the river flows, the almost imperceptible gradient of the stream with its series of lakes and

connecting channels, and because of the large volume and long duration of flooding, no simple or obvious solution has heretofore been found." Little appears to have changed.

A proposed scheme to extract water from the Shannon to Dublin, for an offtake of 330 million L/day from Lough Derg drew concerns about the effect this would have on the ecology of the lake. It is estimated that the extracted water will reduce on average 2% of the volume of flowing water from the Shannon River. Given the governance challenges, including charging, surrounding water, and historical regional positions, the pipeline proposal will continue to attract considerable debate. The Shannon-Dublin pipeline proposal highlights the political nature of water supply and demand. At the time of writing, proposals made up to 15 years ago for ecological studies of the potential effect on Lough Derg have still not progressed, and important governance issues remain pending.

The Annacotty Weir on the lower Mulkear River, is a little over 2 km upstream of the confluence with the River Shannon and is illustrative of an hydromorphological barrier affecting river connectivity. The river is of major importance for Atlantic salmon (*Salmo salar)*, sea lamprey (*Petromyzon marinus*) and river lamprey (*Lampetra fluviatilis*), brown trout (*Salmo trutta*), and European eel (*Anguilla anguilla*). The majority of the main river and its tributaries form part of the Lower Shannon SAC under the Habitats Directive. Annacotty Weir was installed in 1749 to power a paper mill. The weir has attracted attention as to its possible removal and is mentioned specifically in the third cycle Water Action Plan. A fish pass installed at Annacotty Weir in 2011 was considered to be ineffective for the passage of lamprey during the typical flow conditions of 3-11 m^3/s during the spawning season. A new lamprey-specific pass was installed in 2016. Monitoring using environmental DNA detected presence of lamprey both below and above the weir in 2015, 2016 and 2017. This does not verify effective migration, only evidence of presence of lamprey above the weir. If the weir is removed, it will present an example of a significant measure to manage the river to improve connectivity but could raise other issues as the weir is considered a local feature of interest.

River Lee, Cork

The city of Cork has had a long history of flooding and disagreement on the most appropriate solutions. A flood relief scheme proposed by the OPW to address flooding issues downstream of Inniscarra Dam was not implemented owing to local opposition to the scheme's design when presented in late 2016. The main concerns raised at that stage were the height of the proposed flood defence walls in the city centre, and their effect on the people's interaction with the river and the conservation of the historic quays. In 2009, Cork faced another high intensity flooding episode when the River Lee broke its banks, with water discharge of up to 500 m^3/s having a heavy impact on buildings at the University College Cork (UCC). A legal case brought by UCC against ESB went to the Supreme the Court. The case involved extensive legal argument, with an eventual part ruling against ESB. A key outcome was that the Appeal Cout was "satisfied that the ESB was in breach of the duty of care." The case identified the need for ESB to have a "Flood Risk Assessment in place to inform the management of the dams.

More recently, permission for flood alleviation works in the city centre in the vicinity of Morrison's Island, to alleviate tidal flooding, was upheld by the High Court. The works are envisioned to decrease the flooding risk for the Lower Lee. Opponents of the scheme consider a tidal barrier a more effective means of flood defence, and that the scheme proposed by OPW would lead to a diminution of the heritage of the quays.

Local researchers claimed in 2019 that complex ground and groundwater conditions at Cork had not been adequately assessed. The high costs of a tidal barrier have led to this option being discounted by the OPW. The large extent of the Lower Lee flood relief scheme will provide for additional hydromorphological alteration to river morphology.

River Liffey - Poulaphouca Reservoir

Poulaphouca Reservoir (also known as Blessington Lake) located S.E. of Blessington town in Co Wicklow covers an area of approximately 20 km^2 and provides a source of water for the Dublin metropolitan area, linked to a chain of reservoirs. Hydromorphological pressures on the river include excess of fine sediment and alteration of the morphology of the river channel, altering habitats. The reservoir is designated as an Artificial Water Body, and has high fluctuation of water levels, preventing a stable littoral or sub-littoral zone. Moreover, the construction of hydroelectric dam on the River Liffey also reduces water levels inside the reservoir. The river is subject to high changes in flow regime, linked to the downstream Golden Falls Reservoir power generation. There is a statutory minimum flow rate of 1.5 m^3/s from the Golden Falls Reservoir. Concerns about poor dilution of effluent from Blessington WWTP from low flow rates appears to have been alleviated by an update of the waste water treatment plant.

River Erne

The River Erne is a transboundary catchment between N. Ireland and the Republic of Ireland and is the second largest river on the island. Lough Erne consists of two parts, the Upper and the Lower Lough Erne. Both are widened channels of the River Erne. In the 1950s, the construction of a hydroelectric power station in Belleek altered the hydrological regime of the lake. The Erne is connected to the Shannon River basin by the Shannon Erne Waterway (which was constructed in the mid-19th century and re-opened in 1994). Although there are numerous pressures on Lough Erne, it is currently designated as a HMWB, of moderate ecological potential, with the target for good ecological potential. This illustrates a difficulty in designation when, for the ecology of the lake, the main pressures are from nutrient run-off from land, and interference of ecological processes from invasive species, while designation is based on hydromorphology. However, extensive data collection over many decades provides for a deeper understanding of the system than in many other water bodies in Ireland. The inter-basin transfers of nutrients and invasive species through the Shannon-Erne canal raises other potential compliance questions, also relating to transboundary management.

Inny Basin

The River Inny, within the Shannon catchment, is subject to a range of pressures common to the Irish midlands. The main anthropogenic pressures that alter the hydromorphology of the Inny catchment include drainage works causing channel re-sectioning, realignment and reinforcement, discharge of nutrients and fine particles, disturbance by livestock, run-off of organic pollutants, and river barriers. Of twenty-nine sites in the lower Inny catchment assessed for hydromorphology, none passed the WFD minimum requirement of good status, with 62% of the sites classified as moderate, 35% as poor and 3% classified as bad status. Bank structure, riparian land cover, and flood plain connectivity scored the lowest (1.09-1.26) on the River Hydromorphology Assessment Technique (RHAT) scoring matrix for lower Inny catchment. No sections of the river were considered to merit HMWB status from the first and second cycle RBMPs. A number of sections of the river are under consideration as re-designation as HMWBs in the third cycle RBMP.

Coastal and transitional waters

Three coastal and transitional water bodies (Tacumshin Lake, Waterford Port and Banrty Bay) were included in the review of Irish case studies.

Tacumshin Lake: Tacumshin Lake in Co Wexford is a shallow coastal lagoon covering f 3.1 km^2. At the end of the 19th century the lake was drained, with some of the reclaimed area used for growing cereal crops. Development of spits and sand bars in the mid-1970s closed the lagoon off from the sea. During this time, water level increases led to the flooding of several hundred hectares of surrounding farmland, leading to reactivation of an older drainage pipe and installation of a second one at a lower level. Even so, the lagoon fills up in winter when inflow from streams is greater than the outflow through the pipes. To speed the drainage from the lagoon two main drains were excavated leading to the landward end of the pipes. The lagoon which was separated from the sea by a gravel barrier and provided fine sand to the beach through an outlet stream in that barrier, is of high ecological importance. Reduced natural supply of fine sand to the beach has led to the removal of the already present fine-grained sediments by longshore currents.

Tacumshin Lake illustrates particularly the different interests of the WFD and Habitats Directive and, as such, necessary interactions between the EPA and National Parks & Wildlife Service (NPWS). The lake has clearly been subject to many changes over the years, driven by both human and natural processes. Defining a reference state is understandably difficult, and the current classification as moderate may be prudent so as to enable ongoing restoration actions.

Waterford Port: Dredging in ports is a routine operation, and such activities in Waterford Port are covered by an EPA licence. A request to extend the dredged area highlighted a number of environmental impacts, especially if the dredged sediments move to the surrounding estuaries. It is also inevitable that dredging disturbs benthic communities, although recovery of these is rapid. Nevertheless, the WFD requires assessment of such disturbance as a hydromorphological alteration. The requirements of the WFD appears not to have been taken into sufficient consideration in the application for review of the permit. Subsequently, however, there was an application for a ‘technical amendment’ which extended the original area but seems to fall far short of the requirements of the EIA, WFD and the Habitat Directives.

Bantry Bay: The bay forms part of the Dunmanus-Bantry-Kenmare catchment, encompassing the input to the tidal waters between Mizen Head and Glanearagh Head, Co. Kerry, draining a total area of 1,898 km². Bantry Bay was a demonstration project for Integrated Coastal Zone Management (ICZM) under European Commission LIFE funding (1997-2000). Many of the goals of ICZM have been superseded by the WFD, with its inclusion of transitional and coastal water bodies, but it is difficult to find evidence of how the outcomes of the LIFE project and a Charter that set out an action programme has fed into the WFD, including coastal and marine issues that threaten the hydromorphological characteristics of the Bantry Bay.

Urban Flood Relief Schemes

The hydromorphological case studies focus on urban flood relief in Clonakilty, the River Deel and Crossmolina, and the River Bride at Blackpool, Cork. The reviews paid particular attention to the extent that Nature Based Solutions (NBS) were considered as viable options. The Blackpool case study drew on significant local stakeholder input.

For Clonakilty, key points that arise from this case study are 1) the recognition of the potential of upstream storage areas as part of the planning for flood alleviation, and 2) how reconnection with the flood plain brings other ecological benefits. A key consideration is the extent that these recommendations will be pursued and any key enabling conditions required.

For the Deel and Crossmolina scheme, two key factors stand out from the case study. First, the original scheme was advised to be a traditional hard engineering intervention through the town, but public consultation appeared to have led to an alternative option of a water diversion channel during high flood events. This is, nevertheless, a hydromorphological alteration, but appears not to be recognised as one.

For Blackpool, there was an extensive review of documents related to the flood defence and engagement with a local community stakeholder. While there may be good reasons for a predominantly hard engineering approach to the flood relief in Blackpool, and upgrade of the culvert system, the information collated suggest that, overall, other options could have been more thoroughly considered. Future climate risks may even undermine the current approach.

The case study of the River Bride also raises important questions about the implementation and associated monitoring and classification within the WFD itself. The River Bride is not an 'assigned water body' for routine WFD monitoring but has been identified as a 'Priority Area for Action' (PAA). LAWPRO completed a desk study on the river in late 2021. The summary report notes high nitrate, organic loads, identifying phosphates, ammonium and sediment as potentially notable pollutants, and that: "river habitat may also have been altered because of drainage works in Bride (Cork City) _010 and culverting in Bride (Cork City) _020." The River Bride provides an example of hydromorphological alteration of a small river, and where that fits into the WFD protocols and reporting, and the need to assess hydromorphological status across all classes of quality.

Legal Overview

Chapter 6 of the report considers the law relating to hydromorphological alterations within the meaning of the Water Framework Directive 2000/60/EC (WFD) and, in particular, the planning and other requirements affecting such alterations. A review of the current patchwork of laws, based on the information available, does not constitute legal advice, nor is it to be used for that purpose. It does suggest, however, that the current legislation is not sufficiently fit for purpose.

There has been a number of significant decisions of the Court of Justice of the EU (CJEU) concerning the WFD in the past number of years, beginning with the seminal decision in C-461/13 Bund für Umwelt und Naturschutz Deutschland e.V (Weser). The Court ruled firmly in favour of the binding nature of the environmental objectives specified in Article 4(1)(a) as respects bodies of surface water, provided that the derogations outlined in Article 4(7) did not apply, and clarified that deterioration of a water body would be established where the status of one of the quality elements of the water body concerned, within the meaning of Annex V to the WFD, falls by one class (e.g. from high to good status) even if this does not affect the overall classification of that water body. Crucially, the Court ruling clarified that the objectives of the WFD are not mere management-planning objectives but apply to individual projects affecting a water body. That means that a Member State is obliged to refuse authorisation for an individual project where it may cause deterioration in the status of a body of surface water.

Until recently, only 60% of surface and groundwater bodies in Ireland were assigned a water quality status as a result of monitoring by the EPA. This poses an obvious question as to how development may be permitted in cases where the water body concerned has not been assigned a status. In Case C-117/17 Comune di Castelbellino, the CJEU held that Article 2(1) of Directive 2011/92 requires that projects likely to have significant effects on the environment must be subject to such an assessment before consent is granted, and in case C-535/18 Land Nordrhein-Westfalen, that there is a requirement that the information to be presented by a developer in an EIA process must be capable of assessing the effects of a project on the status of the bodies of water concerned. Information to be made available to the public during the procedure for approving a project must include the data that are necessary to assess the effects of that project on water, in the light of the criteria and requirements laid down, *inter alia*, by WFD Article 4(1).

A 2022 ruling in a preliminary reference to the CJEU (Case C-525/20) considered whether the obligation to prevent deterioration in the status of water bodies included just effects of a permanent nature or whether it also included temporary effects to status. The Association France Nature Environnement (AFNE) had brought an action against the French Council of State seeking the annulment of a decree which provided that, in assessing the compatibility of programmes and administrative decisions adopted in the field of water to prevent the deterioration of water quality, "no account shall be taken of the temporary, short-term impacts which are without lasting consequences*."* The CJEU found that it was clear from Article 4 that deterioration of the status of a body of water, even if transitory, is authorised only subject to strict conditions, as set out in Article 4(6) and Article 4(7) and that, consequently, the threshold beyond which breach of the obligation to prevent deterioration of status of a body of water is found must be set as low as possible

Planning in Ireland is regulated by the Planning and Development Act, 2000 (as amended) and accompanying *Planning and Development Regulations, 2001 (as amended),* which flesh out much of the detail of the parent Act. The PDA, 2000 contemplates a hierarchy or framework of plans and strategies at a national, regional and local level which together provide the basis for proper planning and sustainable development. Collectively, these plans form the physical planning framework against which applications for development permission are assessed, including those bearing on developments near to, or affecting bodies of surface water or groundwater. The Planning and Development Act 2010 (as amended) had the potential to strengthen the overall planning framework relationship with the WFD, providing a clearer requirement for local authorities to consider potential impacts on water bodies. However, while the WFD must be taken into account, so far it has not proved to be a specific priority point of focus in planning matters in Ireland. The Planning and Development Act 2000 (as amended) is now being replaced by the Planning and Development Act, 2024. The information provided in Chapter 6 follows the current law (the 2000 Act), with some references to the 2024 Act, as appropriate, as not all of the provisions of the new legal framework have been commenced and with much yet to be fleshed out in Regulations.

Under section 10(2)(c) of the Planning and Development Act, 2000 (as amended), the development plan must include objectives for the promotion of compliance with the environmental standards and objectives established for bodies of surface water under the *European Communities (Surface Water) Regulations, 2009* ("2009 Regulations"), the standards and objectives being those set out in the relevant river basin management plan (as specified in Regulation 13 of the *European Communities (Water Policy) Regulations (2003*)

("2003 Regulations"). The 2009 Regulations sets out the duty of public authorities with respect to the WFD.

In PART II [4], it is stated that "A public authority shall, in so far as its functions allow, comply with the requirements of these Regulations and take all reasonable steps including, where necessary, the implementation of programmes of measures to: […]. And in section [5]: A public authority shall not, in the performance of its functions, undertake those functions in a manner that knowingly causes or allows deterioration in the chemical status or ecological status (or ecological potential as the case may be) of a body of surface water." These authorities include An Bord Pleanála, Inland Fisheries Ireland, the ESB, Bord Na Móna, Coillte, and Waterways Ireland.

In a recent High Court case, Sweetman v An Bord Pleanála [2021] IEHC 16, concerning a privately owned lake (Loch an Mhuilinn) of just over 8 hectares in size, the Court held that An Bord Pleanála has an obligation under EU law to refuse planning permission if either a deterioration in water body status or a jeopardization of the attainment of that status would occur. The Court found that it was clear from the provisions of the WFD, and from the decision of the CJEU in the Weser case, that the concepts of deterioration and good water status are bound up inextricably in the evaluation framework for water bodies set out in the WFD. Consequently, it was not possible for the Board to clearly determine that the proposed development (the subject of the appeal) would not result in a deterioration in ecological status or a jeopardization in the attainment of good status in a situation where no standard of water quality had been assigned to the water body concerned, leading to quashing of the decision of An Bord Pleanála to grant permission for the proposed development.

Since that judgment, a question arose as to whether Loch an Mhuilinn needed to be characterised under the WFD, an issue not raised during the original hearing. According to the EPA, under Guidance Document No. 2 relating to the Identification of Water Bodies produced by the European Commission (2003a), such characterisation was required only for lakes greater than 50 hectares in surface area (which Loch an Mhuilinn was not) or if the Member State considered that the lake was otherwise considered significant in the context of the WFD's purposes and provisions.

In April 2024, the CJEU (Case C-301/22) found that Member States were not obliged to establish type-specific reference conditions for surface water bodies like lakes with a surface water area of below 50 ha, irrespective of whether the Member State used classification system A (as provided for in section 1.2 of Annex II of the directive) or system B (as also provided for in Annex II). Nor were Member States obliged to establish the ecological status of such lakes in accordance with Article 8 of the WFD or to establish programmes for the monitoring of the status of lakes below 50 ha in surface area. The court considered the obligations of competent authorities in dealing with a project potentially affecting a water body not subject to characterisation or classification (in this instance, a lake below 50 ha in surface area). The court ruled that in order to assess the effects of a project potentially affecting such a lake, it would also be necessary to take into account the effects of the changes ensuing to the lake on the other water bodies, if any, to which that lake is connected. In circumstances where a competent authority of a Member State could not rule out a deterioration in the status of a "connected" water body subject to characterisation in line with Article 5 of, and Annex II of , the WFD, as a result of a project, Member States would be obliged (unless a derogation was granted) to refuse consent for that project.

In the context of Loch an Mhuilin, the CJEU held that it was a matter for the Irish court to determine whether or not the project would affect the status of the other lakes and stretch of coastal water to which it is linked and which have been, or should have been, identified as a surface body "types" for the purposes of the WFD.

For HMWBs, an important consideration given the cost-benefit analysis used for flood defence schemes is that the stipulations in Article 4(3)(a) set out that a proposal to restore a HMWB to its natural state may be rejected if those changes would have significant adverse effects on a range of factors, including the wider environment, navigation, water storage, water regulation, flood protection, land drainage or other important sustainable human development activities. These stipulations are bracketed with another stipulation set out in paragraph (b), that the objectives served by the required changes to the water body cannot be achieved by other means because of the technical unfeasibility of those alternatives, or the disproportionate costs of the alternatives which better meet environmental (including WFD) needs.

The latter criterion of "disproportionate" requires that some additional (even significant) costs must be acceptable to the authorities carrying out the works if that alternative option (not involving a modification to the water body) is to be realistically considered alongside the water body-modifying but cheaper alternative. A greater cost for water body protection is very clearly contemplated by, and acceptable, in the framework established by the WFD.

Designation of water bodies to HMWBs are not exempt from the obligations of the WFD. Rationales for any subsequent changes of designation should be in the public domain, including the clarity on the use of "best available information" for HMWBs, obliged to attain good ecological potential in place of good ecological status. The status of HMWBs is subject to periodic review and justification.

Recommendations

Given the array of issues involved in hydromorphology and compliance with the WFD, a large number of recommendations can be made. These are provided in Chapter 7. It cannot be an exhaustive list, as new knowledge and interpretations of existing procedures are subject to change and change itself courts controversy.

There is much law relating to water but, like its subject matter, the sources and connections are diverse and not always immediately evident. A primary focus must be on the consolidation (and simplification) of much of the existing law, which has emerged in a somewhat haphazard and inconsistent manner, some of it driven by domestic requirements, and otherwise by how we have chosen to implement European obligations. As a general principle, the number of general exemptions provided for in the legislation should be strictly curtailed, unlike the current hotchpotch of legislation which has wide exemptions from its application. There is a clear need to review Irish water law with a view to producing a Water Act, consolidating and updating existing water-related legislation to provide a single comprehensive source of reference to water matters and a single source of law as far as possible.

Chapter 1

1 General Introduction

1.1 Physical structure and the ecological integrity of water bodies

The Water Framework Directive 2000/60/EC (WFD) provided a new vision for the protection of European water resources and aquatic habitats. A fundamental element of the legislation is the recognition of the importance of hydrological regimes, the connectivity of aquatic ecosystems, and the nature of the habitat within and adjacent to water bodies. These components that combine hydrology, hydraulics, and morphometry fall within the new integrated term of hydromorphology. The WFD requires policy measures to prevent or mitigate hydromorphological alterations. These measures apply to all water bodies defined in the Directive, including a class identified as water-dependent habitats, such as vegetated wetlands. Good hydromorphological conditions provide an ecosystem structure of physical habitat for biotas such as fish, invertebrates and aquatic macrophytes commensurate with good ecological status.

The term hydromorphology within the context of the WFD draws particularly on hydrology, hydraulics, and morphometry, and how these have and can be used for the management of water bodies and groundwater dependent terrestrial ecosystems, referred to further in this report as groundwater dependent ecosystems (GDEs). Traditional approaches to the topic and the management of water flowing through catchments and water bodies were dominated by engineering solutions. Objectives of the engineering-focused approach to water management frequently involved the controlled movement of water off the land and down the river, or holding the water back in reservoirs for flood control, water storage and/or energy generation. This approach has been generally damaging for ecosystems, while often not solving negative effects such as flood risks. In coastal zones, the need for ports as efficient conduits of trade necessitated the large-scale transformation of estuarine habitats, and the continuous dredging of sediment to keep shipping lanes open. The costs of the traditional approach hardly factored in impacts on natural systems, many of which provide significant economic as well as social and ecosystem benefits (Jacobs et al., 2016; Ma et al., 2014; Schindler et al., 2016).

The assessment of the quality of water bodies has been built on three main approaches: water pollution, biology and physical structure (Chapman, 1996). The biological communities were often used as indicators of the extent of pollution, initially with attention on emissions from industry and wastewater treatment plants (e.g. Hynes (1960)) and later from catchment processes at large (Smol, 2008). Interest in the physical structure of water bodies was largely the domain of hydrologists, hydraulic engineers, geomorphologists (Knighton, 1998) and physical limnologists (Imberger and Patterson, 1989). With some notable exceptions (Newson, 2002), there was relatively little attention to the integration of ecological and physical structure in rivers and, when occurring, was largely in the interests of nature conservation. Moreover, the history of working in and managing different habitats separately has led to a fragmented approaches across habitat types. It belies the reality that different inland water bodies are interconnected, as well as with the land and sea. This has led to a neglect of important, even integral, ecological linkages that support ecological processes (Lamberti et al., 2010).

Many of those linkages depend on the physical structure of water bodies and terrestrial habitats within and across catchments. Connectivity may be through aerial processes, but more often than not is it through hydrological connection.

Motivations for a more holistic approach to rivers came with increasing attention to river restoration with the need to re-establish and monitor morphological and ecological processes (Clifford et al., 2006; Kemp et al., 1999; Walker et al., 2002). In lakes, physical structure is a basic and traditional element for lake ecology (Wetzel, 2001) and reservoir management (Townsend, 1999), but largely confined to open-water patterns of stratification and its effect on trophic structure, deoxygenation of the lower hypolimnetic layers and surface nuisance algal populations (Vollenweider and Kerekes, 1980).

Tidal cycles and riverine inputs over saline layers in transitional zones between sea and rivers resulted in a focus on the physics and effects on salinity, but relative neglect of the details of its effect on ecological structure beyond general distribution patterns of marine organisms, including low diversity in intermediate salinities (McLusky, 1989).

Given that the need for environmental management arises from identified problems, it is not surprising that the management of water bodies would often lack a holistic approach, and focus rather on how to address identified pressures that lead to measurable impacts (Smeets and Weterings, 1999). In water bodies, impact manifests as noticeable, often visible signals such as high concentrations of phytoplankton, loss of key species such as salmonids, or sickness from polluted water with consequences for human health. Even when there is quantified causality between the water body's physical and ecological structure, this may not stimulate management actions. Management actions often lag someway behind economic demonstration of the impact caused by alterations to water bodies. Decisions for remedial actions, when implemented, may also not live up to expectations (Feld et al., 2011; Kristensen et al., 2014).

Recognition of environmental and species loss and degradation also play out in the political arena of public concern, leading to the development of environmental policies. For water bodies, the global milestone was the US Clean Water Act (1972). Similar ambitions for the protection of waters have been introduced in many countries e.g. Australian and New Zealand (ANZECC/ARMCANZ, 2000), Canada (CCME, 2007), China (Su et al., 2017), Colombia (Díaz-Casallas et al., 2019), Japan, and South Africa (Roux et al., 1999). In Europe, a series of legally binding Environmental Directives have been instigated since the 1970s. For water law, this culminated in Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy; commonly known as the Water Framework Directive (WFD).

Modern legislation and practice for water body protection incorporate to a greater or lesser extent the concept of ecological integrity or health (Karr and Chu, 1999), a general definition of which is provided in Box 1.

Box 1. A definition of Ecosystem Health after Millennium Ecosystem Assessment (2005). *A measure of the stability and sustainability of ecosystem functioning or ecosystem services that depend on an ecosystem being active and maintaining its organization, autonomy, and resilience over time. Ecosystem health contributes to human well-being through sustainable ecosystem services and conditions for human health.*

The concept of ecosystem health, or integrity, is very much rooted in the functions as well as the structure of ecosystems (Borja et al., 2009; USEPA, 2002). The term 'full ecological integrity' used by Fennessy et al. (2004) is synonymous with an unimpacted reference state. A functioning ecosystem is one where biological and chemical processes are integrated, and ecosystem processes are efficient in terms of energy and biological transfers. These concepts are well established (McIntyre et al., 2007; Vannote et al., 1980; Wilson and Tilman, 1993). They can, however, be severely affected by anthropogenic disturbance (Vörösmarty et al., 2010).

Disturbing habitat conditions either by changing the physical structure or hydrological patterns puts pressure on ecosystem integrity, with the risk of changing the ecology. Ecosystems prevail within natural boundaries of change. Exceeding these provides a risk of altering the physical, chemical and geomorphological baselines, often with far-reaching consequences (Bunn and Arthington, 2002).

Globally we have already experienced dramatic impacts on ecosystems, of which freshwaters are, overall, the most damaged (Tickner et al., 2020). This includes the consequences to ecology or changes to hydrology, hydraulics and geomorphology, concepts that are embedded within the very broad term of hydromorphology, and the need for their better integration for management (Vaughan et al., 2009; Vaughan and Ormerod, 2010).

For Europe's surface waters, transitional and coastal waters, many negative effects are already evident through physical modifications from land or water body use, diminishing ecosystem integrity of surface waters, riparian zones, and groundwater-dependent habitats. Impacts can be direct through alterations in water flow and residence time affecting hydrological patterns, or indirect through e.g. sediment and nutrient loading, and changes that accentuate the impact from other, perhaps interacting, pressures, such as the spread and impact from invasive species and climate change. The potential of morphological change to have a negative impact, singularly or in combination with other human pressures, is an issue that should be addressed by the WFD.

1.2 Hydromorphology and WFD

The WFD approach to the management of European waters is based primarily on the ecological status of water bodies, as judged by a departure from a reference state where pressures from human activities are minimal, as defined in Annex V of the WFD. The WFD classification system is type-specific, so that ecological status is judged relative to the defined reference state within a classification typology that accounts for inherent differences in topography and climate across Europe. This is designed so that individual water bodies are compared with others of similar expected biological composition. While this approach brings some inevitable challenges in an appropriate grouping of water bodies of perceived similar character (Hering et al., 2010; Jusik et al., 2015; Moss, 2008a; Moss et al., 2003), it does allow for national and pan-European comparisons and assessment of the state of the aquatic environment (Borja et al., 2007; Poikane et al., 2014).

The WFD aims to ensure ecosystem-based management of waters by ensuring that human use of water is compatible with a certain quality of ecosystem structure and function, achieving at least good status of all water bodies, unless derogation to a lower standard is approved.

Annex V of the Directive defines good ecological status such that “the biological quality elements for the surface water body type show low levels of distortion resulting from human activity but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions.” The WFD also requires that water bodies do not decline to good status from the high status defined as “The values of the biological quality elements for the surface water body reflect those normally associated with that type under undisturbed conditions, and show no, or only very minor, evidence of distortion.” High status also requires that “there are no, or only very minor, anthropogenic alterations” to the values of the physical and chemical, and hydromorphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions.

The WFD classification scheme is set up with an emphasis on the assessment of Biological Quality Elements (BQEs). The reported ecological status for a water body is determined by the biological element that signals the worst status, in what is known as the ‘one-out, all-out’ principle. This has enormous relevance for the operational roll-out of the WFD. The linking of water chemistry with biotic communities, and the mindset of the ‘indicator species’ (Karr and Chu, 1997; Nijboer et al., 2005) has shaped the approach to monitoring in many aquatic systems (Clarke et al., 2003; Rosenberg and Resh, 1993; Swedish Environmental Protection Agency, 2000).

This has been particularly so for rivers and the epilimnion (upper zone) of lakes. Even in the profundal (deeper zone beneath the thermocline) of stratified lakes, classification schemes were developed largely on the relationship between oxygen and a few well-studied worms and chironomid insects (Milbrink, 1978; Saether, 1979; Wiederholm, 1980). The hydrological regime, river continuity, and morphological conditions, while recognised as important by aquatic ecologists as explaining variables for ecological integrity, tended to be dealt with in separate academic domains of hydrologists and geomorphologists.

For the assessment of the effects of physical modifications to water bodies, the WFD use of the term ‘hydromorphology’ encompasses a wide range of situations where hydromorphological alterations may occur. Hydromorphological alterations have the potential to affect the ecology of water bodies across a large range of scales and are associated with impacts that can change hydrology, hydraulics, geomorphology and surface and groundwater interactions. In broad terms, hydrology relates to the movement of water and the water cycle involving evaporation, precipitation, surface- and groundwater flows, bulk transport through water bodies (often measured as m^3/s in rivers and residence time in lakes), and tidal and wind-driven water movement (currents) in coastal zones and estuaries. Hydraulics is concerned with the physics of water movement, involving concepts such as shear stress and wave energy. It is important for the forces that move material through water bodies and for how organisms cope with those forces, whether through behavioural or physical adaptation. Flow and hydraulics shape the movement and distribution of sediment, and hence water bodies' geomorphology and habitat structure at the sediment-water interface. In this report, we use the terminology of the WFD as much as possible.

The hydromorphological elements of the hydrological regime, river continuity, and morphological conditions, and the physical and water chemical variables (thermal conditions, oxygen, salinity, acidification status, and nutrient conditions) are there to support the assessment of the biological elements. In the WFD, the hydromorphological elements comprise:

- hydrological regime (quantity and dynamics of flow, connection to groundwater);
- continuity (the ability of sediment and migratory species to pass freely up and down rivers and laterally within the floodplain); and
- morphology (i.e. physical habitat – compositions of substrate, width/depth variation, the structure of the bed, banks and riparian zone).

Good hydromorphological conditions are those that are commensurate with ecosystem structure that provides physical habitat for biota such as fish, invertebrates and aquatic macrophytes commensurate with good ecological status. After the WFD came into law, the European Commission issued a series of Common Implementation Strategy (CIS) guidance documents

A number of these apply to hydromorphology, but that there is no specific stand-alone guidance on hydromorphology likely reflects: a) the large range of possible aspects that come under the term, and b) the need to further integrate the European experience of hydromorphology into the holistic management advocated by the WFD (Voulvoulis et al., 2017). A consolidation of advice on the use of hydromorphology in the WFD, including clarification of many key issues is provided by Kampa et al. (2019). This is a valuable interpretative document from the European Commission CIS ECOSTAT group, including a comprehensive list of technical and policy guidance and summary of related workshops. This report can be accessed (as of 5th September 2025) via: Library ⇨ working_groups ⇨ ecological_status ⇨ 10 - Hydromorphology Resource Library.

In Annex V of the WFD, hydromorphological conditions are only explicitly described for high status water bodies. This has led to an interpretation among some Member States that, as a supporting element to the BQEs, specific assessment of hydromorphological conditions and its alteration is not applicable for good or less than good status for WFD classification. This appears to be the position taken by the Irish Environmental Protection Agency (EPA), such that “Only sites that are at high status based on other ecological quality elements may be downgraded to good status based on the hydromorphological assessment failing to reach high status. As the rules of the Directive currently stand, this is the only scenario where hydromorphology can be used in classification” (EPA, 2021a).

For good and moderate status, hydromorphological conditions are to be “consistent with the achievement of values specified for the biological elements.” Interpretation from the European Commission ECOSTAT group is that there is a need for hydromorphological assessment for each of the 5-class biological classifications, although formal guidance on this is still not clear. Nevertheless, it would be logical and necessary to assess ecological effects of hydromorphological alterations for assessment methods to reliably assess hydromorphological conditions along the full status gradient, from good to bad (Kampa et al., 2019). Furthermore, in the early stages of the WFD when water bodies were being delineated and classified according to type-specific reference state, many hydromorphological features and processes were not taken into account. The WFD typology should reflect the natural variability in hydromorphological characteristics and processes, which in turn will result in different reference values in those BQE methods that are sensitive to hydromorphological alterations (European Commission, 2003a, 2003b). Therefore, hydromorphological conditions are part of the definition of type-specific reference conditions (Kampa et al., 2019). The water body types and their specific reference conditions were determined before WFD-related reviews were done. With the intervening development of many hydromorphological methods,

typology and water body delineation would benefit from a reconsideration or reaffirmation in each RMBP cycle (Kampa et al., 2019).

In the CIS guidance on 'Pressures and Impacts' (European Commission, 2003c), it is stated that: "The hydromorphological elements are not used in the determination of ecological status, but could be the cause of the failure to achieve good or high ecological status," and, therefore, used independently to downgrade an ecological classification from high status to good status. There appears, then to be an evolving interpretation of the WFD rules regarding the assessment of hydromorphology in water body classification. The hydromorphological quality elements mentioned in that guidance (Table 1) are referred to as "Possible impacts or changes in state that can be identified from monitoring data."

As evident from the wording "possible impacts or changes in state that can be identified from monitoring data", the WFD is not specific in what physical attributes comprise a hydromorphological element. It can be concluded that hydromorphological pressures comprise all physical changes that can threaten aquatic ecosystems (Bureao de Recherches Géologiques et Minières, 2007). The wording in the Directive text is sufficiently general to cover descriptors with the potential to affect the ecology of water bodies across a large range of scales and possibilities. Hydromorphology applies to all types of water bodies covered in the WFD. This includes coastal and transitional (e.g. estuaries and lagoons) and GDEs. Elsewhere in the text of the WFD is mention of abstraction as an element to characterise, as well as a potential impact on, groundwaters.

Table 1. Hydromorphological quality elements that might be identified in WFD monitoring programmes (European Commission, 2003a).

Hydrological regime	Quantity and dynamics of water flow Connection to groundwater bodies Residence time
Tidal regime	Freshwater flow direction of dominant currents Wave exposure
River continuity	River depth and width variation Structure and substrate of the riverbed Structure of the riparian zone
Morphology	Depth and width variation Quantity, structure and substrate of the bed Structure of the riparian zone, lakeshore or intertidal zone

The logical conclusion from the phasing in the 'Impacts and Pressures' report (European Commission, 2003c) that "the hydromorphological elements are not used in the determination of ecological status, but could be the cause of the failure to achieve good or high ecological status" is that the assessment of ecological status as determined by a departure from reference state necessarily incorporates any possible impact from hydromorphological alteration. A guiding principle is that if a physical alteration has the potential to affect the capacity of a water body to support the habitat and living space of the biological elements referred to in Annex V of the WFD, it can be considered a hydromorphological alteration.

The supporting hydromorphology for good status for each of the separate categories of hydrological regime, river continuity and morphological conditions are to be “consistent with the achievement of the values specified […] for the biological quality elements.” The use of a hydromorphological reference state is still under development and has been applied in several different ways (European Commission, 2019a; Kampa and Bussettini, 2018; Phellan et al., 2021).

Irrespective of the interpretation that assessment for classification only relates to a departure from high status or an estimate that status less than good may be attributable to hydromorphological alteration, the view of Kampa et al. (2019) is that assessment of hydromorphology is crucial for the management of all water bodies, and to develop and predict effects of measures and mitigate effects of hydromorphological alterations. This is needed for a better understanding of responses and the need for associated monitoring. “This is not possible with a single qualitative 2-class method” (Kampa et al., 2019).

That hydromorphological alteration is identified as a primary factor for a water body to have a risk of failing to achieve the environmental objective of good ecological status (EEA, 2018), indicates the link with the BQEs. Such an assessment is, however, a very approximate reflection of ecosystem processes unless there is demonstrable causality between pressure and impact across the range of water body conditions (see Sections 1.3 and 1.4).

For heavily modified water bodies (HMWBs) and artificial water bodies (AWBs), Annex V (1.2.5) of the WFD specifies that for high ecological potential, “the hydromorphological conditions are consistent with the [only] impacts on the surface water body being those resulting from the artificial or heavily modified characteristics of the water body once all mitigation measures have been taken to ensure the best approximation to ecological continuum, in particular with respect to migration of fauna and appropriate spawning and breeding grounds.”

A surface water body is considered an AWB when created by human activity. A HMWB refers to a body of surface water that as a result of physical alteration by human activity is substantially changed in character. Understanding responses of BQEs to hydromorphological pressures is also essential for the designation of HMWBs, the evaluation of the significance and permanence of modifications, and the definition of ecological potential (European Commission, 2003d). An HMWB may be designated on the grounds of:

- navigation, including port facilities, or recreation;
- activities for the purposes of which water is stored, such as drinking-water supply, power generation or irrigation;
- water regulation, flood protection, land drainage; and
- other equally important sustainable human development activities.

Under Annex V (1.1.5) of the WFD, “The quality elements applicable to artificial and heavily modified surface water bodies shall be those applicable to whichever of the four natural surface water categories [rivers, lakes, transitional waters, coastal waters] most closely resembles the heavily modified or artificial water body concerned.”

CIS Guidance Document No. 4 on the designation of HMWBs and AWBs (European Commission, 2003e), distinguished between restoration measures that ensure the hydromorphological conditions of a water body are consistent with good ecological status, or where measures do not restore a water body to good ecological status these are referred to as mitigation measures. That includes measures to achieve good ecological potential (GEP). All mitigation measures are to be identified to establish the maximum ecological potential. That such wording comes from a more theoretical basis than based on existing policy experience or extensive restoration practice, is effectively acknowledged in that the approaches are "somewhat theoretical", requiring further work. This is revealed further by "Nevertheless, by definition, the environmental objectives assigned to AWB and HMWB expressed in terms of ecological potential take into account the physical modifications due to their designation."

Therefore, only those measures that will not have a significant adverse effect on the use for which the body has been designated can be used in mitigating the adverse ecological effects of the modification." The implication here is that good ecological potential is likely largely, or perhaps only, judged on a case-by-case basis. The WFD and hydromorphological pressures technical report (European Commission, 2006) states (See Section 3.6) that "the definition of GEP is recognised as a major technical challenge", and (See Section 4.1) that "The precise definition of the measures appropriate in any given situation is likely to depend on the particular characteristics of the water body and the water use concerned." However, there is no hydromorphological assessment method for the quantification of the impact from hydromorphological pressures on already impacted water bodies.

In order to evaluate the impact on hydromorphological and biological processes, which in turn will help in the prioritisation of measures, Keogh et al. (2020) recommended a system that describes the magnitude and grade of pressures that should be introduced. Progress towards detailed assessment of rivers has been progressed by a number of projects (e.g. Belletti et al., 2015; Rinaldi et al., 2015a, 2015b). Irrespective of these theoretical and practical challenges, "the objective for HMWB (GEP) is based on a forecast of how the biology in the water body is expected to be when all mitigation measures are in place and effective...[and]…monitoring needs to measure the response of the biological communities to the measures implemented" (European Commission, 2003d; Kampa et al., 2019). An updated guidance document for the designation of HMWBs provides an overview of key issues (European Commission, 2019a). Further details on EU projects to develop and assess methods are given below in Sections 1.3 and 3.1.

If hydromorphological restoration to good ecological status is elusive, it could be viewed that mitigation comprises management measures to achieve the best ecological state in the circumstances, but with no clear definition of a measurable target. If this interpretation has validity, it means that there could be a policy incentive to maximise the number of designations of HMWBs (see Section 2.2.8). However, it is also clear that there is an onus on Member States to restore hydromorphological characteristics where these are a cause of failure to meet good ecological status (Orr et al., 2008). Merely deciding that hydromorphological alteration is itself a reason to designate a water body as heavily modified is counter to the objectives of the WFD (Kampa and Hansen, 2004).

While a Tool Box to support the designation of HMWBs and AWBs has been provided by the European Commission (2019a, 2003d), with detailed step-by-step advice and the use of specific examples, some fundamental challenges in deciding on what comprises good ecological potential remain. Furthermore, the extent to which economic considerations are relevant is likely to have a much greater bearing on the management and procedures to reach good ecological status for HMWBs and AWBs. Exemptions are also allowed in the form of extension of deadlines or less stringent objectives, supported by "infeasible" or "disproportionately expensive" reasons and reported in the River Basin Management Plans (RBMPs). However, the EC Guidance document No. 37 is clear in that "Designation of HMWB is not a type of exemption. HMWB are a specific water body category with their classification scheme and objective [of GEP]" (European Commission, 2019a). Assessing the cost-effectiveness of measures in terms of the likelihood that they will lead to anticipated improvements within defined periods, perhaps dictated by the river basin management cycles, compared with other water bodies will be a consideration for all programmes of measures (PoMs) (European Commission, 2006) (Figure 1). Hydropower, for example, has important external costs and benefits, as well as a need for an Environmental Impact Assessment (EIA).

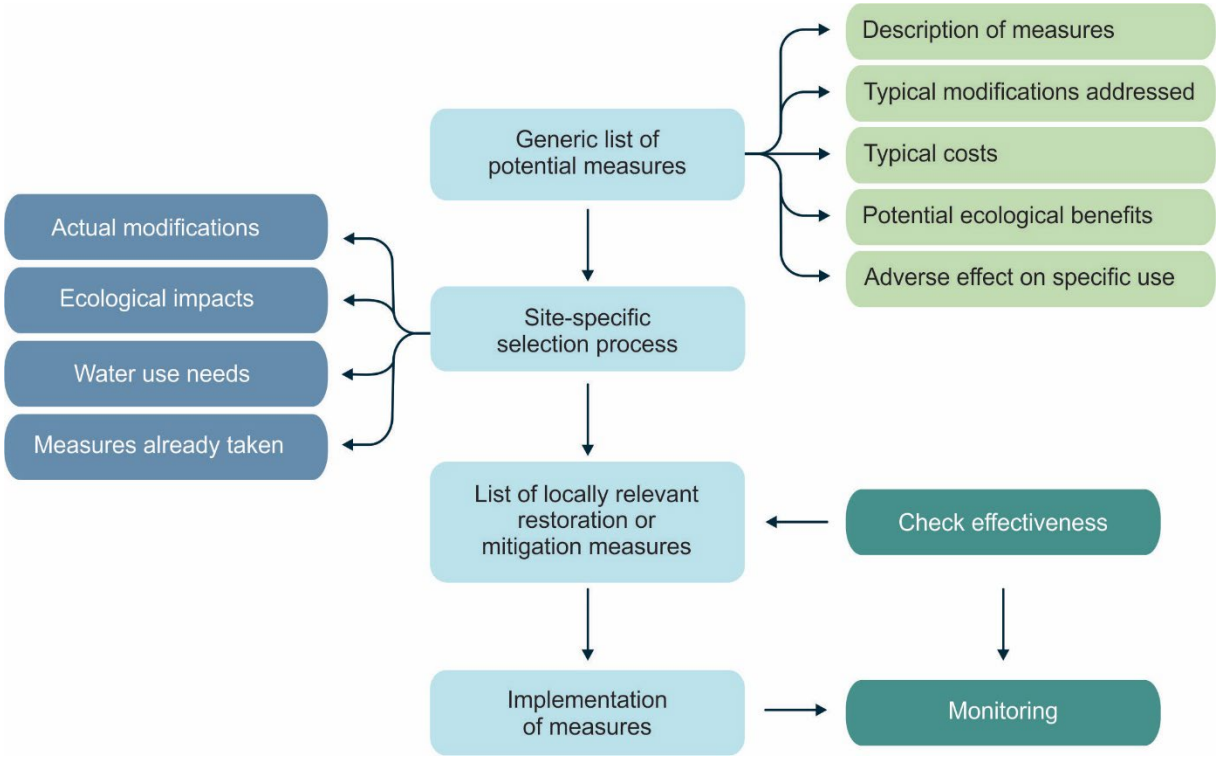


Figure 1. A generic overview of potential measures for hydromorphological alterations to be considered within the implementation of the EU Water Framework Directive. Adapted from European Commission (2006).

For HMWBs and AWBs, for which good ecological potential needs to be judged on the closeness to maximum ecological potential, a similar approach as a type-specific reference state is required. The guidance of the European Commission (2006) that "Involving water users and other stakeholders in the identification of cost-effective measure options can help identify practical solutions and improve the effectiveness of the selected measures by increasing stakeholders' understanding of, and support for, them" can play out in different ways.

It may, therefore, be important to avail of full economic valuation tools, including externalities and catchment services to guide decision-making on measures to achieve good ecological potential (Blignaut et al., 2014; de Groot et al., 2010; Rolston et al., 2017; Russi et al., 2013) and the potential consequences of mitigation measures (European Commission, 2019a).

The WFD Article 5 reporting of 2004 estimated about 20% of European surface water bodies as HMWBs and 4.5% as AWBs. This finding led to the creation of a CIS advisory group on hydromorphological alterations. The initial focus was on hydropower generation, navigation and flood protection (European Commission, 2006), and followed by "WFD and Hydromorphology – Recommendations for better policy integration" (European Commission, 2007).

During the first cycle of the RBMPs (see also Section 4.1), 16.4% of European water bodies were designated as HMWBs or AWBs. These were associated with densely populated, urbanised areas with industrial areas and ports (Fehér et al., 2012). In the Netherlands, the majority of river-type water bodies were designated as HMWBs, while in Sweden almost all river water bodies were considered to be in a natural hydromorphological condition. The Netherlands, Czech Republic, and Belgium designated nearly all their lake water bodies as either HMWBs or AWBs.

1.3 Assessment Methods

A compilation of many of the published assessment methods for hydromorphology is shown in Table 2 (Belletti et al., 2015). These have tended to focus on physical habitat, riparian habitat and morphology, and less so on underlying physical processes, partly because they are more difficult to assess rapidly (Belletti et al., 2015). They have also tended to focus on rivers. Early methods focussed on physical in-stream and riparian habitats, as provided by the UK River Habitat Survey (Raven et al., 2002), with other European classifications developed in Austria (Werth, 1992), Germany (Patt et al., 2004) and France (Agences de l'eau Aquascop, 1998). These techniques were drawn on in the development of the European Committee for Standardisation (CEN) Guidance Standard 14614 on the assessment of hydromorphological features of rivers, first published in 2004, and updated by EN 14614:2020 - Water quality - Guidance standard for assessing the hydromorphological features of rivers (CEN, 2020). The CEN Rivers' Standard covers categories of physical assessment, covering the channel, riparian zone and floodplain.

These methods have similarities with the conservation-orientated approach to river assessment offered by the System for Evaluating Rivers for Conservation (SERCON) (Boon et al., 2002) and connected to geomorphology and the evaluation of the WFD good status and concepts of geomorphological and fluvial naturalness (Newson and Large, 2006). WFD classification has generally overlooked important processes of geomorphology.

CEN Guidance documents setting out a minimum requirement for assessment for hydromorphology and related standards are:

- *EN 16039:2011 (WI=00230254). Water quality - Guidance standard on assessing the hydromorphological features of lakes (CEN, 2011);*
- *EN 16503:2014 (WI=00230294). Water quality - Guidance standard on assessing the hydromorphological features of transitional and coastal waters (CEN, 2014);*

- *EN 16870:2017 (WI=00230285). Water quality - Guidance standard on determining the degree of modification of lake hydromorphology (CEN, 2017);*
- *EN 17123:2018 (WI=00230343). Water quality - Guidance on determining the degree of modification of the hydromorphological features of transitional and coastal waters (CEN, 2018);* and
- *EN 14614:2020 Water quality - Guidance standard for assessing the hydromorphological features of rivers (CEN, 2020).*

For all water bodies, the main assessment methods for hydromorphology consider: 1) physical habitat; 2) riparian habitat; 3) morphological; 4) hydrological regime alteration; and 5) longitudinal fish continuity (Rinaldi et al., 2013). Following previous reviews (Fernandez et al., 2011; McGinnity et al., 2005; Raven et al., 2002; Weiß et al., 2008); Belletti et al., 2015) (Table 2) reviewed the limitations, strengths, and gaps in hydromorphological assessment methods used between 1983-2013. They compared the assessment of physical habitat, riparian habitat, morphology, and hydrological regime alterations. Of 121 studies reviewed, 73 methods were of physical habitat assessment, 15 for riparian zone, 22 for morphological assessment, and 11 for hydrological regime alteration.

While a large range of hydromorphological changes can have an impact on river ecology, the majority of European countries use physical habitat assessment methods for studying hydromorphology as they align well with the WFD objectives. This is, however, limited by a focus on river habitat descriptors, and the use of site-specific data that is then scaled to larger geographical river sections that define the water body (Kondolf et al., 2006). Riparian habitat assessment itself is not generally sensitive to the wider evaluation of river hydromorphology, and morphological visual descriptors do not necessarily capture ecological condition. The assessment of hydrological alteration methods does not incorporate the influence of groundwater very well. Reference conditions were considered in 64% of studies that incorporated the morphological assessment, 58% of physical habitat assessment methods, and 40% of studies of riparian habitat assessment (Bellatti et al., 2015).

A more recent analysis for lakes (Argillier et al., 2023) based on a questionnaire distributed to Member States identified that while many techniques were being applied, methods were still under development in many countries. Only 3 of 20 methods used by Member States were formally included in national regulations. A description of the assessment methods for lakes collated from the questionnaire are provided in Argillier and Carriere (2023). Further work developed a multi-metric index applicable to French lakes (Carriere et al., 2024) There remains a need for better linking components of hydromorphology with the underlying processes and their impact on the biological quality elements.

Table 2. Assessment methods for river hydromorphology reviewed by Bellatti et al (2015).

Category	Year	Country	Acronym	Key reference	Percentage coverage regarding		
					Method characteristics (Ch)	Recorded features (Fe)	River processes (Rp)
PH	1983	US	MESC	Platts et al. (1983)	47	56	33
PH	1987	Austria	Werth	Werth (1987)	59	48	17
PH	1989	Austria	WatercSt	Spiegler et al. (1989)	53	59	17
PH	1989	US	QHEI	Rankin (1989)	59	63	33
PH	1992	Sweden	RCE	Petersen (1992)	47	33	33
PH	1993	Australia	SRS	Anderson (1993)	59	41	33
PH	1993	Belgium	SEvalW	Schneiders et al. (1993)	47	33	17
PH	1994	Belgium	SK	Wils et al. (1994)	35	11	0
PH	1996	Austria	GEBD (RSR)	Buhmann & Hutter (1996)	59	56	17
PH	1996	France	Qualphy	Denortier & Goetghebeur (1996)	59	63	33
PH	1996	US	RSAT	Galli (1996)	41	41	17
PH	1997	England	RHS	Raven et al. (1997)	53	67	50
PH	1997	Poland	EcomorphEval	Ilnicki and Lewandowski (1997)	47	41	33
PH	1997	US	FFHSIP	Overton et al. (1997)	41	33	17
PH	1997	US	VSMM	US Environmental Protection Agency (1997)	59	52	33
PH	1998	Austria	AssRivSt	Muhar &Jungwirth (1998)	59	67	50
PH	1998	Austria	RATyrol	BUWAL (1998)	41	26	17
PH	1998	Denmark	DSFI	Danish Env. Protection Agency (1998)	35	7	0
PH	1998	France	SEQ-P	Agences de L´Eau (1998)	59	63	33
PH	1998	Switzerland	ModConc	Liechti et al. (1998)	41	37	33
PH	1998	US	MCSH (NAWQA)	Fitzpatrick et al. (1998)	47	37	0
PH	1998	US	RHVSA-EMAP	Lazorchak et al. (1998)	41	37	0
PH	1999	Australia	ISC	Ladson et al. (1999)	65	30	33
PH	1999	Denmark	Aarhus	Kaarup (1999)	47	18	17
PH	1999	Denmark	NPHI	National Environmental Research Institute (1999)	47	37	0
PH	1999	Denmark	PhysSC	Skriver et al. (1999)	41	41	0
PH	1999	US	PHC (EMAP)	Kaufmann et al. (1999)	41	41	0
PH	1999	US	RBP	Plafkin et al. (1989), Barbour et al. (1999)	59	56	33
PH	2000	Australia	HPM	Davies et al. (2000)	59	48	17
PH	2000	England	MesoH	Tickner et al. (2000)	41	11	0
PH	2000	Germany	LAWA-FS-MToL	LAWA (2000)	59	48	50
PH	2000	US	WCE	Oregon Watersh. Enhanc. Board (2000)	71	52	33
PH	2001	Austria	NÖMORPH	Freiland Umeltconsulting (2001a, b)	59	41	17
PH	2001	Germany	BfG–WW	Bundesanstalt für Gewässerkunde (2001)	47	56	50

PH physical habitat assessment, RH riparian habitat assessment, M morphological assessment, HRA hydrological regime alteration assessment.

Table 2. (continued) Assessment methods for river hydromorphology reviewed by Bellatti et al (2015).

Category	Year	Country	Acronym	Key reference	Percentage coverage regarding		
					Method characteristics (Ch)	Recorded features (Fe)	River processes (Rp)
PH	2001	US	SCA	Yetman (2001)	47	48	50
PH	2001	US	SRHRAP	Starr and McCandless (2001)	41	41	33
PH	2002	Germany	LAWA-FS-SToL	LAWA (2002a)	59	52	50
PH	2002	Germany	LAWA-OS	LAWA (2002a, b)	53	37	50
PH	2002	Italy	IFF	Siligardi et al. (2002)	59	37	17
PH	2002	Spain	IHF	Pardo et al. (2002)	41	18	0
PH	2002	Sweden	BiotopeMap	Hallden et al. (2002)	65	44	17
PH	2002	US	HHEI	Ohio Env. Protection Agency (2002)	59	30	0
PH	2002	US	MinHWCP	Minnesota Pollution Control Ag. (2002)	41	44	17
PH	2003	Denmark	DHQI	Pedersen & Baattrup-Pedersen (2003)	71	41	17
PH	2003	England	GeoRHS	Environment Agency (2003)	59	48	67
PH	2003	US	MNHWA	Crowe and Kudray (2003)	47	26	33
PH	2004	Australia	AusRivAs-PAP	Parsons et al. (2004)	65	70	50
PH	2004	England	URS	Davenport et al. (2004)	53	56	50
PH	2004	Germany	GSI	Feld (2004)	59	52	17
PH	2004	US	BURP	Idaho Dep. Env. Quality (2004)	53	37	17
PH	2004	US	SEvalAH	Kansas Dep. of Wildlife & Parks (2004)	53	37	33
PH	2004	US	VSGA	Vermont Agency of Natural Resources (2010)	53	63	67
PH	2004	US	WSAss	US Environmental Protection Agency (2004)	47	44	33
PH	2005	Italy	CARAVAGGIO	Buffagni et al. (2005)	59	70	50
PH	2005	Portugal	HCI	Oliveira and Cortes (2005)	53	26	0
PH	2005	US	NWHI	Wilhelm et al. (2005)	41	22	17
PH	2006	Czech Rep.	EcoRivHab	Matoušková (2006)	65	52	33
PH	2006	Spain	HIDRI	Munné et al. (2006)	71	59	17
PH	2006	US	SIH	US Forest Service (2006)	53	44	50
PH	2007	NL	Handboek HYMO	Dam et al. (2007)	53	41	67
PH	2007	Slovakia	HAP–SR	Lehotský and Grešková (2007)	59	63	67
PH	2008	S. Africa	IHI	Kleynhans et al. (2008)	53	41	33
PH	2009	NZ	SHAP	Harding et al. (2009)	53	59	17
PH	2009	Poland	MHR	Ilnicki et al. (2009)	59	56	33
PH	2009	Slovenia	SI_HM	Tavzes and Urbanic (2009)	53	67	50
PH	2009	US	SCS-SH	Maine Dep. of Env. Protection (2009)	59	48	50
PH	2009	US	SVAP	US Department of Agriculture (2009)	53	59	67
PH	2010	Austria	HYMO	Mühlmann (2010)	47	41	50
PH	2010	China	USM	Xia et al. (2010)	41	44	50

PH physical habitat assessment, RH riparian habitat assessment, M morphological assessment, HRA hydrological regime alteration assessment.

Table 2. (continued) Assessment methods for river hydromorphology reviewed by Bellatti et al (2015).

Category	Year	Country	Acronym	Key reference	Percentage coverage regarding		
					Method characteristics (Ch)	Recorded features (Fe)	River processes (Rp)
PH	2010	France	CarHyCE	ONEMA (2010)	35	44	33
PH	2010	US	MBSS	Stranko et al. (2010)	47	52	17
PH	2011	Ukraine	UA-FS	Scheifhacken et al. (2012)	47	48	17
PH	2012	Ireland	RHAT	Murphy and Toland (2012)	65	67	67
RH	1995	US	HGM	Smith et al. (1995)	35	7	17
RH	1998	Italy	BSI & WSI	Braioni and Penna (1998)	59	67	0
RH	1998	Quebec	IQBR	Saint-Jaques and Richard (1998)	35	22	0
RH	1998	Spain	QBR	Munné & Prat (1998), Munné et al. (2003)	47	33	17
RH	1998	US	PFC	Prichard et al. (1998)	29	41	50
RH	2000	US	RWA	Oregon Watersh. Enhanc. Board (2000)	47	22	17
RH	2000	US	VRRA	Winward (2000)	41	15	17
RH	2003	US	VARH	Ward et al. (2003)	35	41	33
RH	2005	Australia	RARC	Jansen et al. (2005)	35	22	0
RH	2005	Australia	TRARC	Dixon et al. (2005)	35	22	0
RH	2006	Spain	IVF	Munné et al. (2006)	47	41	0
RH	2007	S. Africa	VEGRAI	Kleynhans et al. (2007)	47	30	0
RH	2010	Spain	RFV	Magdaleno et al. (2010)	47	22	0
RH	2011	Spain	RQI	González and García (2011)	47	63	50
RH	2012	Australia	RVC_RCI	Healey et al. (2012)	47	22	17
M	1984;1986	US	CEMs	Schumm et al. (1984), Simon & Hupp (1986)	29	29	67
M	1994	US	SCRS	Harrelson et al. (1994)	41	48	33
M	1995	US	RGAs	Ministry of Env. (1999), Simon & Downs (1995)	59	41	33
M	1996	US	NCD	Rosgen (1996)	53	52	33
M	1998	England	FA	Environment Agency (1998)	65	81	83
M	1998	England	SRH	Thorne (1998)	53	70	50
M	2000	S. Africa	GI	Rowntree & Wadeson (2000)	71	56	33
M	2000	US	CMA	Oregon Watershed Enhancement Board (2000)	65	26	33
M	2005	Australia	RSF	Brierley & Fryirs (2005)	65	56	67
M	2005	S. Africa	GAI	Kleynhans et al. (2005)	53	44	83
M	2006	Spain	HIDRI-P1	Munné et al. (2006)	41	11	0
M	2006	US	WARSSS	Rosgen (2006)	53	56	67
M	2007	Czech Republic	HEM	Langhammer (2007)	71	48	50
M	2007	Spain	IHG	Ollero et al. (2007)	59	63	83
M	2008	England	GAP	Sear et al. (2008)	59	81	83

PH physical habitat assessment, RH riparian habitat assessment, M morphological assessment, HRA hydrological regime alteration assessment, n.a. not applicable

Table 2. (continued) Assessment methods for river hydromorphology reviewed by Bellatti et al (2015).

Category	Year	Country	Acronym	Key reference	Percentage coverage regarding		
					Method characteristics (Ch)	Recorded features (Fe)	River processes (Rp)
M	2008	France	SYRAH-CE	Chandesris et al. (2008)	47	37	100
M	2008	Scotland	MImAS	UK Technical Advisory Group on the WFD (2008)	59	52	67
M	2009	Poland	RHQ	Wyżga et al. (2009)	65	56	83
M	2009	US	SAP	Starr (2009)	53	48	50
M	2009	US	SCS-RGA	Maine Department of Environmental Protection (2009)	65	22	50
M	2010	France	AURAH-CE	Valette et al. (2010)	41	18	17
M	2013	Italy	MQI	Rinaldi et al. (2013a, b, c)	65	59	83
HRA	1998	US	RVA	Richter et al. (1996)	32	54	n.a.
HRA	2000	US	HCA	Oregon Watershed Enhancement Board (2000)	36	41	n.a.
HRA	2005	Scotland	DHRAM	Black et al. (2005)	46	54	n.a.
HRA	2005	S. Africa	HAI	Kleynhans et al. (2005)	39	41	n.a.
HRA	2006	Spain	QM-HIDRI	Munné et al. (2006)	39	18	n.a.
HRA	2006	US	HIT	Henriksen et al. (2006)	29	50	n.a.
HRA	2008	Taiwan	HMA	Shiau & Wu (2008)	46	54	n.a.
HRA	2009	US	IHA	The Nature Conservancy (2009)	25	59	n.a.
HRA	2010	Spain	IAHRIS	Martínez SM and Fernández Yuste (2010)	39	54	n.a.
HRA	2011	Italy	IARI	ISPRA (2011)	57	68	n.a.
HRA	2012	Australia	HS_RCI	Healey et al. (2012)	50	54	n.a.

PH physical habitat assessment, RH riparian habitat assessment, M morphological assessment, HRA hydrological regime alteration assessment, n.a. not applicable

1.4 Monitoring for hydromorphology

The WFD requires the identification of significant pressures on water bodies. Significant pressures are defined as contributing to an impact that may result in failing to meet the requirements of Article 4(1) Environmental Objectives (of not having at least good status). Pressures arise from multiple sources, and direct and indirect drivers. These include activities that lead to hydromorphological alterations. Following the guidance of the CIS (European Commission, 2003a), the Drivers, Pressures, Impact, State, Response (DPSIR) model (Smeets and Weterings, 1999) can guide the response to an impact on a water body, directed as an intervention to any, or several, appropriate part(s) of the DPSI chain. The basic model has been elaborated by Poikane et al. (2020a) (Figure 2). To meet the good water status objective, Member States can apply basic and supplementary measures (the Response) to alleviate pressures. Basic measures are those that are needed "to implement Community legislation for the protection of water" as laid out in the WFD. Supplementary measures are "those measures designed and implemented in addition to the basic measures." This means that Member States are obliged to put in place what is necessary to meet the environmental objectives of the Directive unless derogations are sought and obtained.

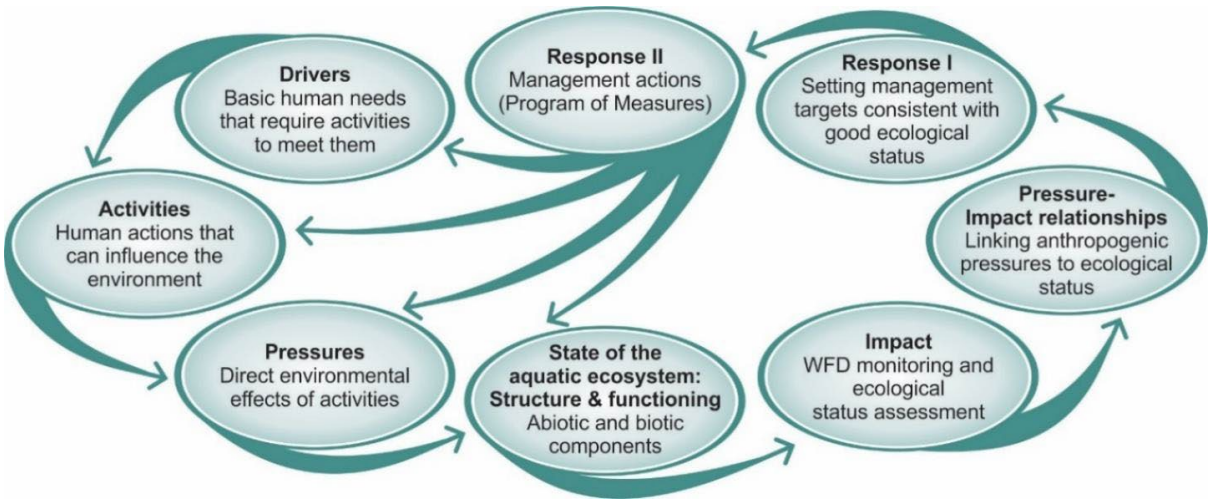


Figure 2. Conceptual links between Drivers, Pressures, State, Impact and Response elaborated on by Poikane et al. (2020a) for the WFD. Based on the original by Smeets and Weterings (1999).

Under Article 11 dealing with the Programme of Measures needed to achieve the environmental objectives of the Directive, Article 11 3 (i) states that ."..measures [will]... ensure that the hydromorphological conditions of the bodies of water are consistent with the achievement of the required ecological status or good ecological potential for bodies of water designated as artificial or heavily modified. Controls for this purpose may take the form of a requirement for prior authorisation or registration based on general binding rules where such a requirement is not otherwise provided for under Community legislation.

Such controls shall be periodically reviewed and, where necessary, updated"; and under Article 11(5) "Where monitoring or other data indicate that the objectives set under Article 4 for the body of water are unlikely to be achieved, the Member State shall ensure that: the causes of the possible failure are investigated, relevant permits and authorisations are examined and reviewed as appropriate, the monitoring programmes are reviewed and adjusted as appropriate, and additional measures as may be necessary in order to achieve those objectives are established, including, as appropriate, the establishment of stricter environmental quality standards following the procedures laid down in Annex V." Article 11(7) specifies that "The programmes of measures shall be established at the latest nine years after the date of entry into force of this Directive and all the measures shall be made operational at the latest 12 years after that date", and Article 11(8) "The programmes of measures shall be reviewed, and if necessary updated at the latest 15 years after the date of entry into force of this Directive and every six years thereafter."

Assessing the impact of pressures and compliance against environmental objectives requires monitoring. Under Article 8, WFD monitoring shall "establish a coherent and comprehensive overview of water status within each river basin district." It includes "the volume and level or rate of flow to the extent relevant for ecological and chemical status and ecological potential", and the quantitative status of groundwaters. Monitoring can occur at three different scales: *surveillance*, *operational* and *investigative* (WFD, Annex V, 1.3). These include hydromorphology, either as a matter of routine or in response to a management need.

Monitoring regimes stipulate that for:

- surveillance monitoring, Member States are obliged to assess "parameters indicative of all hydromorphological quality elements for each monitoring site for a period of one year during the period covered by a river basin management plan";
- operational monitoring, this "shall be undertaken in order to: establish the status of those bodies identified as being at risk of failing to meet their environmental objectives; and assess any changes in the status of such bodies resulting from the programmes of measures;
- bodies at risk from significant hydromorphological pressure, there is a need for "sufficient monitoring points within a selection of the bodies in order to assess the magnitude and impact of the hydromorphological pressures. The selection of bodies shall be indicative of the overall impact of the hydromorphological pressure to which all the bodies are subject"; and
- investigative monitoring, this shall be carried out: "where surveillance monitoring indicates that the objectives set out in Article 4 (environmental objectives) of the WFD for a body of water are not likely to be achieved and operational monitoring has not already been established, in order to ascertain the causes of a water body or water bodies failing to achieve the environmental objectives." There is no reason to assume this does not refer to the investigation of hydromorphological alterations, where these may be a reasonable, but unverified, cause for a water body failing to meet its environmental objectives.

The frequency of monitoring specified in Annex V (1.3.4) of the WFD for hydromorphology is 6 years (i.e. within each river basin planning cycle), except for hydrology which should be "continuous" and for lakes, "monthly." The details of what monitoring comprises at these frequencies are not specified, as it will depend on the hydromorphology of the water body.

The need then for including hydromorphology in monitoring for WFD compliance and linking this to the PoMs is clearly laid out in the text of the Directive. Assessing effects of pressures applies as much to hydromorphology as it does to other pressures. Meaningful monitoring clearly needs to be at relevant temporal and spatial scales, even if these are more intense than that specified in the text of the WFD (Irvine, 2004).

Hence, it would be expected that monitoring to determine the ecological status of water bodies includes: hydrological regimes, continuity (migrant aquatic life such as fish and sediment) and morphological condition for rivers and streams; hydrological regimes and morphological conditions for lakes; tidal regime and morphological conditions for transitional and coastal water bodies; and effects of alterations of the hydrological regime for GDEs. This is required to identify the effect of human interventions that alter the hydromorphology of water bodies which can lead to a deterioration of biological status and hence pose a risk of failing to meet the environmental objectives of the WFD.

Although the WFD requires the assessment of hydromorphological characteristics and their correlation with biological and chemical data to assess the ecological status of waters, it does not prescribe how to do so. Although there is no common monitoring methodology for hydromorphological elements, guidance has been developed through the CIS advisory group on hydromorphology and the CEN standards for general standardised approaches to biological and physical monitoring. Standard Operating Procedures (SOPs) are developed by individual Member States to guide the monitoring of water bodies. For hydromorphological, and other, assessments, methodologies are determined by the Member States under principles of subsidiarity and recognising individual county traditions. This is well demonstrated in an assessment by Poikane et al. (2020a) of national methods used to assess and report on pressures on BQEs. Overall, 423 methods from 29 countries were in use. At least for newer methods, there have been calls for greater use of common assessment methods to assist in monitoring and restorative management of water bodies (Dedić et al., 2020). Member States have also participated in the intercalibration of methods used for assessing the ecological status of their water bodies (Birk et al., 2013; Erba et al., 2009; Lyche Solheim et al., 2008; Poikane et al., 2015).

The confidence of status classes determined from monitoring is subject to a number of operational and statistical errors. Providing acceptable levels of confidence and precision around legally defined class boundaries is difficult and subject to intense discussion, as clearly important for the reliability of reported water body status (Clark, 2002; Ellis, 2006; Howarth, 2006; Irvine, 2012). As the methods for assessing hydromorphology for the WFD were less established than many other quality elements, the methods and estimates of confidence around them have largely arisen since the WFD became operational, and in many cases are still under development. While there has been significant progress in identifying the range and interactions of hydromorphological pressures, alterations and methods to assess that, further work is required to determine reliable biological metrics responsive to hydromorphology (Kampa et al., 2019; Poikane et al., 2020a).

1.5 Overview of main hydromorphological pressures on the European water bodies

Since humans began to settle by water bodies, travel by water ways, exploit the land in organised agriculture and build structures on floodplains, there have been hydrological alterations affecting the integrity of water bodies. The 'Doomsday Book' of the Norman conquerors documented the extensive number of mills on the rivers of England (Hodgen, 1939). In the seminal 'Taming of the Flood', Purseglove (1989) documents the widespread drainage of land in the British Isles dating from Elizabethan times, using Dutch engineering prowess and the need to reclaim land and control water levels. Physical modification of European water bodies and alterations affecting catchment hydrology increased with successive waves of agriculture, as well as urban and industrial development. Kaplan et al. (2009) simulated how early agriculture and population increases would have led to widespread deforestation, already prevalent by 300 BC in south east Europe, spreading eastwards over the next centuries altering land-use and cover (Foulds and Macklin, 2006; Macklin et al., 2006). Deforestation was interspaced with some re-establishment of tree cover because of social upheavals, with more forestry growth and management from the 19th Century (Grober, 2012). Changes in land-use are associated with alterations in climate and catchment to water body run-off (Ruddiman, 2005).

For example, the rivers and floodplains of the Danube have been, respectively, channelised and drained since medieval times, and accelerated following the Treaty of Paris (1856) which prompted further navigation control and river 'improvements. Since the 1920s the Danube Commission oversaw increasing modification of the river's hydromorphology (Iordachi and Van Assche, 2015). A 2008 assessment of the Danube, the second largest river in Europe, estimated it to be 40% slightly modified, 28% moderately modified, 29% severely modified and 3% totally modified. The banks are 17% nearly natural, 22% reinforced in small sections, 40% reinforced in large sections, 18% continuous bank reinforcements and 3% totally reinforced (Jepsen and Umlauf, 2008; Liška et al., 2008). Alteration to the Danube included extensive dam building, which can have major negative consequences for river integrity and those who depend on it (Huđek et al., 2020; Zarfl et al., 2015). Agricultural development mobilises sediment. The introduction of the plough in medieval Denmark has left a signal of nutrient and sediment loads in the lakes (Johansson et al., 2005), as also occurred as a consequence of high human population densities tilling the land in pre-famine Ireland (Donohue et al., 2010).

Hydromorphological alterations are varied and occur across numerous scales from individual river obstructions, hard embankments on riverbanks and shorelines, to the complete transformation of large areas of estuarine habitat for ports and intensive drainage of catchments. The drivers are myriad, from direct major alterations for e.g. navigation, and water storage, to impacts that arise from external use such as water abstraction, land-use, urbanisation, and recreation and tourism. In an overview of the human-induced hydromorphological alterations, agriculture plays a major role throughout Europe (Fehér et al., 2012). These include changes in catchment hydrology, the morphological characteristics of riverbeds and coastal zones, removal of vegetation of riparian buffer zones, bankside erosion, water abstraction for irrigation, and detachment of floodplains from river channels. Intensive agriculture also has multiple effects on the chemical and ecological status of water through eutrophication by leaching nutrients from the soil and pesticide pollution. Dedić et al. (2020) highlighted the need for further integration with the agricultural sector and improvement of implementation of WFD measures through the EU Common Agricultural Policy (CAP).

The consequences and controversies of global modification within water bodies arising from alterations in their catchments, economies and livelihoods are all too apparent (Green et al., 2015). This will become more so with climate change (EEA, 2020; Vörösmarty et al., 2021, 2010; Woolway et al., 2020). In Europe, the morphological alterations of rivers, lakes, and coastal zones have led to widespread increasing ecological impact over the last century as a consequence of *inter alia* more infrastructure affecting water bodies, drainage programmes used to enhance agricultural production and expanse and harvesting of commercial forestry. The ecological impact of hydromorphological alterations often acts in concert with those from industrial, urban and rural-derived pollution, or accentuates the impact from other pressures such as nutrients or the spread of invasive species. Invasive alien species have caused major changes in aquatic ecosystems and the services they provide globally (Dudgeon et al., 2006; Pejchar and Mooney, 2009; Pyšek et al., 2020; Richter et al., 1997; Shine et al., 2010). Jeschke et al. (2021) provide a very readable overview of the impact and management of invasive species in inland waters, with a focus on Europe- An EU list of 'Invasive Alien Species of Union concern'. This list relates to the EU Regulation 1143/2014, which focuses on non-native species in the whole EU region. Of 66 currently listed species, 28 (42%) are from freshwaters, which is striking because they are much less researched than terrestrial ones (Jeschke et al., 2012). The cumulative number of high-impact alien invasive species on the island of Ireland continues to expand (Maguire et al., 2011). Species with the highest impact are shown in Table 3.

Table 3. Alien invasive species in Ireland that have a known impact on aquatic ecological integrity from Maquire et al. (2011).

Established High Impact	Species	Common Name
Aquatic plant	*Lagarosiphon major*	Curly waterweed
	Elodea nuttallii	Nuttall's waterweed
	Myriophyllum aquaticum	Parrot's feather
	Crassula helmsii	New Zealand pigmy weed
	Azolla filiculoides	Water fern
	Lemna minuta	Least duckweed
	Nymphoides peltata	Fringed waterlily
	Hydrocotyle ranunculoides	Floating pennywort
Invertebrate	*Dreissena polymorpha*	Zebra mussel
	Gammarus pulex and G. tigrinus	Crustacean (freshwater shrimp)
	Eriocheir sinensis	Chinese mitten crab
Fish	*Leuciscus cephalus*	Chub
	Leuciscus leuciscus	Dace
Riparian plant	*Fallopia japonica*	Japanese knotweed
	Impatiens glandulifera	Himalayan balsam
	Heracleum mantegazzianum	Giant hogweed

Conversely, nutrient enrichment can alter hydromorphology through, for example, the prolific growth of aquatic plants. Invasive species such as the zebra mussel (*Dreissena polymorpha)* can drastically modify lake benthos, as a hydromorphological alteration. Some other examples established and with the potential to alter habitat and ecological structures in Ireland are the curly waterweed (*Lagarosiphon major*), Nuttalls waterweed (*Elodea nuttallii*), and the bloody-red shrimp (*Hemimysis anomala*), but many others have varying degrees of impact.

Collectively, the impacts on inland and coastal waters have led to dramatic declines in biodiversity and water quality (Dudgeon, 2010; Smith et al., 2006; Tickner et al., 2020), both of which are accepted as international crises. Falkenmark et al. (2007) reviewed the “cost of going too far” in relation to landscape changes associated with loss of natural or semi-natural habitats. The challenges of reversing the negative trends in water quality and, especially, aquatic biodiversity (Darwall et al., 2018; Tickner et al., 2020) cannot be underestimated. For sustainable land and water management in Europe, there is either inherent conflict or disconnection between sectors, which play out across national and EU policy arenas (Irvine et al., 2016).

An increased understanding of hydromorphological processes and their relationships with biological communities, as well as the identification of effective approaches to mitigate the effect of hydromorphological pressures, are needed for more effective river basin management (Kampa et al., 2019). Such enhanced understanding can be also used for assessing the environmental impact from proposed development and in river basin planning for PoMs and restoration actions.

The implementation of the WFD is based on successive adaptive management cycles (Kingsford et al., 2011; Pahl-Wostl, 2009) (see Section 4.1). It places ecosystem management centre stage. The first steps towards the achievement of good hydromorphological conditions are to identify the key threats to water bodies on a catchment basis and then develop the necessary measures for alleviation or mitigation of those threats. With a long history of water body investigations and management, there is a firm body of knowledge to support better water and hydromorphological and ecosystem management, although some key areas of research needs remain (Carvalho et al., 2019; Gurnell et al., 2016; Langhans et al., 2019).

A key component of the first cycle RBMP was to identify the pressures on European waters. The characterisation of river basin: pressures, impacts and economic analysis required under Article 5 to have been done by 2004, was largely achieved through a review of the literature, catchment mapping associated with the river basin characterisation and modelling, and use of expert opinion. A number of research projects were initiated to address key areas needed for WFD implementation (see Section 3.1), although views from policy makers that this would fill in all relevant knowledge gaps were, unsurprisingly, somewhat optimistic. Fehér et al. (2012) estimated that hydromorphological pressures presented a risk for more than 40% of all river and transitional water bodies of failing environmental objectives.

The collation of pressures and possible impacts guided the implementation of the first river basin management cycle (2009-2015) and is expected to do so for subsequent cycles, as the understanding of causality between pressures and impact develops (Kampa et al., 2019). The link between hydromorphological pressures and BQEs used in the assessment of ecological quality status of European water bodies was reviewed in the first phase of the WFD (Alonso et al., 2013; European Commission, 2015a; García de Jalón et al., 2013) and included in the EU wide intercalibration exercise (Birk et al., 2013; Poikane et al., 2015, 2014). It is, however, unclear to what extent these were providing meaningful results to guide management (Carvalho et al., 2019).

European Member States have generally adopted different methods for assessing hydromorphological pressures (Poikane et al., 2020a), often accompanied with very general, even vague, descriptions in reporting. Furthermore, hydromorphological assessment methods based on an analysis of pressures rather than on the impacts of those pressures on BQEs are not appropriate, as methods must be able to assess observed, not theoretical impacts.

Hydromorphological assessment should integrate pressures and responses to establish causality and guide response (measures). ECOSTAT guidance is clear in the view that "Pressure based methods are therefore inappropriate for risk assessment and any other stage of implementation of WFD other than analysis of pressures" (Kampa et al., 2019).

Many hydromorphological assessment methods show insufficient links with BQEs or are not sensitive enough to identify underlying hydromorphological effects on biota (Belletti et al., 2015; Bucior et al., 2021; Fryirs, 2015; Poikane et al., 2020a; Rinaldi et al., 2013). A survey by Kampa and Bussettini (2018) showed, however, that several methods included considerations of processes affecting hydromorphology (Table 4).

Many Member States have produced detailed guidance on survey procedures and protocols for hydromorphological assessment and links with WFD classification have been proposed or produced across national territories or individual catchments (Tables 2 and 4). Examples of comprehensive guidance are those produced for Croatia (Hrvatske, 2013), and the Drava and Mura Rivers, tributaries of the Danube (Schwarz, 2007). The Austrian National Water Management Plan (BMLFUW, 2009) identified extensive sets of metrics for hydromorphological assessment. The Northern Ireland Department of Agriculture, Environment and Rural Affairs produced a 'Surface Waters Alterations Handbook' (DEARA, 2017). This outlines a range of surface water alterations that can require formal permissions and guidance on best practice, and with examples of maintenance and enhancement of important features for hydromorphology. As indicated above, further development of methods, especially through European collaborations, continue (Rinaldi et al., 2015a).

Perceptions of the sensitivity of methods to detect hydromorphological changes relevant to the biotic indicators and the underlying processes can vary quite widely. Poikane et al. (2020a), using the submission of the Member States for intercalibration (European Commission, 2018a; Poikane et al., 2014), provided a comprehensive overview of both the methods being used for WFD assessment and the strength of the pressure-response relationships. Most Member States were not using hydromorphological techniques for impact assessment for most of the water body categories. Of the 423 methods assessed, 160 were designed specifically for the assessment of hydromorphological pressures, or hydromorphology was incorporated in a multimetric that included a number of other pressures. For hydromorphological pressures, 74 methods were used for rivers, 39 for lakes and 15 for coastal waters. Transitional waters largely used multimetric that included all pressures. The explained variance (r^2) for pressure-response relationships overall BQEs covered a large range (from 0.10-0.96).

In rivers, hydromorphological methods were used for benthic invertebrates (n=29), fish (n=23), macrophytes (n=6) and phytobenthos (n=2). In lakes, the figures were: for benthic fauna (n=14); fish (n=9); and macrophytes (n=1). In coastal waters methods were applied to angiosperms (n=9), benthic fauna (n=3) and phytoplankton (n=1), and in transitional waters for fish (n=9), angiosperms (n=8), and benthic fauna (n=7). Across Europe, hydromorphological pressures were reported for at least one BQE in 90% of countries for rivers, 75% for lakes and transitional waters, but only 25% for coastal waters. Most reporting for hydromorphological pressures lacked pressure-response evidence. This is not surprising as these have generally not benefited from the extent of research applicable, for instance, to the assessment of eutrophication. Indeed, only 20% of the countries reported pressure-specific relationships had been developed for at least one BQE for lakes, and 50% of countries for rivers.

Table 4. A compilation of river hydromorphological assessment methods was collated through a questionnaire to Member States by Kampa and Bussettini (2018). Some methods are still under development.

Country	Name of method	Components covered		
		Hydrology	Morphology	Continuity
Austria	Austrian Guidance on hydromorphological assessment of rivers	x	x	x
Belgium (Flanders)	meetnet Hydromorfologie		x	x
Belgium (Wallonia)	Qualphy		x	x
	Walloon method derived from SYRAH (Fr) (National method)	x	x	x
	Riparian Remote Monitoring - RiReMo (future development)	x	x	x
Switzerland	Modul-Stufen-Konzept (MSK) Methode Ökomorphologie Stufe F (Flachdekkend)		x	x
Switzerland	Modul-Stufen-Konzept (MSK) Methode Hydrologie Stufe F (Flachdekkend) Konzept HYDMOD-F	x		
Cyprus	Integrated Pressure Index (IPI)		x	
Czech Republic	HEM 2014 (Metodika monitoringu hydromorfologických ukazatelů ekologické kvality vodních toků)	x	x	x
Germany	The hydromorphological classification tool Valmorph for large and navigable surface waters	x	x	x
	Klassifizierung des Wasserhaushalts von Einzugsgebieten und Wasserkörpern	x		
	Evaluation of sediment continuity (Bewertung der Durchgängigkeit von Fließgewässern für Fische und Sedimente, hier: Sedimentdurchgängigkeit)			x
	LAWA-Verfahrensempfehlung zur Gewässerstruktur-kartierung – Verfahren für kleine bis mittelgroße Fließgewässer		x	x
Denmark	Dansk fysisk indeks, DFI (Danish physical Index)	x	x	
Estonia	River HYMO EST	x	x	x
Spain	Protocol for the hydromorphological characterization of water bodies	x	x	x
	DRAINAGE	x	x	x
	Indices para la evaluación de la calidad hidrogeomorfológica (IHG)		x	x
Finland	HyMo method (Kevomu-menetelmä)	x	x	x
France	AURAHCE (AUdit RApide de l'Hydromorphologie des Cours d'Eau) / Hydromorphology auditing		x	
	CARHYCE (CARactérisation HYdromorphologique des Cours d'Eau) / Hydromorphological characterization of rivers		x	
	ICE project (for “Informations sur la Continuité Eco-logique”)			x
	RHUM (Référentiel Hydromorphologique Ultra-Marin) SYRAH-CE adapted to the French overseas departments (tropical systems)	x	x	x
	ROE (Référentiel des Obstacles à l'Ecoulement)8	x	x	x
	SYRAH-CE (SYstème Relationnel d'Audit de l'Hydro-morphologie des Cours d'Eau)9	x	x	x
Hungary	Planned_HU	x	x	x
	HU_RBMP2	x	x	x

Table 4. (continued) A compilation of river hydromorphological assessment methods collated through a questionnaire to Member States by Kampa and Bussettini (2018). Some methods are still under development.

Country	Name of method	Components covered		
		Hydrology	Morphology	Continuity
Ireland	Abstraction impact screening assessment	x		
	River Hydromorphological Assessment Technique/RHAT		x	x
	SNIFFER (WFD III)10 (is being/to be used in developing PoM for Ireland)			x
Italy	MQI Morphological Quality Index	x	x	x
	Indici di hydropeaking	x		
	IARI indice di alterazione del regime idrologico	x		
	Caravaggio11		x	x
Lithuania	Lithuanian River Hydromorphology Index	x	x	x
Luxembourg	Klassifizierung des Wasserhaushalts von Einzugsge-bieten und Wasserkörpern	x		
	Strukturgütekartierung (LANUV 2012)	x	x	x
Latvia	HAP-LR	x	x	x
Netherlands	Handboek Hydromorfologie 2.0 (Oste et al. 2013)	x	x	x
Norway	Characterization, analysis and risk assessment of water bodies as defined in WFD art. 5	x	x	x
Poland	Hydromorphological Index for Rivers / HIR	x	x	x
Portugal	River Habitat Survey (RHS)	x	x	x
Romania	Methodology to determine the hydromorphological indicators for Romanian rivers	x	x	x
Sweden	HVMFS 2013:19 (Agency regulation)	x	x	x
Slovenia	Hydromorphological Monitoring in Slovenia - HIMO.SI	x	x	x
Slovakia	Hydromorphology Quality Assessment	x	x	x
	Physical habitat assessment	x	x	x
Turkey	Nehir Hidromorfolojisi Değerlendirme İndeksi (NHDI) / River Hydromorphology Assessment Index	x	x	x
UK England & Wales	Designation of A/HMWB	x	x	x
	Mitigation Measure Assessment	x	x	x
	River Habitat Survey (RHS)		x	x
	Morphology Risk Assessment		x	x
UK Northern Ireland	River Hydromorphology Assessment Technique (RHAT)	x	x	x
	Low Flows Enterprise	x		
UK England	Hydrology - Water Resources GIS (WRGIS)	x		
UK Scotland	Hydrology water body classification	x		
	Morphological Impact Assessment System (MImAS) 12		x	x
	Morphological Impact Assessment System 2 (MImAS2)		x	x

Disentangling the extent of the use of hydromorphological-based methods from Poikane et al. (2020a) is not straightforward as many countries use surrogate pressure-response relationships from land-use mapping, or as part of a multimeric, where assessing the influence of the hydromorphological alteration is unclear. Even where it is clear that a metric has been developed specifically to detect an effect on a BQE from hydromorphological alteration, these may have been developed for a fairly limited range of water body types, such as in German streams (Poikane et al., 2016) and Alpine lakes (Urbanič, 2014). The conclusions of Poikane et al. (2020a) concur with those of Garcia de Jalon et al. (2013) about a lack of understanding of how and which pressures influence hydromorphological processes, and how those measured affect biological metrics. In an attempt to develop hydromorphological metrics for BQEs in rivers, the EU-funded project 'REstoring rivers FOR effective catchment Management' (REFORM) concluded it was not possible to detect robust pressure effects for phytobenthos, macroinvertebrates, or most macrophytes (Alonso et al., 2013). A lack of relationship between macrophytes and river sediment and siltation measurement was also found in Irish rivers by Bucior et al. (2021). However, a significant effect of at least one hydromorphological pressure was found for 69% of European fish species assessed by Alonso et al. (2013).

That assessment methods for hydromorphology are seemingly not that sensitive in detecting the relationship between pressure and BQEs response is of critical importance given that hydromorphological alterations have been consistently reported as the most significant pressures reported under the WFD, affecting around 40% of European surface water bodies; mainly rivers and transitional waters (EEA, 2018). This is second only to eutrophication. Haase et al. (2012) reported that almost all the rivers in central Europe require immediate hydromorphological and ecological restoration. In the UK, Orr et al. (2008) report that 60% of all river channels assessed by the 'River Habitats Survey' (RHS) were classified as modified.

Alonso et al. (2013) found that the largest amount of variation in macroinvertebrate species composition was explained by physical variables. Riparian and submerged vegetation, tree roots and bed substrates were all important, but analysis of an extensive data set from Denmark, Spain and the UK only explained a low to moderate variance (maximum circa 40%) when using a combination of hydromorphological indicators as predictors.

Poikane et al. (2020a) conclude that "indicators cannot, in most cases, diagnose the cause(s) of ecological degradation" such that failure to meet environmental objectives requires further investigation as to the cause. In contrast to the methods used to assess impact from eutrophication on BQEs, the authors stated: "there is not much evidence that the assessment methods reliably pick up the effects of hydromorphological alterations, as only a few methods have clearly documented responses to hydromorphological degradation."

These are telling outcomes from a team of researchers who are extremely familiar with the policy objectives and who have been involved in method development for the WFD. It illustrates the need for further concerted efforts in linking hydromorphological alterations to indicators of change as measured by the WFD BQEs. See also EPA (2024a) in relation to this point in Section 4.1.1 below. It could also be that the use of the 'likely suspects' of biological indicators may not be inherently sensitive to hydromorphological alterations, or that the research that has been developed on the topic is not (yet) translated to the consciousness of the agencies charged with monitoring for the WFD. There can also be a difference between methods reported and methods used and endorsed by national agencies (Poikane et al., 2020a).

Many other methods to assess hydromorphology have been and are under development that can aid in ecological assessment, including investigating combined metrics and incorporating responses to biological and hydromorphological pressures (Verdonschot and Verdonschot, 2021). However, a sufficiently robust consideration of ecology within the ecological assessment of the WFD could still be lacking (Bouleau and Pont, 2015; Moss, 2008a). A more ecosystem-based management approach is advocated in European policy (European Commission, 2011; Mack et al., 2019), but has been extremely difficult to implement. The EU 2030 Biodiversity Strategy calls for urgent action to restore damaged aquatic and terrestrial ecosystems, with a specific target to establish at least 25,000 km of free-flowing rivers by 2030 (European Commission, 2021).

The effects of climate change are also largely disregarded by the WFD but will have a potentially dramatic effect on how hydromorphology relates to ecological state. The need for an adaptive management strategy will apply to a range of pressures including invasive species spread, more extreme climate events and the associated need for greater hydropower production, and associated impacts, to meet climate targets (EEA, 2019; Vaughan et al., 2009). Because the WFD is based on the changes in an ecosystem relative to a reference state, or high ecological potential, it follows that under the meaning of the WFD hydromorphological alterations refer to the impact from human activities. This provides a bit of a conundrum in relation to impacts and response to climate on e.g. floods and drought (Hedelin, 2017; Nones and Pescaroli, 2016), and changes in the thermal structure of water bodies from rising temperatures. The WFD is an instrument to manage water, and in the interests of pragmatism, we consider climate-induced changes to fall within the scope of this report but leave discussions on addressing climate policy and action to others. Indirect effects of human activities on hydromorphology such as climate change and invasive species tend to fall outside the practical application of the WFD. The text of the WFD is also not clear on how to accommodate changes with respect to alien invasive species, and the interface with the EU Habitats Directive (92/43/EEC) (Irvine, 2009).

A broader, and more water body-specific approach to the assessment of hydromorphological alterations is provided in the next sections. This includes sections on rivers, lakes, transitional and coastal water bodies, GDEs and land-use.

Chapter 2

2 Hydromorphological Assessment on Water body types

2.1 Methods for gathering literature to review

To provide an overview of the pressures and impacts on surface water, groundwater and groundwater dependent ecosystems (GDEs) posed by physical/hydromorphological alterations to inland, coastal and groundwater bodies, a literature review, focussing on Europe and including secondary and tertiary literature sources was done. Principally, scientific literature written in the English language was reviewed for the years 2000-2021.

In the first stage, the search connected hydromorphology and the WFD with keywords 'hydromorphology' and 'WFD', while at the second stage, other keywords were also used (Figure 3). The words that are presented in the word cloud were those used for the literature search. The font size indicates the importance of the keywords for this study based on relevance for the review and abundance in the literature search.

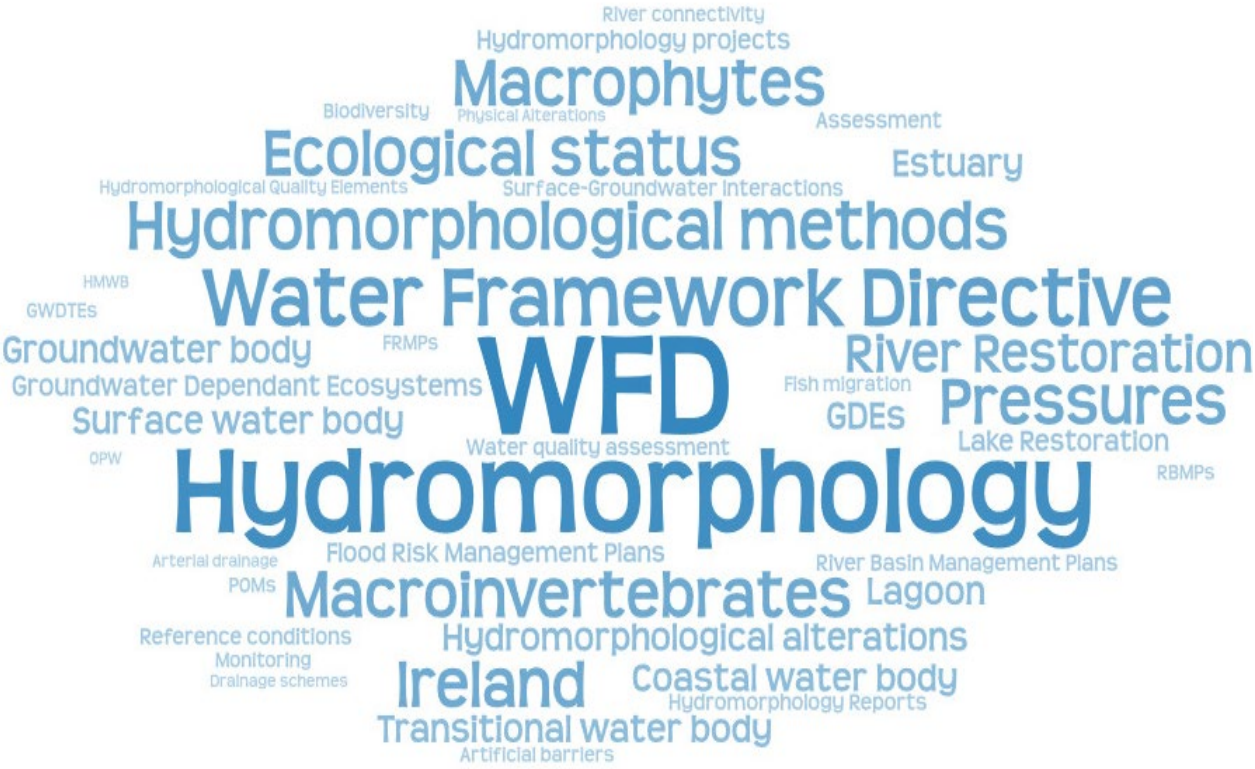


Figure 3. Main and peripheral keywords that were used to gather literature for the report.

The main search was carried out using the Scopus database. At the end of the second stage, a number of about 200 articles and conference proceedings were retrieved and used after their initial review based on titles abstracts and keywords. Reference lists helped identify other relevant sources.

At later stages, a search using the Google web interface assisted in the identification of European research projects and their deliverables. It included a review of major EU-funded projects with a major hydromorphological theme, as well as other projects that focused on Ireland (see also Sections 3.1 and 4.2). A search was done on the websites of Irish authorities with a role in either the science or policy aspects of hydromorphology. A screening for other relevant reports and 'grey' literature was done through relevant stakeholder groups. This included a questionnaire that was shared, and a follow-up stakeholder workshop held in June 2021 (see Annex I and Section 4.2).

The review of primary, secondary and tertiary literature provided an overview of the pressures and impacts on surface water, groundwater and GDEs posed by physical/hydromorphological alterations to inland, coastal and groundwater bodies. Moreover, a critical analysis was done of the current relevant EU and Irish policy, legislation and guidance (incl. planning) governing physical/hydromorphological alterations, the impacts and pressures report of Ireland and the RBMPs to assess WFD compliance and risks of water bodies, including international ones, to fail to meet their environmental objectives.

The review provided input for the critical analysis of the policy and legislative provisions governing physical/hydromorphological alterations, in the context of the meeting of WFD requirements. Moreover, an overview of how land-use practice and water body management influence ecosystem health of surface and groundwaters is included. Finally, an inventory of the hydromorphological alterations from the literature review was compiled.

The following sections outline key hydromorphological principles for water bodies necessary to guide management. It is structured per broad water body types and the potential effects of hydromorphological alteration on them. Where informative it includes connections with land and floodplains, as water bodies, or water body types, do not exist in isolation. Connections to landscape and other water bodies are integral components of aquatic ecosystem structure and function (Lamberti et al., 2010). We have at times included some fundamental concepts where this helps with the understanding of the topic, but have tried to avoid basic descriptions, which occur in numerous excellent textbooks.

2.2 Surface water bodies: Rivers

The form and function of a river is a fundamental consequence of geology, landforms, and climate. Rivers are inherently embedded in and reflect the nature of the catchment. A natural free-flowing river comprises a complex and interrelated array of hydrological patterns, dynamics of flowing organic and inorganic materials from dissolved nutrients to woody debris, riparian and in-stream vegetation and biofilms, in-stream distinguishable channel morphology of e.g. pools, glides and riffles, and a hyporheic zone as an interface between surface- and groundwater. The nature of the channel bed, and flow regimes of a river, in its natural state reflects ambient geomorphological processes of sediment transport, erosion and deposition (Knighton, 1998). Natural rivers tend to retain their character over time and are considered to be in "dynamic equilibrium" when average properties of width, depth, slope, sediment input and output are consistent over time (Kemp and Sandin, 2022). Such rivers can, however, be dynamic and mobile in the landscape, while maintaining longer-term geomorphologic stability, and characteristic ecology (Gordon et al., 2004; Shields et al., 2003).

Maddock (1999) wrote: “The combined effects of pollution, channelisation and river regulation mean that rivers that could be considered as natural are indeed a rare phenomenon.” Impact occurs mainly across a continuum of, often multiple, pressures. Many rivers have been altered dramatically, often through a combination of alterations from pollution, invasive species and hydromorphological alterations (Gregory, 2006). Channel re-sectioning, realignment, and reinforcement were the principal characteristics of hydromorphological alterations, with approximately 70% of sites examined by Stefanidis et al. (2020) having extreme hydromorphological alterations. This is following the overall pattern recorded for Europe (EEA, 2018).

Pressures often interact, leading to a potentially complex matrix of impacts. The list of anthropogenic hydromorphological pressures on rivers is a long one. Direct pressures include upstream and downstream barriers, impoundments and hydropeaking, increase in velocity, channelisation and realignment, construction of embankments, levees or dikes, dredging, sand and gravel extraction, weed cutting, alteration of riparian vegetation, removal of woody debris, water abstraction from the river, and inter-basin transfers (Alonso et al., 2013). Indirect pressures include those from groundwater abstraction; land-use and changes to that such as land drainage, land and overgrazing, which also increase sediment mobility; and drought and floods. Changes to river hydromorphology can have major effects on river form and function, and river biology. The physical and ecological processes within a river determine how it will respond to alteration (Kemp and Sandin, 2022). Hydromorphological alterations that affect the river can occur within, or far from, the river channel. Observed impact of morphological alterations on species biodiversity include the decline or alteration of species abundance and composition, hindrance of species migration and corresponding decline of naturally reproducing fish populations. Such hydromorphological alterations can occur at any, or multiple, stretches along a river from the estuarine and coastal areas to headwater fish spawning sites.

The classification system of the WFD is based on the reference condition concept (Irvine, 2022; Pardo et al., 2012; Stoddard et al., 2006). The true reference condition of rivers, needs, therefore, to be compared with natural spatial and temporal variation of flow regimes. The natural flow regime of most rivers in the world has been altered to some extent by human activity that will have some impact on river ecology. This has had major consequences on river health, not only as a direct consequence on flow, and the organisms adapted to it, but through effects on e.g. channel morphology, sediment dynamics, vegetation growth, hyporheic interstitial spaces, and water aeration (Knighton, 1998). Furthermore, many in-stream and floodplain habitats in Europe have been lost or altered for such a long time that they may be missing from modern assessments (Peacock, 2003). This also illustrates that the WFD definition of river can itself be constrained. Any ecologically meaningful definition of a river would include the floodplain as an integral part of hydromorphological and ecological form, function and, hence, assessment. Many European floodplains have been dramatically modified, affecting both extent and geomorphological and hydrological processes (Hein et al., 2016). Ward et al. (2001) identified the importance, and general neglect, of lateral, connection of river channels to corridors and floodplains, along with that of the vertical, linking to aquifers.

In response to the WFD requirements, a number of early reports (Alonso et al., 2013; Fehér et al., 2012; García de Jalón et al., 2013) were produced to review information and guide the approach to assessing hydromorphological alteration on water bodies. The attention was mainly on rivers. An overview of how various drivers lead to the alteration of river hydromorphology by Fehér et al. (2012) is shown in Figure 4. The following text is structured to identify and summarise the effects of the main hydromorphological alterations on river hydromorphology and acknowledges the contribution of these early reports and the projects they were part of (see below Section 3.1 for a summary of EU hydromorphological projects).

The extensive and historic dimension of modifications has meant that it is not possible to comprehensively address all modifications in this review, and we refer the interested reader to the reports cited above for a more comprehensive treatise. Here, we focus on related hydromorphological pressures under the headings of 1) Barriers and Impoundments; 2) Water Abstraction; 3) Channelisation; 4) Dredging, sand and gravel extraction and removal of in-stream and riparian vegetation; 5) Flood protection; and 6) Land-use.

Many physical alterations have similar effects on hydromorphological processes. For example, both impoundments and water abstraction can reduce flow regimes with consequences for fluvial sediment dynamics. Impoundments can lead to sediment depletion downstream in a similar way as direct dredging of river sediment. The combination of deteriorated habitat quality from pollution and multiple hydromorphological impacts can make it difficult to separate the effects of river fragmentation from other stressors explaining species decline (Van Puijenbroek et al., 2019).

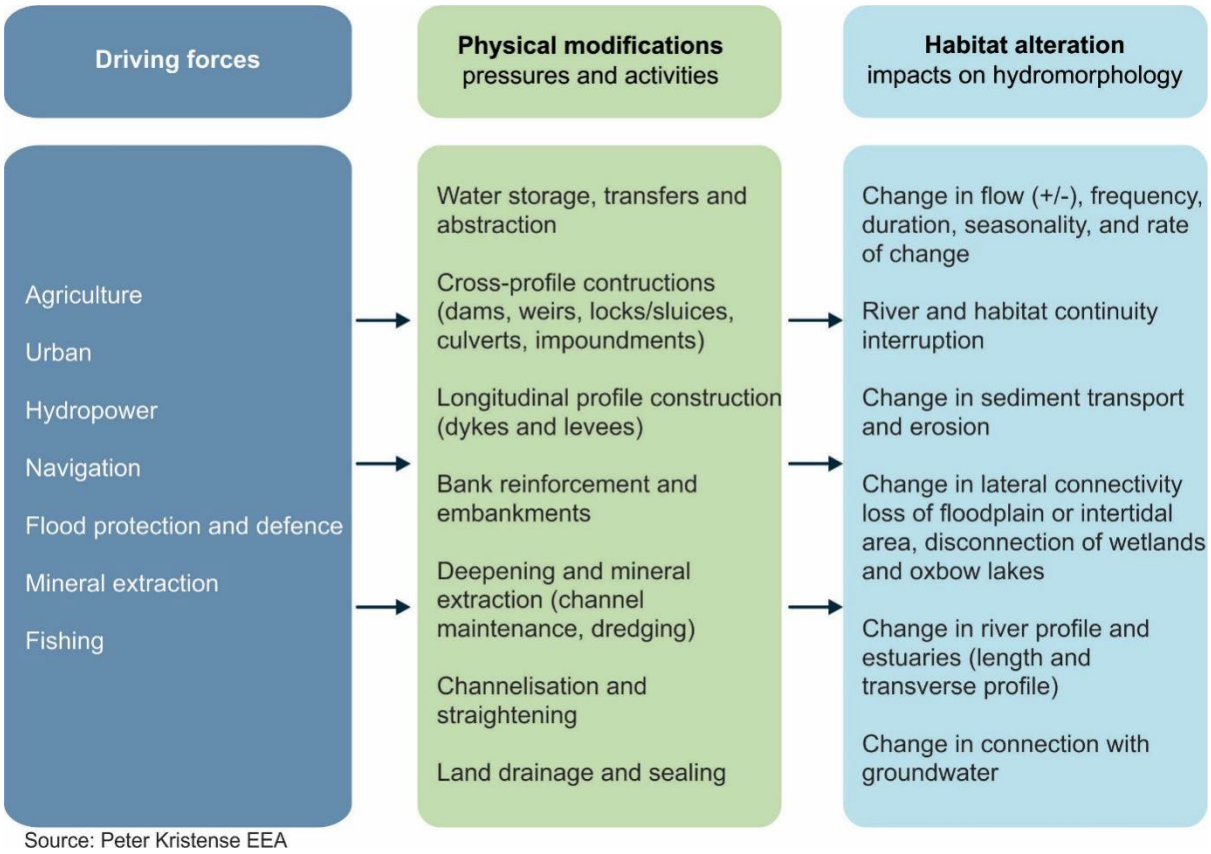


Figure 4. Conceptual overview of the relation between drivers, hydromorphological pressures and habitat and flow alterations. Adapted from Fehér et al. (2012).

2.2.1 Barriers and impoundments

Human constructed barriers in rivers range from small weirs that create small water retention areas upstream, to mega dams that completely alter the hydromorphology of large sections of rivers and water and sediment outflow to coastal areas. Dams are mainly built to provide storage water for consumptive water use, flood protection and energy, and often are used for additional purposes of e.g. flood protection, recreation and fisheries (Biemans et al., 2011; Brinker et al., 2018; European Commission, 2007; Magadza, 2006).

A number of reviews of hydromorphological and ecological impacts downstream of dams provide a comprehensive overview of the topic (Clifford et al., 2006; European Commission, 2021; Grant et al., 2003; Ligon et al., 1995; Petts, 1984; Renöfält et al., 2010). Most dams have been built in the last 60 years and about 50% are primarily for irrigation (Mulligan et al., 2020). More than 800,000 dams worldwide obstruct approximately two-thirds of the freshwater flowing to the oceans, and dams higher than 15 m are estimated to have a combined storage capacity equivalent to one-sixth of the total annual river flow to the oceans (Mulligan et al., 2020). Over 70% of the large rivers of Europe, North America and the former Soviet Union are strongly regulated (Kemp and Sandin, 2022). Fehér et al. (2012) estimated that there were 7,000 large dams in Europe, and thousands more of smaller ones. The EU Amber project (Table 3) recorded over 600,000 barriers on rivers and streams across Europe. Follow-up work suggests an estimated 1.2 million in-stream barriers in Europe, with 68% of these less than 2 m high (Belletti et al., 2020).

Many of the smaller structures that transverse a stream date back in Europe to medieval times or earlier. In other parts of the world, with earlier well-developed civilisation, these can be associated with traditional water management dating back millennia. While all transverse structures will affect a river's hydrological regime, their impact on ecosystem structure and services relates to how much they interfere with ecological function, notably the restriction of material and biotic movement up and downstream (Brandt, 2000; Magillan and Noslow, 2005; Poff et al., 2007). The main effect of smaller weirs is some local alteration of habitat, including water depth and flow, sedimentation, trapping of woody debris and interactions with local aquifers (García de Jalón et al., 2013). Often the effects may be short-term on local water depth and velocity, and deposition of, mainly, fine sediment. These are usually washed downstream during high water flows. Even small structures can, however, interfere with fish migrations, especially for the upstream journey, and affect spawning grounds, especially in headwaters. Larger transverse structures, which are commonly considered as dams, can have multiple and major impacts on river form and function, and the ecosystem services these provide (Figure 5). These include the creation of upstream reservoirs, retention and depletion of downstream sediment transfer, quantity and timing of downstream water flow regimes, river fragmentation, and associated hard embankments and channelisation in the vicinity of the dam. Fragmentation is one of the major threats to river ecosystems, including restricting lateral connectivity to floodplains.

Vörösmarty et al. (2003) estimated that more than 50% of the basin-scale sediment flux in regulated basins is trapped in artificial impoundments, with an earlier estimate by Vörösmarty et al. (1997) that more than 40% of river sediment discharge is intercepted by 633 of the world's largest reservoirs. In their review of the alteration of European Rivers,

Fehér et al. (2012) reported that in the lower Danube suspended load was reduced by 70% by the construction of the Iron Gate dams, and only about one-third (from 53 to 18 million ton/yr) of natural sediment supply reaches the Danube Delta. Dams in the Ebro River trapped approximately 95% of suspended sediment load compared with the beginning of the 1900s. The decrease in river discharge leads to saltwater intrusion and coastal retreat and land subsidence.

Sediment trapped in reservoirs has major implications for downstream river structure and for reducing the accretion of sediment in estuaries. This often has drastic impact on fisheries and the livelihoods that depend on inshore habitats (Ziv et al., 2012). Globally, however, development of large dams continues (Zarfl et al., 2015).

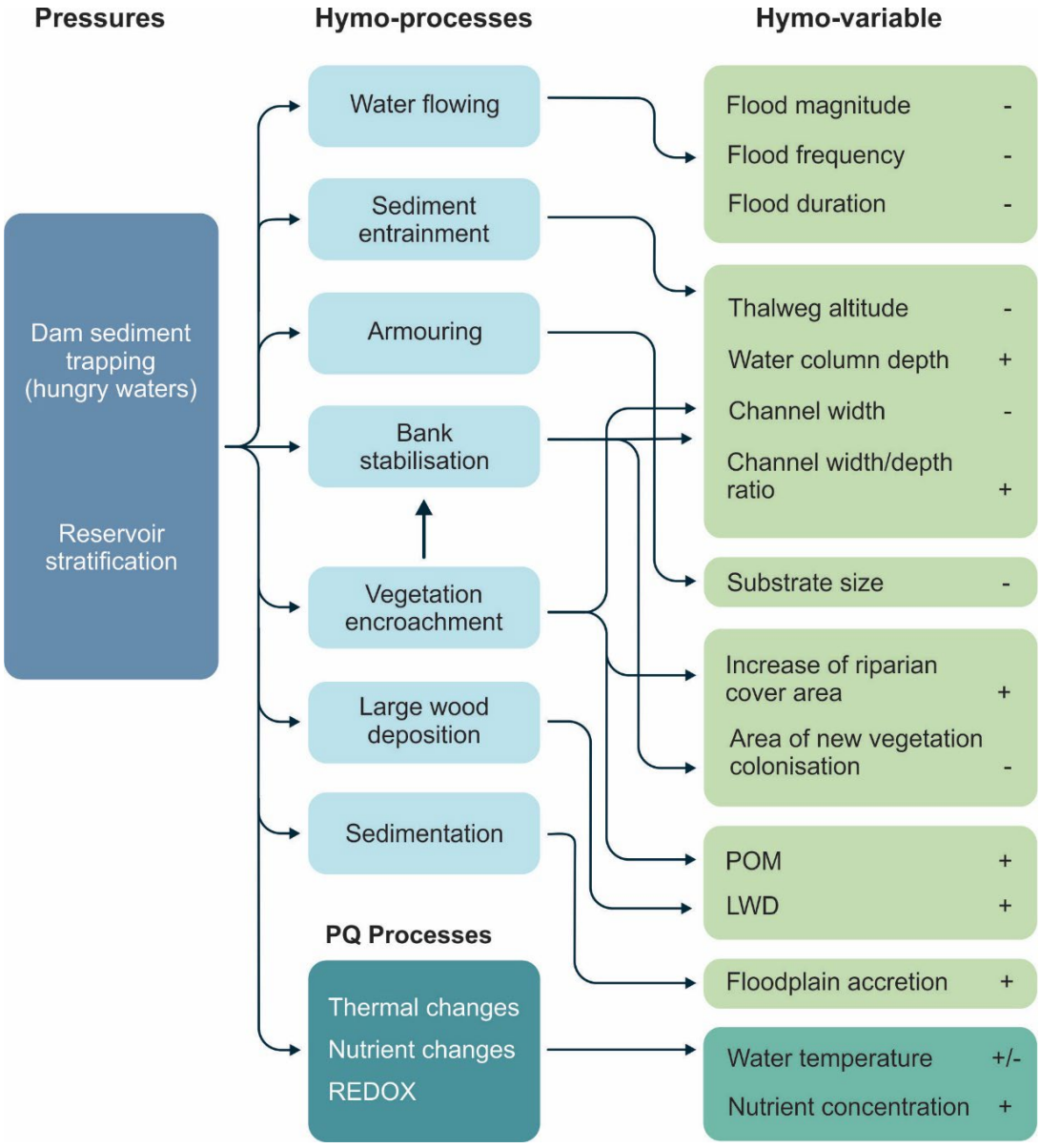


Figure 5. Potential impacts on river hydromorphology from large impoundments. Modified from García de Jalón et al. (2013).

Petts (1984, 1980) identified three orders of impact on river fluvial processes from large impoundments:

1. First-order direct physical and chemical changes affecting flow regime, particularly flood magnitude and frequency; the quantity and quality of sediment supply; and water quality released, including temperature and oxygen;
2. Second-order impacts downstream, notably adjustments in channel morphology (including vegetation encroachment) and ecological response to changes in flow, sediment and water quality supplied to downstream reaches; and
3. Third-order ecological effects from further adjustments of the biota in response to the second-order changes in river morphology and bed sediment that led to a completely different assemblage of hydraulic and morphological habitats.

Barriers that reduce the interconnectivity of a river also have potential effect on flow regimes and a range of ecological processes (Hermoso et al., 2018; Kingsford, 2000; Kondolf et al., 2006). Reduced river connectivity by the dams, and hydropower, can not only reduce or prevent fish migration but can also prevent migration upstream of invasive species.

Changes in water flow affect bed-load transport and sediment dynamics, as well as physical processes crucial for fluvial habitats (Church, 1995). Riverbeds can be eroded as a consequence of reduced sediment transport arising from dams, water abstraction or dredging. Downstream of impoundments, natural processes of incision, where the river cuts into the channel bed, can be accelerated depletion of sediment (Binh et al., 2021; Grant et al., 2003; Stähly et al., 2019). This can lead to migration of incision downstream, channel narrowing, and colonisation by riparian vegetation into the former channel (Schmidt and Wilcock, 2008) (Schmidt and Wilcock, 2008). The extent to which this occurs after a dam is constructed is a function of river slope and flow regime with impacts possible on downstream river morphology, riparian zones and landscapes, including urban settlements Schmidt and Wilcock (2008)), reviewing the effects of 60 dams in the US, devised three metrics to assess impact: 1) the shift in balance between sediment supply and transport capacity as an indicator of downstream sediment accumulation or removal; 2) potential for channel incision; and 3) relative reduction in flood magnitude. They concluded that more than 60% of 4,000 km of some of the major rivers in the western United States were sediment deficit, with only a few in sediment surplus. Working in the Sarine floodplain in Switzerland, Stähly et al. (2019) developed a hydromorphological index to evaluate the riverine habitat quality from variability of flow depth and flow velocity, concluding the need for artificial sediment replenishment to maintain habitat suitability. However, for many impoundments, sediment replenishment is not a viable management option. See Section 2.2.4 for further information on sediment regimes.

Interconnectivity and flow regimes

The importance of flow for river health and ecosystem services is recognised by the Brisbane Declaration of 2007 as “the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems.” A plan of 35 recommendations in the Declaration includes emphasis on the better understanding of environmental flows through integrating it into global legislations, policies and stakeholder responsibilities. The principles of such ‘environmental Flows’ (eFlows) are outlined by Bunn and Arthington (2002) (Figure 6). Globally 48% of the freshwater resources are severely impacted by flow regulation (Arthington et al., 2018).

Flood peaks are typically reduced by river regulation, which reduces the frequency and extent of peak floods, scouring of river channels, and floodplain inundation and flow through side channels (Gerge et al., 2002; Henry et al., 2002). Decreased variation of flow dynamics can reduce vertical hydrological connectivity by reducing hydraulic gradients (Kondolf et al. 2006). Maintaining natural flow regimes is vital for many ecosystem processes and life cycles of river biota, and the ecosystem services that these provide (Anderson et al., 2019; Naiman et al., 1999; Poff and Zimmerman, 2010).

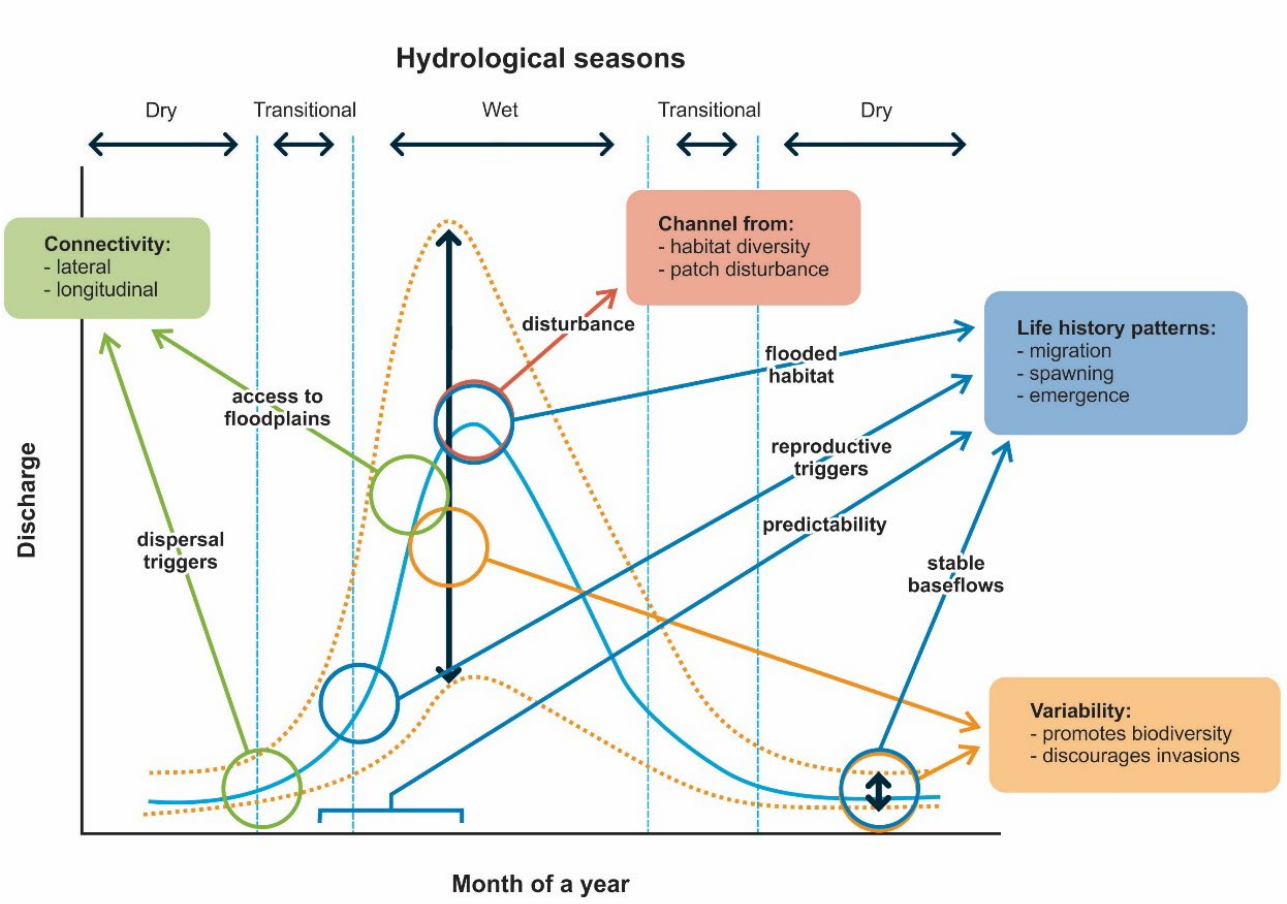


Figure 6. The importance of different parts of the hydrological flow regime (after Poff et al., 1997; Bunn and Arthington, 2002).

The benefits of environmental flows are increasingly recognised and there is now extensive international literature on the topic and its development (Arthington et al., 2018; Poff et al., 2010; Tonkin et al., 2014). Reduced continuity of river flow, relating to pressures from dams and abstractions, now accentuated by climate change, is of major international concern (Grill et al., 2019; Zarfl et al., 2015). Environmental flow alterations impact socio-economic value of freshwater bodies, including facilitating invasive plant and animal species (Bunn and Arthington, 2002). Natural resistance to pressures in estuaries declines. Flow variability in sustaining riverine ecosystems is well understood, as is the ecological consequence of imposing static flow regimes for river regulation (Naiman et al., 2008). Environmental flow regulation and guidance is increasing, whether in legislation (e.g. in national water laws in South Africa (South African National Water Act 36 of 1998, 1998); Peru (Ley No 29338 - Ley de Recursos Hidricos, 2009); in the 2008 Constitution of Ecuador (2008), and in state laws and statutes in the US (Boyd, 2003).

Guidance has been produced for the incorporation of environmental flows to meet WFD environmental objectives, and in relation to hydropower and EU habitat legislation (European Commission, 2018b, 2015b), for hydropower and financial institutions (Anderson, 2013; IHA, n.d.; Krchnak et al., 2009; Schramm et al., 2016; World Bank Group, 2018), and from UNEP (2020). Nevertheless, there is much scope for further policy development and better implementation of environmental flows (Arthington et al., 2018). In terms of assessing hydromorphological alterations, the time of year to do that is important. Stefanidis et al. (2020) considered that surveys need to take place in summer to keep away from floods that may represent a hazard but also may hamper the capacity to notice features related to the river types and the channel substrate.

Implementation of environmental flow regulations and measures is hindered by a number of socio-political factors considered by Degefu et al. (2018) as: a) a lack of public and political support; b) factors constraining the policy development from institutional barriers; and c) a lack in knowledge, understanding and implementation capacity. Ultimately what commonly constitutes environmental flow and the balance of benefits provided is a societal debate (Anderson et al., 2019; Warner et al., 2008), but for the WFD a stricter environmental stand is taken in that “In order to achieve WFD environmental objectives in natural rivers, the PoMs should ensure the protection of ecological flows and their restoration” and that “the definition of eFlows should be the result of a technical/scientific process with no consideration of the associated socio-economic impacts” (European Commission, 2015b). Otherwise, it would appear that there will be a need for designation as an AWB or HMWB, with environmental objectives of good ecological potential. “In the WFD, approximation to ecological continuum (WFD Annex V 1.2.5) is a key aspect of ecological potential. Achieving ecological continuum ensures that the habitats for type-specific aquatic species are interconnected in space, and time, so that the species can fulfil their life cycles in self-sustaining populations” (European Commission, 2003f; Kampa et al., 2019).

Many of the effects from a complete barrier across a river can also apply to partial obstructions from hydropower structures, with the extent of impact very much dependent on the engineering design. This also applies to sequences of small hydropower dams, which can result in e.g. a cumulative decline in survival of migratory fish (Ibisate et al., 2013).

Fehér et al. (2012) reviewed impacts from three types of hydropower stations following ENV/Arcadis and Floecksmühle (2011):

1. Hydropower stations with storage reservoirs that can be used to supply peak electricity demands. This can lead to the phenomenon of ‘Hydropeaking’, as water is released from hydropower plants to meet electricity demand, often causing short-term and extreme flow patterns (Young et al., 2011). It has been shown to alter downstream hydraulic gradient, river morphology and habitat structure (Moreira et al., 2019; Sear, 1995), and groundwater interactions (Arntzen et al., 2006; Curry et al., 1994);
2. ‘Run-of-the-river stations’ that use natural flow to generate electricity. There is no water storage capacity. These are usually small hydropower stations, but can also be combined with larger stations, or operate as a series of small plants. They are normally considered within the limits of small hydropower that vary from 1 MW (common in a number of African countries, to 10 MW (European Union, US) or even 50 MW (China, Canada) (Liu et al., 2019). Small hydropower is developing with improvements for less impact on river flow, and possibilities to integrate into small weirs (Marence et al., 2016; Ulibarri et al., 2022); and

3. Pumped storage hydropower plants using two reservoirs at different altitudes. Water is pumped from the lower into the upper reservoir and can be released back to the lower reservoir producing energy on the way to meet peak time demands. Water can be pumped back to the upper reservoir when there is surplus of available energy.

Hydropower plants will increase globally (Zarfl et al., 2015). In Europe, the Renewable Energy Directive (2009/28/EC) set legally binding national targets for electricity and transport of 20% of gross final consumption, and requirements for renewable energy action plans.

For example, this is seen as part of the climate action response by the Scottish Government, who estimated a potential for more than 7,000 new small hydropower projects and the UK Environment Agency identified between 4,000 and 12,000 potential new small hydropower plants in England and Wales (Fehér et al., 2012). An associated guide for 'Good Practice for Hydropower Development' was issued by the Scottish Government, Scottish Natural Heritage and the Scottish Environment Protection Agency (SEPA, 2012a).

There are many opportunities for better basin-scale planning balancing power generation and ecosystem needs (Opperman et al., 2018; Renöfält et al., 2010). Many dams built in the 20th century, however, are past their projected lifespan of 20 to 40 years. A need to remove accumulated sediment, obsolete power generation technology and increasing awareness of net ecosystem services that rivers can provide has also led to decommissioning of hydroelectric schemes and the dams that store the water for them. Rates of decommissioning of all dam types have increased, with an estimated 1,700 removals in the US and 5,000 to 6,000 in Europe (Ulibarri et al., 2022; Vahedifard et al., 2021). In Sweden, for example, the rationale for building the Sofieholm hydroelectric scheme in the early 1900s to power a textile factory no longer exists; and because of impacts on local fish populations, the plant was removed (Dam Removal Europe, 2017). Costs of upgrading, sediment build up and ecological impact on fish migrations led to the removal of the Elwha Dam in the US, the largest hydropower dam removal to date, including 21 million m^3 of trapped sediment (Magirl et al., 2015). However, the removal of dams can be as controversial as building them. In France, although it was decided to remove two dams on the Sélune River in 2009, local opposition by elected representatives delayed the implementation for over a decade (Germaine and Lespez, 2017) (see Section 2.6.2 on the Loire). In Japan, a decision to remove the Arase Dam in 2003 was delayed after a new government reversed the decision, although the dam was removed in 2018 (Noda et al., 2018). The EU Amber project (Table 14) identified 858 barriers with high reconnection potential in large and medium-sized European rivers, the removal of which would potentially reconnect about 14,400 km of rivers (Schwarz, 2021). The removal of barriers in rivers to support the EU Biodiversity Strategy is gaining momentum, with a recent report by the European Commission (2021) outlining key opportunities for a better-connected river network.

In Ireland, the building of Ardnacrusha in the interest of the nation's energy needs severed one of the largest salmon runs in Europe, with permanent effect on water levels in the Lower Shannon. While the Ardnacrusha scheme was an important part of Irish State Building (Bielenberg, 2002), the controversies over lost livelihoods reported locally at the time as the 'Battle of the Tailrace' are now confined to local folklore although the economic return on such a salmon run these days can only be a matter of speculation. The impact of the operation of the hydropower station is explored further in Section 5.1.1, and plans for an updated fish pass as part of a programme of measures of the third cycle River Basin Management Plan, summarised in Chapter 4

After dam removals, fish communities often respond positively and quickly (Foley et al., 2017), although this is not always the case (Marks et al., 2010). Predictably, upstream habitats usually show little hydromorphology change, while effects downstream depend on the extent of the new flow regime and sediment distributions (Foley et al., 2017).

2.2.2 Water Abstraction

Water is abstracted from freshwater bodies for multiple reasons. Mostly this is for agriculture, which uses about 70% of global consumptive water, largely for irrigation. While water for abstraction is an essential ecosystem service, in many parts of the world abstraction from rivers and aquifers is a major concern for maintenance of human populations and ecosystem services, on which those populations depend. The extent that water abstraction is a serious hydromorphological alteration depends, naturally, on the extent of its use. In the most extreme cases it leads to complete drying out of the lower reaches of rivers. Across Europe, especially in southern countries, water scarcity is a significant problem. However, even in the more temperate parts of Europe, water abstractions can be a serious localised problem, causing hydromorphological alteration of rivers. This has been prevalent in chalk streams in southern England for decades (Bickerton et al., 1993), and is now considered to be a crisis (Salter and Singleton-White, 2019), with UK water companies making pledges to protect this fragile habitat. Small individual abstraction can also lead to large cumulative effects, as reported by Boddy et al. (2020) for fish in New Zealand streams. In Ireland it is estimated by Uisce Éireann (formally Irish Water) that approximately 30% of the public drinking water supply is supplied from behind impoundments, whose beneficial use provides options for designation under the WFD as Artificial or Heavily Modified Water Bodies.

The most obvious effect of water abstraction on river hydromorphology is decreased water flow, although this also interacts with other pressures and stressors (Matthaei et al., 2010). General effects of reduced water flow are described in Section 2.2.1 on interconnectivity and flow regimes. Water abstraction has also been associated with reduced water depth, wetted area, channel width, thermal regime and water chemistry (Dewson et al., 2007; James et al., 2008; Kleynhans, 1996). Fehér et al. (2012) reported 384 rivers in Ireland as having significant pressure from water abstraction.

2.2.3 Channelisation

Channelisation of rivers refers to straightening of the channel, altering the natural planform and gradient and usually associated with all or some: alterations of the channel profile and width; removal in stream vegetation and habitats; presence of modified or hard embankments, and loss of riparian vegetation (Figure 7). It results in, often extensive, modified habitats and effects on geomorphological and ecosystem functions (Gordon et al., 2004; Gurnell et al., 2012; Urban and Rhoads, 2003). This leads inevitably to loss of species or a change in their dominance (Baattrup-Pedersen et al., 2005). Natural stream channels are a consequence of gradient and seasonal water flow. A sinuous river has a lower bed slope than a straight river. Increases in stream power after straightening of a river channel can be dramatic. Guzelj et al. (2020) calculated over 13 times increase in stream power, based on a six-fold increase in stream slope and a more than doubling of bank full discharge, in a formerly meandering lowland river. This would render impossible any subsequent attempts at restoration (Kemp and Sandin, 2022). Increasing the velocity of water in the channel leads to scouring and deepening of the stream bed. It can create a ‘nick-point’ at the upstream end, causing an

erosive process to move upstream (see Section 2.2.4 on sediment below) and mobilising sediment that then gets transferred downstream.

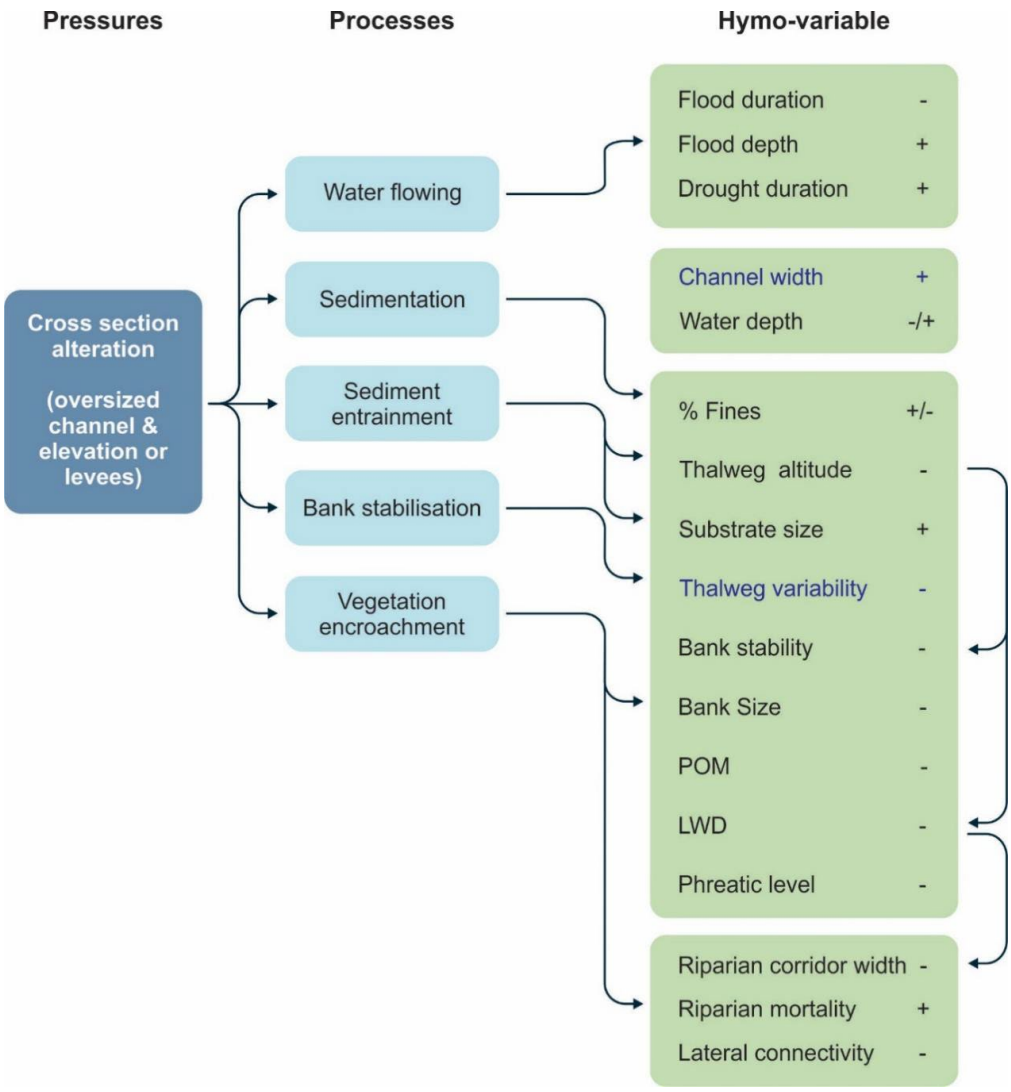


Figure 7. Conceptual effects on processes and hydromorphological variables from channelisation Modified from Fehér et al. (2012).

Scouring of the channel means that removal of finer bed sediment can create an armoured bed. Incising of the channel can lead to riverbanks becoming higher and often more unstable, resulting in erosion and effects of sediment deposited on downstream sections (Knighton, 1998; Owens et al., 2005). In lowland sections of a river, where slope is less inclined, straightened channels can have little power to reshape the channel (Grabowski and Gurnell, 2016; Urban and Rhoads, 2003). They do, however, tend to fill up with silt, sand and gravel and have prolific plant growth, leading to ongoing dredging and loss of original riffle-pool morphology and cobble and gravel habitat (Kemp and Sandin, 2022).

Channelised sections require river maintenance to keep the new course in its channel and remove accumulated sediment where the gradient has been reduced and the energy of flow is not sufficient to clear sediment downstream and restrict lateral and vertical connectivity, with potentially severe ecological effects (Poole et al., 2006; Simon, 1989). Rip-rap hard

embankment engineering is often needed to retain the channel in its new course (Eaton and Lapointe, 2001). These physical impacts can have knock-on impacts on e.g. fish movement and riparian and water edge wildlife suitability. Removing stream meanders reduces pool development, bank undercutting and exposure of vegetation roots that supply a variety of habitats (Alonso et al., 2013; Fehér et al., 2012).

2.2.4 Dredging of sediments and removal of in-stream and riparian vegetation

Sediment distribution and dynamics are fundamental components of fluvial geomorphology (Wohl et al., 2015). It is worth reiterating that in the WFD the concept of continuity includes the free movement of sediment within rivers and the connection of floodplains. Whereas sediment as an element in the monitoring of pollutants is a feature of the WFD (Carere et al., 2012), excess loading or replenishment of sediment is also a usual need to maintain ecological integrity (Ock et al., 2013). Channelisation, flood control measures and navigation often include ongoing and periodic dredging, that can occur from small scale with smaller diggers to extensive operations involving extremely large purpose-built industrial river dredgers. The objective in all cases is the same, to remove material from the river channel. The impacts on river ecology will be reduced habitat and alteration of sediment dynamics (Kondolf, 1997). Extraction of sand and gravel has similar effects, ranging in scale from small artisanal works in many rivers of the world to industrial-scale licensed activities. Global annual estimates of sand and gravel used for construction are up to 25 billion tonnes (Koehnken and Rintoul, 2018). Supply comes from mainly alluvial deposits from in-stream mining or excavation from floodplains (Bussettini and Schmidt, 2022; Juez and Franca, 2022).

Dredging, sand and gravel extraction

Changes in the river channel as a result of dredging can have knock-on effects on river channel size and planform, in-stream vegetation and the riparian zone tree species (Gurnell et al., 2012, 2007). As sediment extraction changes shear stress at the site of extraction, erosion moves upstream. As extracted sediment provides a collection point for sediment moving downstream, it depletes sediment supply further down the river. Hence, sediment extraction can lead to riverbed erosion both up and downstream (Kondolf, 1998). Removing sandbars alters sediment dynamics in other ways, leading to reduced flow velocity, with consequential sediment deposition, widening of the channel, bank erosion, loss of riparian habitat (Koehnken and Rintoul, 2018) and, in braided rivers the formation of a deep incised channel (Padmalal and Maya, 2014). Conversely, incised channels can lead to a reduction in river width (Bussettini and Schmidt, 2022). Sediment extraction leads to the sorting of sediment particles by size, altering river structures such as riffles, and leading to movement downstream of fine particles affecting river turbidity, with potential to clog habitats (Owens et al., 2005). Associated changes from sediment dredging can increase risk of flooding (Kemp et al., 2011).

The impacts of sand and gravel extraction and dredging on river dynamics and ecology are generally under-appreciated but summarised well in Koehnken et al. (2020). Franca and Juez (2022) provide dramatic examples of impacts from sediment extraction, including collapsed bridges.

An overview of in-stream effects from dredging and bottom reinforcement is summarised in Figure 8. This provides many of the features described above and relates to others described further below.

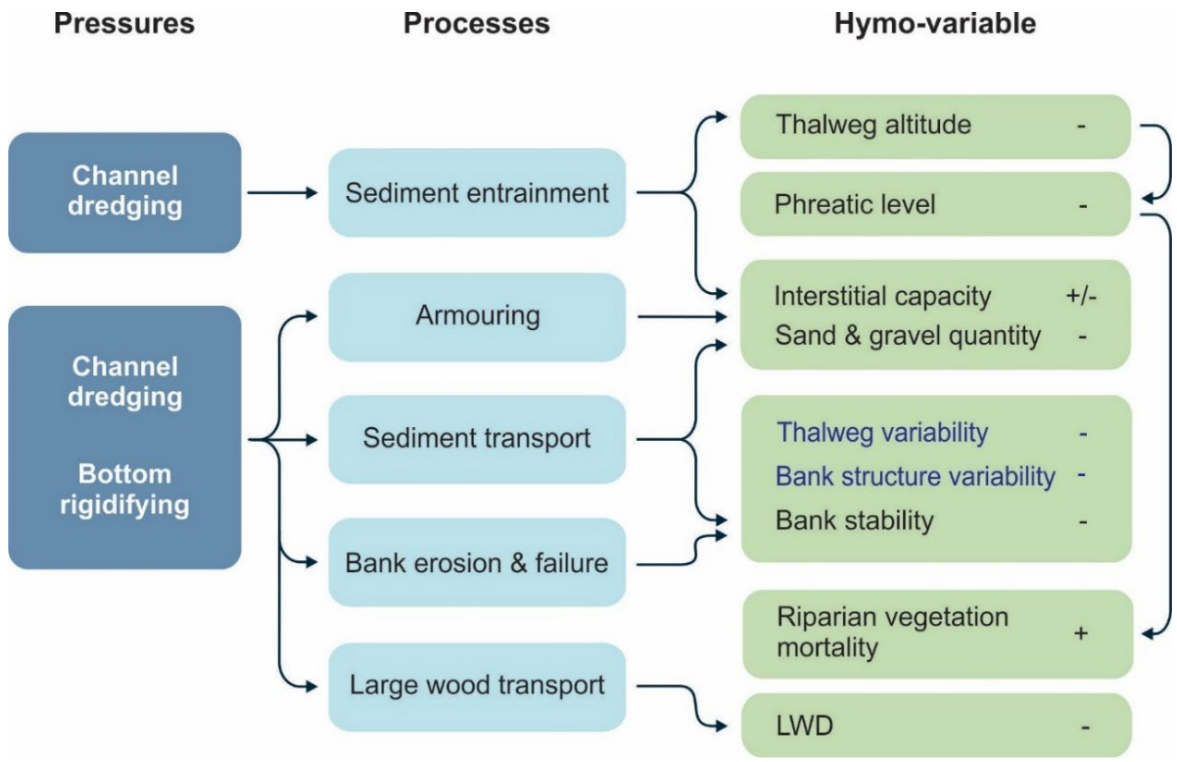


Figure 8. Conceptual framework of alteration of in-stream habitat effects on HYMO processes and variables (LWD = Large Woody Debris). Modified from Fehér et al. (2012).

Sediment

Sediment depletion or excess of fine sediments can have a major impact on biological communities (Bilotta and Brazier, 2008; Collins et al., 2011; Kemp et al., 2011; Moorkens, 2010). The lack of attention to sediment dynamics and the link with hydromorphology specifically in the WFD and Floods Directive is considered an important omission, as without sediment as a key component of quality assessment, "the WFD may give a misleading and optimistic assessment of ecological status" (Nones et al., 2017). It could be argued that sediment condition, like nutrients or other supporting elements will, in theory, be reflected in the assessment of the biota relevant to a reference condition. This may not be a sound assumption (see Discussion above on BQEs and work by Poikane et al. (2020b, 2020a)).

Sediment loss from catchments is a global concern (Golosov and Walling, 2019; Yang et al., 2003). Apart from some recommended limits on in-stream sediment concentration in the European Fish Directive (78/659/EEC) (see Section 2.2.4), and the implications related to hydromorphology of the WFD, attention to sediment as a pollutant in EU Member States legislation is generally lacking, with some notable exemptions (SEPA, 2012b). The Fish Directive was replaced by Directive 2006/44/EC and subsumed by the WFD in December 2013. A proposed EU Soils Directive for the sustainable management of soils in Europe, although adopted in 2006, was withdrawn by the Commission in 2014, likely as a result of opposition from the UK, Germany, France, the Netherlands, and Austria (Chen, 2019).

This has not prevented the continued realisation of the importance of sediment transfer from land to water, from both the perspective of loss of soil structure and impact on water bodies. While essential for river and coastal geomorphology, and associated habitats, it is also a pollutant. The principles are not so different to the way that nutrients are essential for ecosystem function, but excess nutrients lead to ecosystem degradation. Sediment, however, is also a conduit for phosphorus, heavy metals and pesticides, which can be mobilised in water and river bodies depending on ambient chemistry (Eggleton and Thomas, 2004; Fritioff et al., 2005; Jain, 2004; Katagi, 2006; Withers and Jarvie, 2008).

Sediment mobilised from the catchment arrives in water bodies through a variety of hydrological pathways. Land-use and land-use change, topography and climate are major factors for sediment yield to rivers, but sediment yield from individual catchments can vary markedly in response to similar land-use changes (Bakker et al., 2008; Hunter and Walton, 2008). Urbanisation and road construction are also important direct or indirect drivers for increasing sediment load to water bodies (Cocchiglia et al., 2012; Donohue et al., 2003; Russell et al., 2017; Taylor and Roff, 1986).

In general, and as might be expected, exposed soils, as in tillage farming and after deforestation, are associated with increased mobilisation of sediment (Allott et al., 2005; Liébault et al., 2005; Scheurer et al., 2009; Ward et al., 2009), while intact or restored forest are generally associated with low yields (Piégay et al., 2004). Sediment yield was found to increase by up to 1300% with increasing rainfall after deforestation (Foulds and Macklin, 2006). Sediment flux is, however, very dependent on topography, management, and the sources and sinks along the hydrological pathways. Pathways of sediment, as for phosphorus, depend on critical source areas and their connectivity with drainage routes. This can be surface transport, along natural channels or those created by e.g. tracks, or subsurface such as field drains (Blann et al., 2009). A review by Lawler et al. (2017) provides an excellent summary of sediment mobility and impact applicable to Irish catchments. Vanmaercke et al (2011) collated sediment flux rates from 1794 sites across Europe, with lowest yields from western, northern and central European catchments.

Most suspended sediment is transported during storm events, with the majority of load from just a few, typically ‘first flush’, events in both rural and urban-dominated catchments (Old et al., 2006; Owens, 2009). Measured Irish sediment yields ranging from 2.1 to 48.4 t/km^2 per year are relatively low in comparison with other European countries but can nevertheless reach high maxima. Harrington and Harrington (2013) estimated that 28% of the annual sediment flux of the Owenabue River occurred over 5% of the time, with maximum suspended solid concentration (SSCs) of 979 mg/L. These were, notably, associated with a grassland dominated study catchment. Maximum SSCs for the Irish Agricultural Catchment Programme,

set up to test the effectiveness of derogations for the Nitrates Directive (91/676/EEC), reported by Sherriff et al. (2015), were in the range 419 to 1,020 mg/L.

A comparison of maxima reported from tillage operations that expose bare soils were peak SSCs of 221 to 2,141 mg/L (Sherriff et al., 2015). When intermittent high sediment yield coincides with sensitive periods of the year for biotic life cycles, such as salmonid spawning, there can be a significant ecological impact (Lane et al., 2009). For context, the EU Freshwater Fish Directive (78/659/EEC) had a safety threshold of minimal impact on fish of < 25 mg/L. High and probable impact on fish occurs at concentrations > 80 mg/L (Lawler et al., 2017).

In grassland agricultural holdings, sediment mobility can be promoted by animals disturbing soil along hydrological pathways. Moreover, erosion because of overgrazing by sheep, often combined with upland forestry, can contribute high loads of sediment to streams (Allott et al., 2005; Clarke et al., 2015; Rodgers et al., 2011). Cooper et al. (2008), in a study of 100 UK catchments found that highest sediment yields came from catchments they classified as high impermeable and low peat catchments.

Loss of soil from peatlands can be particularly harmful to ecological health of rivers because of the prevalence of particulate organic matter (Ryder et al., 2014). In the future, land-use changes in response to climate patterns and continued urbanisation will alter hydrological response of catchments (Lawler et al., 2017), with likely unpredictable outcomes. Management measures now and in anticipation of land-use and climate changes are needed to reduce sediment yields by, primarily, reducing the risk of sediment mobilisation in the first place and, then, through retention and recycling to reduce run-off to rivers. That hydrological connectivity of large landscape units can be controlled by a small number of geographically localised areas has great implications for the control of sediment, and nutrient, mobilisation (Collins et al., 2011; Haygarth et al., 2005). Both lateral and horizontal sub-surface flow paths are important (Collins et al., 2011; Fox and Wilson, 2010). This informs where management measures may be targeted so as to: 1) disconnect drainage from streams; 2) retard flow, such as with the use of contours to slow up movement of water so that sediment settles; and 3) store water in settlement ponds to allow sediment to settle (Lawler et al., 2017). In farms, the use of constructed wetlands is an effective method to capture sediments and other pollutants (Boano et al., 2020; Ockenden et al., 2012; Vymazal and Dvořáková Březinová, 2018). Riparian buffer strips retain sediment, but the effective width and structure vary depending on the nature of the land-water interface. Management mechanisms for reducing mobilisation and impact from sediment loss to streams are provided in Tables 9.1-9.5 of Lawler et al. (2017).

Along the edge of streams and rivers, bank erosion, also caused where livestock have direct access to the bank, can be an important source of sediment load to rivers (Green et al., 1999; Hassan et al., 2017; Langendoen et al., 2012; Magner et al., 2008). This can alter in-stream sediment dynamics where local inputs from bank erosion can change a naturally depositing section of a river to a source. Orr et al (2008) point out that such changes are “merely…an indication of the relative importance of erosional and depositional features.” Models of risk assessment, including geomorphic setting and use of remote sensing, have been used to estimate sediment loss from banks to rivers (Hensley and Ayers, 2018; Kessler et al., 2012; Segura and Booth, 2010; van Eps et al., 2004). A number of techniques can be used to reduce bank erosion, which is also strongly, often predominantly, influenced by water flow and hydraulics in modified rivers. These include restoring to a more natural character (Lawler et al., 2017), bankside vegetation (Abam, 1993), rock armouring (Bogen and Bösnes, 2004), and structures for the redirection of flow (Rodríguez-Amaya et al., 2020; Shafai-Bejestan et al.,

2016) including vanes (Bhuiyan et al., 2010), and large woody debris (Donadi et al., 2019; Harvey et al., 2018; Shields et al., 2004).

Within the river channel sediment is mobilised and distributed in relation to flow velocity, sediment supply and river geomorphology (Figure 9), forming channel planforms and bedforms, which are largely governed by sediment calibre and supply rate, together with local flow conditions. Fine sediment can be stored in the interstices of coarser channel substrate, deposited on bar tops after high flows, and accumulate in channel pools and in the lee of in-channel natural and man-made structures. Fine sediments dominate in low-energy flows (Church, 2006; Lawler et al., 2017), and many methods have been suggested as means to measure fine sediment in rivers (Clapcott et al., 2011; Duerdoth et al., 2015; Hedrick et al., 2013; Kozerski, 2002; Sutherland et al., 2010).

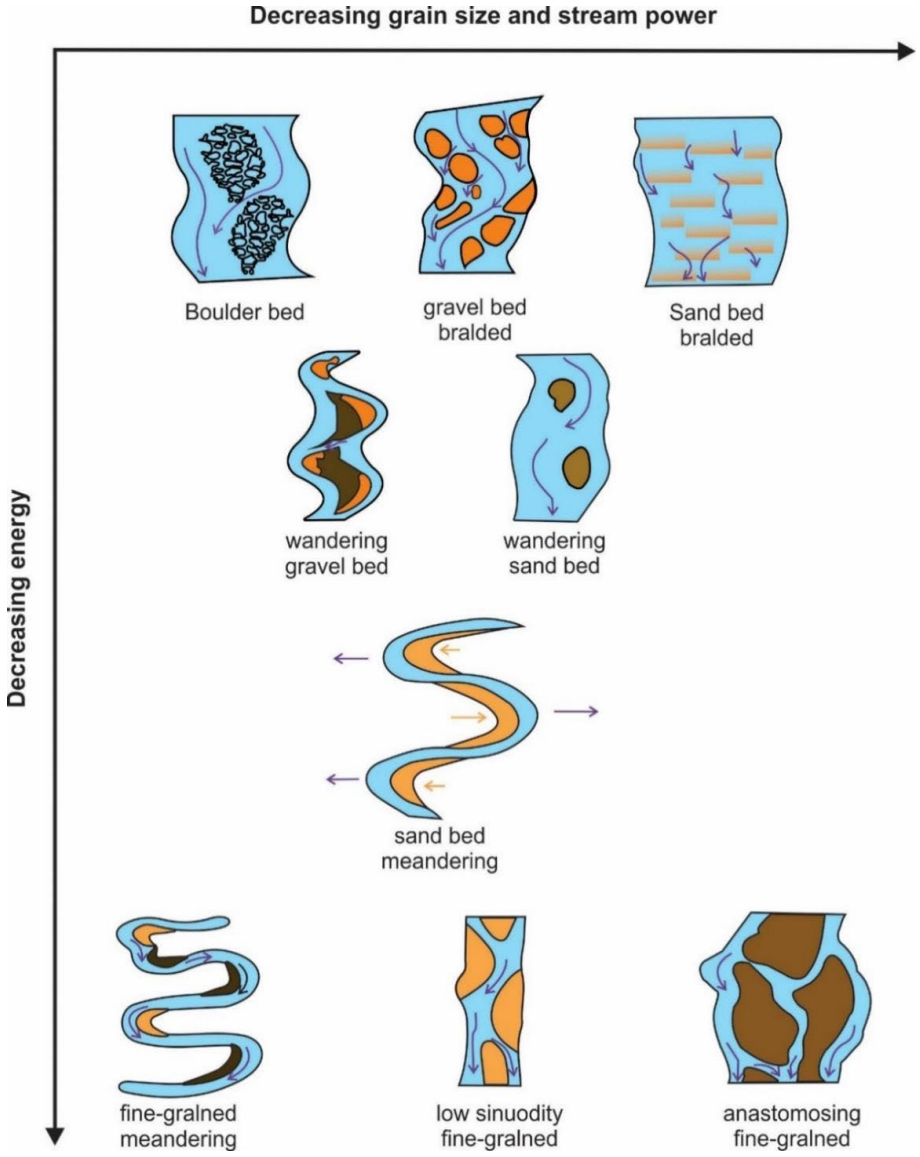


Figure 9. The continuum of channel planform variants of alluvial river morphology along an energy gradient is closely related to predominant sediment load and channel stability (reproduced from Lawler et al, 2017, after Brierley and Fryirs (2005)).

During low flows accumulation of fine sediment, through a process known as colmation, occurs in the interstitial spaces of the upper channel bed, hindering water exchange with the hyporheic zone and groundwater, and altering microbial and biochemical processes of the microbial films (Brunke and Gonser, 1997; Hancock, 2002). This can negatively affect invertebrate habitat and suitability of gravel for fish spawning. High flows, and especially bedload movement can flush this sediment out, but colmation increases or becomes "unbalanced" when flushing is reduced. Colmation is a common consequence of permanently reduced flows following impoundment, or from water extraction for drinking, industrial and irrigation water (Petts, 1988). It can also occur from sewage loads, the build-up of organic layers and biofilms, and fine sediment loads from land-use (Brunke and Gonser, 1997; Hancock, 2002).

Tables 4.1-4.4 of Lawler et al. (2017) illustrate some of the ecological impacts and sources of suspended and deposited sediment in rivers. Studies for biotic groups include those on invertebrates (García Molinos and Donohue, 2011; Harrison et al., 2007; Jones et al., 2012; Wood and Armitage, 1999), macrophytes (Jones et al., 2012) and fish (Kemp et al., 2011; Richter et al., 1997). Biotic effects are also related to how sediment in rivers interacts with other stressors and temporal patterns (García Molinos and Donohue, 2011; Molinos and Donohue, 2010), although it has also been found that fine sediment is more damaging for macroinvertebrates than nutrient enrichment (Townsend et al., 2008; Wagenhoff et al., 2011) for macroinvertebrates.

The importance of sediment in rivers calls for the need for Supplementary Measures for sediment transport management. This would include assessment and mitigation connected with infrastructures or other interventions in rivers and estuaries, dredging, siltation of riverbeds, erosion of beds and banks, receding deltas, and infilling of estuaries. This calls for the need for sediment budgets at the river basin scale.

Woody debris

Woody debris and riparian vegetation are key elements for river ecology, providing habitat for an array of organisms, and contributing to carbon and nutrient dynamics from allochthonous inputs (Gurnell et al., 1995; Hering et al., 2001; Magilligan et al., 2008; Premke et al., 2010; Vannote et al., 1980; Wohl et al., 2019). Woody debris, or large coarse woody debris, affects the character of streams, including flow paths, sediment retention, water height and connection with side channels (Brummer et al., 2006; Harvey et al., 2018). An updated overview of the ecological importance of woody debris in rivers by Wohl (2020) is provided by Oxford Bibliographies, but requires a user subscription for full access. Key introductory literature on the topic and the multiple roles that woody debris plays in the ecology of rivers is provided by Harmon (1986) and Hassan (2005). However, across Europe many streams have been denuded of woody debris, which is often intentionally removed to reduce flooding, but this leads to not only loss of important ecological habitat, but also to changes in flow hydraulics, a simplification of channel bed and reduction in organic matter retention; and often a reduction in bed and bank stability (Diez et al., 2001; Piégay and Gurnell, 1997). The extent that woody debris should be managed or used in river restoration was the topic of a workshop reported by Grabowski et al. (2019) to discuss key issues of: (i) hydro-geomorphological effects, (ii) current use in restoration and management, (iii) uncertainties and risks, and (iv) tools and guidance required to inform process-based restoration and management.

These issues are highly relevant given the debate on natural function of rivers e.g. River restoration is a multi-million-pound industry in the UK, and it was estimated by Roni and Beechie (2012) that about ca. US $2 billion is spent on it globally.

Key recommendations from Grabowski et al. (2019) were to:

- “develop a framework to support the use of wood for restoration and management;
- establish acceptable levels of uncertainty and devise ways to assess and monitor risk;
- formulate approaches to link riparian and channel management (e.g. flood risk management, forestry, water quantity and quality, biodiversity) to maximise beneficial impacts;
- create mechanisms to link agricultural land management (e.g. agri-environment schemes) and environmental benefits; and
- advise on natural capital and ecosystem service approaches to compare options and benefits of wood for restoration and natural flood risk management.”

In-stream and riparian vegetation

In-stream, bankside and riparian vegetation influence and control geomorphological processes to varying degrees and depending on local circumstances (Gurnell et al., 2016, 2014). Riparian trees and other vegetation provide ecological structure for both aquatic and terrestrial life and a natural physical roughness at the edge of the stream that reduces the scouring of the riverbank. With decreasing stream width, and predominantly in headwater streams, riparian zones have high importance for supply of organic matter from leaf fall, habitats for adult stages of aquatic insects, buffers from terrestrial run-off and shade to moderate temperature fluctuations (Death and Collier, 2009; Harrison and Harris, 2002; Vannote et al., 1980). In small and mid-sized streams, channel and stream bed modifications are major morphological stressors on physical habitat quality (Gieswein et al., 2017; Townsend et al., 2008). This includes denuding rivers of woody debris or riparian vegetation. From headwaters to coastal zones, this is a major hydromorphological alteration, which removes a key component of an integrated structure (Gurnell et al., 2019). The removal of woody debris generally increases river flow velocity because of reduced boundary roughness. This has similar effects as those impacts from channelisation (Fehér et al., 2012).

Intact ecosystems generally have resistance to colonisation by invasive species (Bunn and Arthington, 2002), so the removal of riparian vegetation can facilitate the invasion of ruderal species, and alien invasive species (Planty-Tabacchi et al., 1996; Richardson et al., 2007). Invasive species are often found along riverbanks, which provide excellent conduits for their spread. A range of invasive species can lead to streambank erosion. These include mammals (e.g. the coypu *Myocastor coypus*), reptilian iguanas (e.g. *Iguana iguana*), fish (e.g. catfish of the Loricariidae family), invertebrates such as invasive crayfish (*Pacifastacus leniusculus*), and plants including knotweeds (*Reynoutria* spp.) and Himalayan balsam (*Impatiens glandulifera*) (Colleran et al., 2020; Faller et al., 2016; Gerber et al., 2008; Greenwood et al., 2018; Harvey et al., 2019). WFD monitoring does not include the riparian zone vegetation, therefore hydromorphological alteration will be greatly underestimated as there is an intimate relationship between in-stream physical, and biological conditions and riparian zones. While riparian vegetation was a feature of early assessment of the ecosystem intactness of rivers (Raven et al., 2002), further developments in the understanding of river form and function suggest that the importance of riparian vegetation has been underestimated in how it can be applied to river assessment (González del Tánago et al., 2021).

2.2.5 Flood protection

Engineering measures are implemented in many parts of the world for land reclamation and flood protection. To quickly move water downstream, characteristic hydraulically optimised channels as fixed trapezoidal river cross-sections are built in combination with bank reinforcements. This naturally affects river morphology, hydraulics and river ecology. While river management has often, but not always, prevented flooding in the target area, it has also had other undesirable, or unanticipated, consequences. This includes the possibilities of increased risk of flooding downstream. The trade-off of loss and alterations of habitats are increasingly and legitimately questioned, and the need to assess and, if necessary, mitigate the impacts of hydromorphological alterations is a requirement of the WFD. This includes the advocacy of "green infrastructure" including the "restoration of riparian areas, wetlands and floodplains to retain water, support biodiversity and soil fertility, and prevent floods and droughts" as cost-effective economic techniques for pollution control, biodiversity enhancement and flood mitigation (European Commission, 2012; Schindler et al., 2016), with clear potential for use in Ireland (Collier and Bourke, 2020).

Infrastructure used in flood management includes bank enforcements and dykes (levees), navigation canals with locks, dredging and drainage, and straightening of rivers. Engineering for flood protection has led to hydromorphological alteration of rivers and in some cases the complete disappearance of urban streams. Surface water storage, through dams, embankments and retention ponds is a traditional approach to attenuating flood peaks. Water storage modifies floods by slowing the rate of rising waters, by increasing the time it takes for the waters to peak and by lowering the height of that peak. Such measures can give a false sense of security, and the potential of hydromorphological alterations to increase flood risk has been generally neglected (Nones et al., 2017; Nones and Pescaroli, 2016). An overview of flood defence works (Figure 10) identifies a range of ecological impacts that have been associated with them.

In a world where hard engineering solutions are seen as the flood defence paradigm, the use of natural 'green' or 'nature-based' mitigation was, and often still is, seen as a far less viable option. It is also one that threatens the traditions that protect land holdings. It is often politically easier to use civil engineering to address flooding than give over land to reduce flood waves.

With loss of slower drainage capacity in the landscape and cities to slow down movement of water off the land, and with increasing intensification of rainfall events, the vulnerabilities of the traditional reliance on the engineering approach are apparent, and all the more evident with climate change (Hedelin, 2017; Nones and Pescaroli, 2016). Since the first large-scale straightening of the River Rhine in the mid-19th century for hydropower, riverine meadows between Basle and Karlsruhe have diminished by 87%, and the overall floodplain of the Upper Rhine was reduced by 60% or 130 km^2 and river straightening shortened the run of the Upper Rhine by approximately 82 km, and on the Lower Rhine by approximately 23 km. This accelerated run-off. For example, the flow rate of the flood wave in the Rhine on the section between Basle and Maxau has reduced from 64 to 23 hours (Fehér et al., 2012). A similar loss of floodplain and wet meadows has occurred throughout many of the larger river basins of Europe, including the Elbe, Danube and Oder, within some sections containing only 10% - 20% of former riverine meadows remaining (BMUB and BfN, 2009). The consequences of reduced storage capacity in the landscape have led to serious flooding of cities, at enormous social and financial costs (Collentine and Futter, 2018; Rogger et al., 2017; Wheater and Evans, 2009).

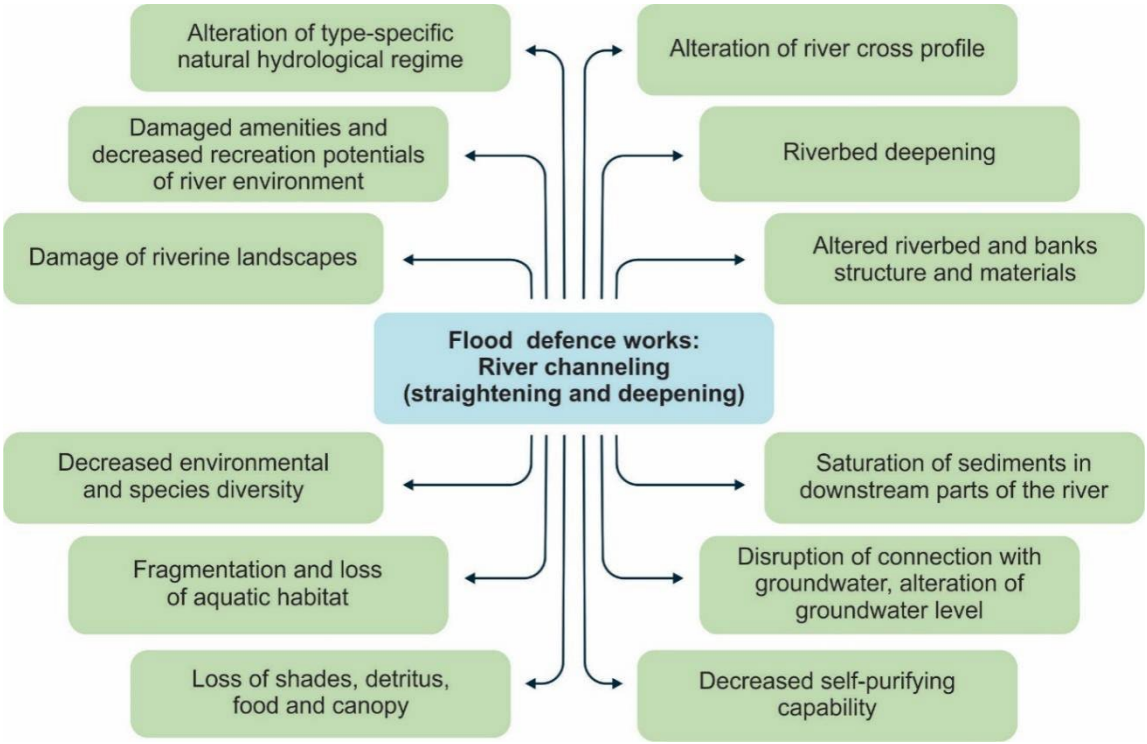


Figure 10. Schematic of ecological effect and impacts associated with flood defence works. Modified from Fehér et al. (2012), and European Commission (2006).

Planning for and lessons learnt from flood and other landscape related disasters can, however, be varied. Following bushfires in Australia grants to rebuild in the same areas are described by Van den Honert and McAneney (2011) as “an example of government generosity not encouraging risk-reducing behaviour”, whereas in another case in Australia, compensation after flooding required citizens to relocate out of the floodplain. However, there are multiple factors involved in managing flood (and drought) risk. These include both features of the geographical and social landscape. An effective overview of intended and unintended consequences of flood and drought strategies is provided by Ward et al. (2020) and the need to consider “Beyond these physical processes [the] utmost importance to better understand complex human decision-making processes and how they are influenced by interactions and feedbacks between hazard, exposure, and vulnerability.”

These aspects become increasingly important as flood risk management is moving away from reliance only on predominantly hard-engineering flood defences to a more integrated river basin approach, using more natural habitats and processes to slow and store water in addition to measures such as flood warning, spatial planning and emergency response (Klijn et al., 2008; UK Government, 2016). Nature Based Solutions (NBS) capitalise on the 'green infrastructure' for flood management, and the mitigation of many other water hazards (Collier and Bourke, 2020; EEA, 2020; Gunnell et al., 2019; Vörösmarty et al., 2021; WWDR, 2018), and other water management. Restoration and use of natural floodplains and wetlands effectively act as giant sponges that soak up water at peak flow, releasing it back slowly to the river.

Globally, functioning floodplains provide a large range of ecological benefits and ecosystem services, with huge economic benefits (O'Brien et al., 2020; Russi et al., 2013; Schindler et al., 2016). However extreme flood events can also have negative impact on aquatic ecosystem services (Talbot et al., 2018). Better understanding and better management of floods have, for some time now, led to calls for a more ecological approach to flood management (England et al., 2008; Skinner and Bruce-Burgess, 2005; Wharton and Gilvear, 2007). This includes adoption of policies and practices that incorporate natural floodplains, water and catchment management (Warner et al., 2012).

National policy and management initiatives in Europe for more sustainable flood management and river restoration include the Dutch Room for the River (van Alphen, 2020), the UK programme for making space for the river and water stewardship, the Swiss guiding principles for sustainable water management (FOWG, 2001), and the Spanish National Strategy for Restoring Rivers (Ministry of the Environment and Rural and Marine Affairs, 2010). The Dutch Room for the River is a featured case study in Section 2.6.1 on Case Studies.

The principles of better use of natural processes apply also to coastal mudflats and salt marshes. There are clear and associated benefits to nature conservation and biodiversity. The loss of coastal wetlands in China are estimated to cause an annual loss of US $31 billion in ecosystem services and about 6% of the gross marine products (Ma et al., 2014). At the other end of the catchment, protecting and restoring peat bogs can provide important protection against downstream flooding, depending on antecedent water saturation during high rainfall events. Upstream saturated wetlands provide little mitigation for downstream flood alleviation (Williams et al., 2012). It is not the case that flood mitigation can depend only on green infrastructure as engineering solutions have enabled human societies to manage the risks provided by flooding and the capacity to provide a more sustainable water and energy provision through storage (Muller et al., 2015). In many circumstances, an appropriately considered approach to flood management has been lacking, and there is clearly a need to better consider how natural processes and traditional hard defences can be used for a more sustainable and integrated approach to flood risk (Fehér et al., 2012). For further information see the case study on NBS below (Section 2.6.4).

The EU Floods Directive (2007/60/EC) is a 'sister Directive' to the WFD. It aims to reduce and manage the risks of floods to human health, the environment, cultural heritage and economic activity. Over half of deaths attributed to natural disasters in recent decades were in floods (Habersack and Schober, 2020). The Directive requires Member States to assess what rivers and coastlines are at risk from flooding, to map the possible extent of flooding and the assets and humans at risk in such areas, and to take adequate and coordinated measures to reduce the risks. The hazard maps are intended to reduce potential damage and provide long-term solutions. The Floods Directive brings the expected mix of challenges and opportunities. Protection of coastal flooding from climate change is alarming for many coastal areas, including densely populated European cities (McEvoy et al., 2021). With impacts of flooding from climate change already evident, there is a need for concerted effort in what this means for risk and the knowledge gaps that need to be filled. It would be foolhardy if green infrastructure and rethinking land-use in the catchment as well as the coastal and city areas to mitigate flooding, as done in the Netherlands, was not a key element of the planning (Müller, 2013; Nones, 2015; Sophronides et al., 2016).

Making space for rivers (see Section 2.6.1) as a flood risk mitigation and for ecosystem enhancement has enormous potential. It can also redress carbon emission and biodiversity loss but needs to be supported by land-use and coastal planning policies. Flood Protection Projects that derive from or assist with the implementation of the Flood Risk Management Plans (FRMPs) require assessment for their compatibility with WFD objectives. Such an assessment should certainly identify potential impacts of proposed measures on water body hydromorphology and status, as required under Article 4(7) of the WFD. This will build on the initial work done during the preparation of the FRMPs to improve assessment methods for river morphology.

2.2.6 Land-use and Floodplains

As described in the sections above, management of a river cannot be separated from that of the catchment. Nutrient loading from land-use is associated with the decline of the ecological status of many rivers, but many hydromorphological stressors within a river are also linked with land-use (Dahm et al., 2013; Fehér et al., 2012). A key conclusion from the work of Dahm et al. (2013) was that measured impacts on biotic metrics at a river reach scale arise from overall degradation of riparian zones, and effects of land-use upstream. Teasing out the direct effect of hydromorphological alterations from larger scale catchment effects can be difficult, This highlights the need for an integrated approach to river (or other water body) management that accounts for combined pressures, the importance of spatial and temporal scales in assessment, and realising the strong effects that water chemistry can have on biological communities (Friberg et al., 2009).

Lateral connectivity is critical for hydrological and pollutant yields from land to water. Conversely, disconnection between the river and the land through altered floodplain topography has an impact on ecological processes. Across Europe, only 17% of European floodplain habitats and species are considered to have good conservation status (EEA, 2020). This can have major consequences for biodiversity, as in most regions of the world far more species live in floodplains than in any other type of landscape unit (Tockner and Stanford, 2002). Between cultivation and urbanisation, maybe up to 90% of European and North American floodplains can be considered ‘functionally extinct’ (EEA, 2020; Tockner and Stanford, 2002).

Many catchments are drained for crop management or human living space, and with frequent loss of small streams (Fehér et al., 2012). Likely, more than 95% of lowland river channels in south-east England and Denmark have been modified for drainage, river navigation and flood prevention (Iversen et al., 1993), leading to a frequent severance from their floodplains.

Changes in land-use patterns can increase or decrease water availability to surface waters (Scanlon et al., 2007) effected by changing surface run-off and groundwater recharge, and the balance between them (Figure 11). The hydrological impacts of different land-use types on aquifer behaviour, including the change in the volume of recharge, the change in discharge patterns, flooding, and waterlogging, are not however well understood (NGC, 2004; Rogger et al., 2017). A major challenge is separating the impacts of the direct effects of modified flow regimes from those associated with land-use changes (Bunn and Arthington, 2002).

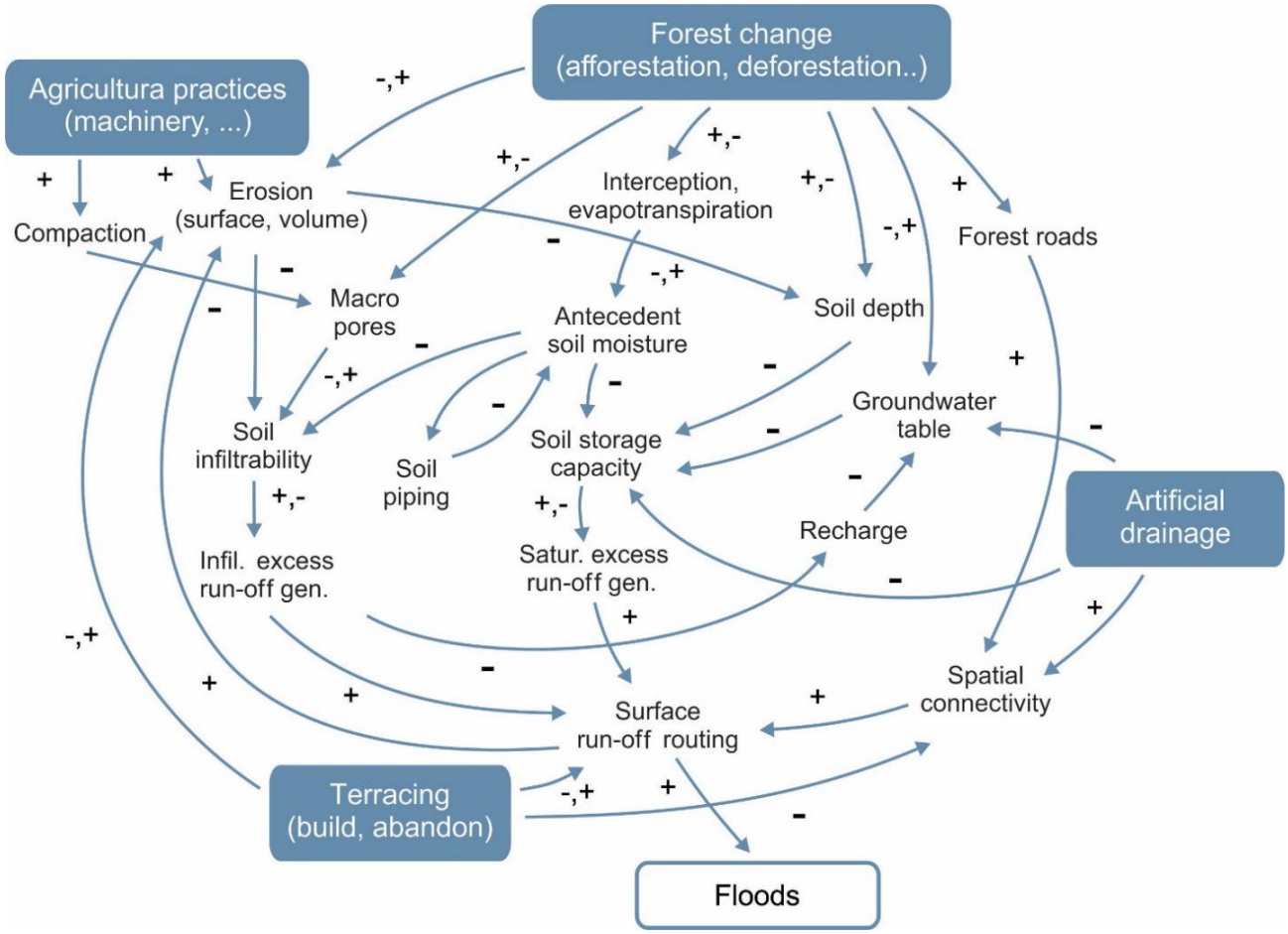


Figure 11. Schematic of process interactions in land-use change effects on floods at the catchment scale. Plus, and minus signs indicate whether an increase in one variable increases or decreases another variable. The processes shown here are embedded in a broader context of environmental and socio-economic processes (from Rogger et al., 2017).

2.2.7 Arterial drainage in Ireland

The practice and art of land drainage has a special place in the history of water management, eloquently described in the 'Taming of the Flood' (Purseglove, 1989). This is essential reading for anyone interested in the topic. The Romans brought engineering brilliance for land drainage to Britain, followed by an enthusiasm by the early Christian Church. This was perfected by Dutch drainage experts, much revelled by the English House of Tudor, and set into a historical course by an Elizabethan Act for recovering "many hundred thousand acres of marshes" (Purseglove, 1989).

Draining of land deemed as unproductive was a driver of agricultural policy across Europe, with progressive decline of wetlands until comparatively recently and continuing for many years after the International Convention on Wetlands, commonly known as The Ramsar Convention, dating back to 1972. Globally the loss and degradation of wetlands even accelerated between 2010 and 2017 (Davidson et al., 2020).

In Ireland, large-scale drainage of land and wetlands may have come later than in the UK but nevertheless progressed with gusto. Purseglove (1989) describes the drainage of the cross-border River Blackwater (funded through EEC funds to promote cross-border harmony) as reflecting “all the tragic carelessness which large-scale drainage represents at its worst.” This presented no problem for Ireland which had in 1945 enacted the Arterial Drainage Act, putting into the law of the new State a practice that had been promoted, largely without national concern or debate, over the previous century. Purseglove (1989) described the prevailing attitude to drainage as “a matter of national pride” and almost a “heresy in questioning its value.” Yet the lack of rigorous economic analysis invites exactly such criticism.” It is over thirty years since these words were published. Within that time, there has been a clear increase in the understanding of the value of wetlands, for conservation and economic value (Kumar et al., 2020; Russi et al., 2013). Ireland’s commitment to the Ramsar Convention appears ‘’low-key’ at best with a notable absence of public profile. While there are 45 Irish designated Ramsar sites, only a small number appear to have management plans either published or in preparation. There is a notable absence of involvement in the Ramsar Convention of the Parties (COP), and the Ramsar website indicates that Ireland has only submitted reports to the COP on three occasions (1999, 2002, 2022). While this does not say anything about the current approach to arterial drainage, it reveals a generally lacklustre engagement in wetland protection outside the statutory responsibilities of the Birds and Habitats Directive (see Section 3.2). An overview of the Irish Arterial Drainage Acts 1945 to 1995 is available. The original 1945 Act was enacted to provide long-term improvement to agricultural incomes in river catchments, with more areas for livestock grazing or production of higher crop yields. This then became inextricably linked to the Single Payment System (SPS), as part of the EU Common Agricultural Policy (CAP), and more recently to Rural Environmental Protection Schemes (OPW, 2021a).

In the early schemes, large areas of bog were drained which facilitated peat extraction for fuel and horticulture. The Act was amended and modified on a number of occasions, for example by measures to give effect to EU Directives such as the EIA, SEA, and Habitats Directives and to give effect to the Aarhus Convention, a legal instrument set up by the United Nations Economic Commission for Europe (UNECE) to which the EU has subscribed (UNECE, 1998). The Arterial Drainage (Amendment) Act 1995 further allows for the implementation of localised Flood Relief Schemes to provide flood protection for cities, towns and villages. Statutory Arterial Drainage Maintenance also entails the maintenance of Drainage Schemes and Flood Relief Schemes. The Office of Public Works (OPW) is responsible for the maintenance of 11,500 km of channels (Figure 12), 800 km of embankments, some 19,000 bridges and further ancillary structures such as weirs, sluice barrages, sluices, pumping stations and tidal flap gates.” The drainage schemes are reported to cover 260,000 ha of agricultural land.

The 1945 Act updated the previous 1925 Act. The 1925 Act provided for financing by State, County Councils and privately, via the drainage rate, and for the duty of maintenance to be borne by County Councils and the cost levied as part of the drainage rate. (O’Brien et al., 1941). It brought drainage into a new era with provisions for:

- all future Arterial Drainage Works would be carried out by OPW on the basis of entire catchments and entire catchments only;
- construction costs would be met entirely from State funds;
- maintenance would be undertaken in future by OPW; and

- cost of maintenance would come from County Councils concerned, as a county-at-large charge.

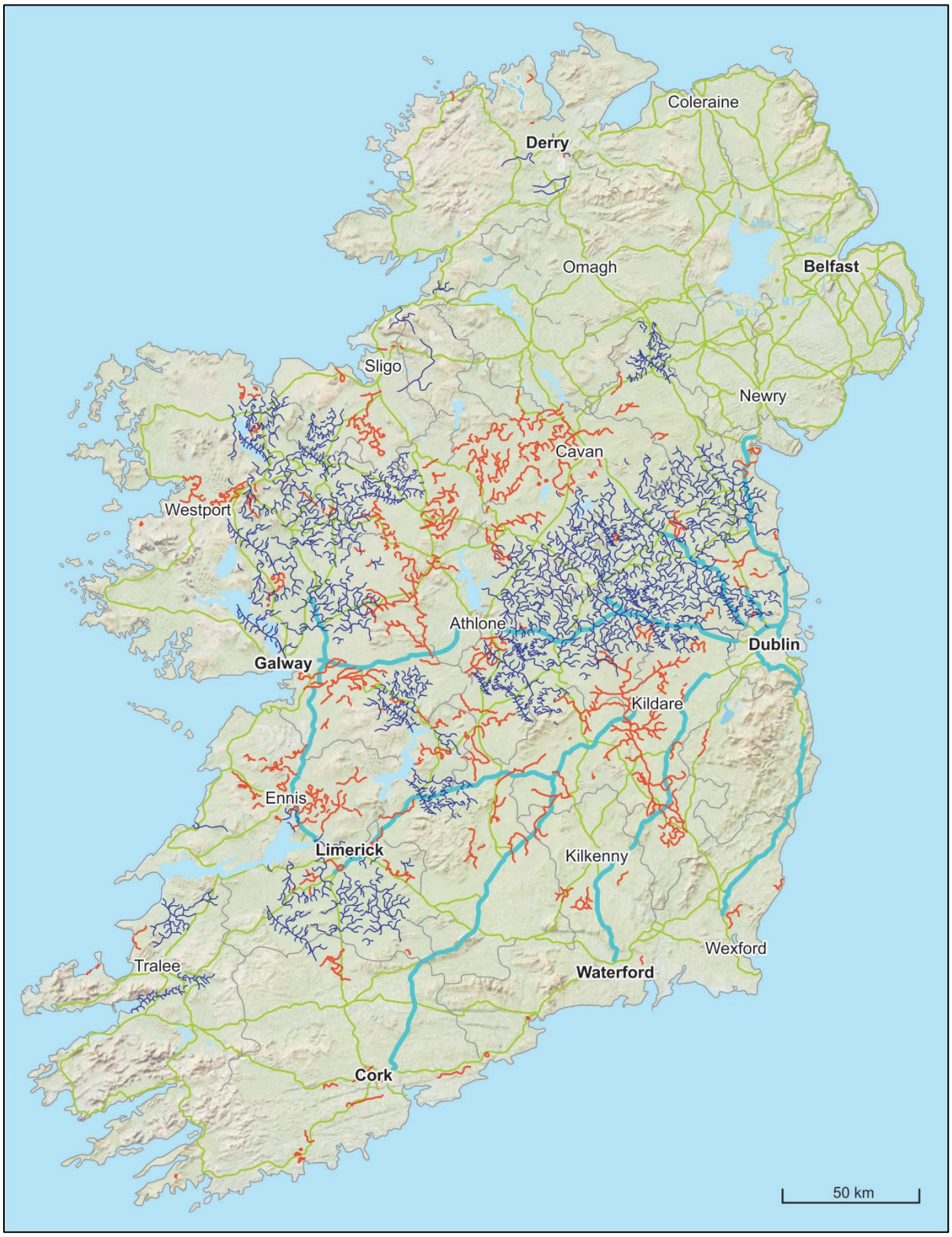


Figure 12. Extent of OPW maintenance of 11,500 km of rivers (the blue lines) and the Drainage District Channels (red). Source: Floodinfo.ie

Kavanagh (1964), while very supportive of the new approach, pointed out the need for deep drainage in callows and that “channels which are highly efficient hydraulically, may create high velocities during flood conditions which could entail expensive bank protection.” The forerunners of the OPW first became associated with arterial drainage with the Drainage Act of 1842, and made responsible for the design and execution of drainage works.

Ryan (1986) provides an overview of the history of drainage in Ireland, also pointing out some of the environmental impacts on fish and wildlife, and need, for example, to restock a lake as large, and ecologically significant, as Lough Mask as a result of impact in salmonid spawning streams. It is clear from the older literature that this was a price worth paying for original works and ongoing drainage maintenance programmes. The Arterial Drainage Acts place a responsibility on the OPW to not only drain for enhancement of agricultural production, but to “maintain that drainage.” Indeed, under Section 37 of the Arterial Drainage Act 1945, the OPW is statutorily obliged to maintain all rivers, embankments and urban flood defences on which it has executed works since the 1945 Act in “proper repair and effective condition.” The maintenance obligation would seem to also apply to local authorities in respect of “Drainage District (DD) Benefiting Areas” constructed under a number of drainage and navigation acts from 1842 to the 1930s (Irish River Project, 2021). About 170 of these DD schemes remain standalone, comprising a further 4,600 km of river channel, with responsibility for maintenance with the Local Authorities.

It has often been suggested by environmental groups that river maintenance by OPW has employed environmentally insensitive practices. Figure 13 shows bankside work on the Newport River, in Co. Tipperary, part of the Lower River Shannon Special Area of Conservation (SAC). Assessment of impact appears not to include the entire river system, while the baseline for impact appears to be the already drained channel (Irish Wildlife Trust). While operational guidance and practice is improving (see below), the fundamental rationale supporting land drainage will remain a source of controversy under the current legislation and remit of OPW. Calls for a review and overhaul of the Arterial Drainage Acts, appears to have been taken up in the third cycle RBMP (see Section 4,1.1, below). When national law conflicts with EU law, then EU law takes precedence.



Figure 13. Photograph of OPW river maintenance in 2018 of Newport River, within the Lower River Shannon Special Area of Conservation. Source: Irish Wildlife Trust

2.2.8 Designation of HMWBs in Ireland

Gilligan and Quinlan (2020) describe the collaborative effort between the OPW and EPA to re-evaluate a "portion" of channels that are subject to arterial drainage as HMWBs which were not designated in the first cycles of the WFD. The justification includes that "In comparison to other EU member states, Ireland has currently designated low numbers of HMWBs at 0.5%", with seemingly a "recommended increase to 4%" that is closer to the EU norm of about 15% for rivers, and that "the main change to the scale of HMWB designation declared by Ireland will be in connection with the arterial drainage channels." The recent review of HMWBs by EPA (2022a) confirms the intention to increase the number of HMWBs and contains guidance on processes for their designation, and the third cycle RBMP is proceeding with the move to designate as HMWBs a number of river water bodies that are subject to arterial drainage (DHLGH, 2025). See Section 4.1,2, below). A reasoned case would need to be provided to the Commission for re-designation, and why some channels of the arterial drained network, and not others, would be re-designated. The complexity, and potential controversy, of the strategy is suggested by Gilligan and Quinlan (2020) with "a further batch of [identified] river water bodies, while having a significant physical change, are not designated as heavily modified as they may have potential to achieve good ecological status when nutrient issues are resolved", but "At a later WFD cycle, if these water bodies move to HMWB, this would bring Ireland to 22% of rivers as HMWB. The increase in HMWB designation for rivers is a truer reflection of the scale of physical alteration and associated hydromorphological pressures that exist in the State."

Further elaboration in the paper is "Therefore, an HMWB designation does not diminish the worth of a water body or means that an impacted water body will not get additional measures; its designation simply means that a realistic objective will be set that acknowledges that the

water body has been physically altered to facilitate the specified purpose" and "There are no key restoration measures (i.e. to restore bed level) that can be implemented without impacting the specified use i.e. the drainage outfall and there are no alternative options whilst maintaining the specified use, land drainage." The suggestion here is that reduced ecological status through HMWB designation is acceptable for WFD compliance. See further comment in Section 4.12.

Any revision of water body designation to increase the extent of HMWBs within the objectives of the WFD needs to be cognizant of guidance on criteria for HMWB designation (European Commission, 2019a; Kampa et al., 2019) that:

- *"*HMWBs should be water bodies that have undergone significant hydromorphological alterations such that the water body is substantially changed in character (WFD Article 2(9)). The change in character must be extensive/widespread and profound, involving substantial change to both the hydrology and morphology of the water body;
- HMWB designation can only take place if the changes to the hydromorphological characteristics of that body which would be necessary for achieving GES [good ecological status] would have significant adverse effects on use or the wider environment. Possible restoration measures to achieve GES need to be identified and Member States need to establish criteria and thresholds for deciding if these measures would have a significant (or not significant) effect on use. This is a key issue for achieving a clear and transparent process of designating HMWB;
- Criteria need to reflect the effects on different benefits provided by water use. Thus, not only one criterion may be considered but several criteria may need to be used;
- A significant adverse effect at a local level may be insignificant in a regional or national context or vice versa. Overall, it is important to define at what level the main importance of the use lies (local, regional, national level or a combination) … the assessment at local scale should not be related to the private interest of one person/or company but to broader public interest;
- For HMWB designation, it must also be demonstrated and described that the beneficial objectives of the physical modifications cannot be achieved by other means, which are a significantly better environmental option, technically feasible and not disproportionately costly;
- Designation of HMWB is not a type of exemption. HMWB are a specific water body category with their own classification scheme and objective, namely good ecological potential (GEP); and
- The methodology and specific criteria for HMWB designation… should be clearly explained in the RBMPs."

For arterial drainage channels, it then appears that the current view of the Irish Government is that some hydromorphologically altered river channels will have an objective of good ecological potential and others will have the objective of good ecological status, but without any clear hydromorphological reasoning provided to support that decision. Current practice is that feasible mitigation measures are applied in any suitable scenario, hence suggesting that there will be no difference in the environmental management standards for HMWB or non-HMWB channels in the arterial drainage network. This appears to be a breach of relevant articles in the WFD. The current view of the EPA (2024a) is that "All waterbodies with hydromorphology as a significant pressure will have a target environmental objective date set to beyond 2027." See further details in Section 4.1.1, below.

Types of mitigation measures that are currently engaged and will continue to expand include drainage maintenance following the 'Environmental Guidance: Drainage Maintenance and Construction' (Brew and Gilligan, 2019), which includes techniques such as how to minimise vegetation removal; river enhancement works on suitable channels to increase morphological diversity; and improvements to longitudinal connectivity. This is in collaboration with Inland Fisheries Ireland (IFI), identifying barriers and mitigating reduced connectivity in drained channels.

The OPW have produced guidance to "help OPW Drainage Maintenance staff carry out their activities in an environmentally sensitive and sustainable manner" (Brew and Gilligan, 2019), and further incorporated into the recent OPW Biodiversity Action Strategy (OPW, 2022). The ambitions are to "manage and substantially reduce potential impacts to the animals and plants that depend on the river corridors, estuaries, lakes, and catchments where drainage maintenance and construction works are carried out" (Brew and Gilligan, 2019).

The guidance includes (pages 27-32) a ten-point plan for works. This has been developed in consultation with IFI (previously Central Fisheries Board), containing many elements of the report, summarised below) on lamprey management by King et al (2009). The guidance document provides further information on all aspects of channel management, and associated mitigation for environmental protection. Where arterial drainage works occur all of the proposals seem reasonable. A more fundamental question is whether specific drainage works are themselves necessary or, in an era where there is acceptance of the climate and biodiversity emergency, still desirable.

This raises larger policy matters related to agricultural support, climate change, European environmental law, and the use of subsidies for agriculture. It also appears to be the case that the OPW has major control over aspects that affect a very large extent of river channels in Ireland. A more integrated approach with other agencies would provide greater safeguards for river ecology to meet the objectives of the Water Framework and Habitat Directives.

The OPW work within five-year cycles and are obliged to apply Appropriate Assessments (AAs) for work within a SAC or SPA, Ecological Impact Assessment (EcIAs) for works that do not impact a designated area or specified qualifying interest, and Construction Environmental Management Plan (CEMPs) for large construction projects. The guidance is a stated means to meet the objectives of EU Directives, as well as "biodiversity goals, fisheries improvement, ecological enhancement and flood management."

The effectiveness of field procedures depends on first, the fit-for-purpose of the guidance. It is clearly difficult for one guidance to fit all circumstances, particularly relating to protected sites or species (King et al., 2009), hence the importance of effective engagement with environmental agencies charged with the protection of nature. Second, field operation needs to be carried out to a satisfactory standard using aware and trained operatives. Curtailing some of the more enthusiastic channel maintenance practices is suggested by the text after the ten-point plan. "When carrying out drainage maintenance work: less is more. Do not over-dig or over-prune, just produce enough work to keep the scheme in effective maintenance and condition. By doing so, environmental impacts are minimised." There are some justified concerns that field operatives may not have the ecological knowledge to identify sensitive habitats, such as bat roosts.

For Site-Specific AA (done outside of the five-year AA planning), it is a requirement that a detailed plan for the works is drawn up and that a Nature Impact Statement (NIS) is submitted

to the NPWS and IFI for a six-week consultation period where it is considered that the drainage works may have a significant effect on a designated site. Any comments received need to be addressed to the satisfaction of the competent authority (OPW), followed by issuing an AA Determination Statement to NPWS. Works proceed on the basis of compliance with the site-specific mitigation procedures. However, as illustrated by the Ballinasloe Flood Relief Scheme, Co. Galway, an AA Screening Determination Statement made by the OPW, based in part on the report provided by the consultants concluded that an AA was not required, although a number of SACs and SPAs were within the "zone of influence of the proposed works". Effectively, it would appear that whether AA is deemed necessary or not, the decision for actions is with the OPW itself and no other, independent, assessment.

Strategic Environmental Assessment S.I. 435 of 2004

As a plan or programme at the scale of the river basin, and with recognised environmental impact, arterial drainage merits an SEA (Brew and Gilligan, 2019; Gilligan and Quinlan, 2020; King et al., 2008). In 2006 the OPW decided that drainage maintenance activities were exempt from SEA. This was not a view shared by the EPA, and after OPW liaised with the EPA regarding the requirements for a SEA for the 2011-2015 Arterial Drainage Maintenance activities, a screening by the EPA led to a SEA. The view of the Government is that it would be also "prudent" to conduct a Scoping Report for a SEA, which was commissioned by the OPW for the arterial drainage programme 2022-2027 (OPW, 2021a).

The SEA Scoping Report outlines the proposed work and covers: a) silt and vegetation management; b) aquatic vegetation cutting; c) bank protection; d) bush cutting/branch trimming; e) tree cutting; and f) other. This category includes mulching embankment, mowing embankment, gate installation, sluice maintenance, bridge maintenance and spraying with herbicide.

There are a number of statutory consultees for a Scoping Report: 1) Minister for Housing, Local Government and Heritage; 2) Environmental Protection Agency; and where there may be significant effects on fisheries or the marine environment: 3) Minister for Agriculture, Food and the Marine 3) Minister for the Environment, Climate and Communications.

Appropriate Assessments are now conducted in accordance with S.I. No. 477/2011 – *European Communities (Birds and Natural Habitats) Regulations 2011, as amended*, for all maintenance works and these assessments are reviewed and updated every five years for each scheme. In the future, with amendments to the Regulations introduced by S.I. No. 293/2021, the AA for the next 5-year cycle will include public consultation .

The SEA Scoping Report (2022-2027) draws heavily on the guidance of Gilligan and Quinlan (2020). Monitoring of activities, and presumably impact, is "in coordination with Inland Fisheries Ireland (IFI) [who] have an ongoing research programme to assess the impacts of Arterial Drainage Maintenance Activities and the Environmental River Enhancement Programme (EREP)." While the Scoping document mentions that the EREP has included monitoring of hydromorphological conditions in its programme and that the River Hydromorphology Assessment Technique (RHAT) has been approved as the appropriate method to determine hydromorphological status, it remains unclear to what extent this will occur for the new programme. A number of other monitoring activities are referred to but without specific details. Key environmental issues highlighted to "consider" in the Scoping document are:

- “some flood risk alleviation for residences near channels because of drainage and maintenance;
- arterial Drainage cannot eliminate the risk of flooding. Most of the schemes carried out by the OPW are aimed at reducing flooding of agricultural fields from the main channel on average at a 'three-year return' flood period. Therefore, flood risk from climate change and changes in land management practices (new developments in flood-sensitive areas) may not be mitigated through Arterial Drainage Maintenance activities on channels;
- it is important to consider the areas where the works are being carried out and their susceptibility to flooding. Consider residences/housing locations both upstream and downstream of the works. It is necessary to ensure that the works will not increase the risk of flooding (i.e., complete removal of treeline, increases erosion and in turn rate at which run-off and sediment can discharge to water courses) by impacting the flows or removing areas of water accumulation/storage. The consideration of areas both upstream and downstream of the potential works is crucial. It is also important to recognise the benefit of drainage and its impact on flood risk management;
- recreational use of water-related tourism (fishing, bathing, navigation); and
- reliance on tourism and recreation on natural, cultural, and heritage resources including landscape, rivers, loughs, and coasts.”

It is, however, clear from the text of the SEA 2022-2017 Scoping Report that there is a merging of environmental objectives and the continuation of the agricultural *status quo*, which merits some critical analysis. An extract from the Scoping Report merits presenting in full: “The Single Payment System (SPS), as part of the EU Common Agricultural Policy (CAP), places obligations on land managers to sustain good environmental conditions. For that reason, the Department of Agriculture, Food, and the Marine (DAFM) proposed the Rural Environmental Protection Schemes (REPS) for farmers to integrate environmental considerations with agricultural objectives to prevent negative impacts on the environment. A new REPS scheme was introduced by the Department in February 2021. The new scheme is aimed at environmental sustainability, and is now operational, as the Agri-Climate Rural Environment Scheme (ACRES) “to help address biodiversity decline while delivering an income support for up to 50,000 farm families in Ireland” (published by DAFM, 11 August 2022, with last update 3 September 2025). The new scheme will be a marked departure from its predecessors, GLAS and AEOS. Payments will now be based on the environmental quality of fields and ditches.

DAFM also promotes enhancement of farm management procedures and strategies. With production in mind, they proposed Food Wise 2025 (DAFM, 2015) increasing productivity and primary output in the agriculture, fisheries, and forestry sectors, enhancing market position, while also increasing export targets (DAFM, 2020). Arterial Drainage Maintenance is not a direct element of Food Wise 2025, but to “increase productivity and bring about more efficient agricultural practices; however, the upkeep of the channels from degradation (vegetation and silt accumulation, obstruction, bank slippage), is necessary to ensure the drainage scheme channels maintain their original design condition to facilitate the drainage purpose.” This clearly connects the potential impact from arterial drainage to the (beneficial) objectives of ‘FoodWise 2025’ (now replaced by ‘FoodVision 2030’,). It demonstrates a continued and primary focus of the OPW to support 'productive agriculture'. The section on peatlands is no more encouraging. After acknowledging the importance of Irish peatlands, and their widespread degradation and impact (NPWS, 2015), it continues that “the NPWS as part of the EU LIFE Raised Bog project and the National Raised Bog SAC Restoration Plan 2017-2022,

has shown that arterial drainage channels can be maintained through and around the periphery of bogs provided they are not deepened."

While praising Bord Na Mona's Peatland Action Scheme on bog restoration (brought about through EU pressure and the diminishing of Bord na Mona's financial viability), the Scoping Report reveals that (italics added here for emphasis) "Arterial Drainage Maintenance Activities (2022-2027) *aim to return the arterial drainage rivers and channel to its intended original design conditions.* The maintenance activities include the removal of obstructions, excess silt, and vegetation, and repairing bank damage or slippage. Although the direct impacts are not assumed to be significant, some of the Arterial Drainage Maintenance Activities (2022-2027) may impact on the hydrology of peatland. The lowering of the local water table can benefit and encourage peat cutting which can result in the drying out of the uppermost peat, increasing temperature, oxygen levels, and hence decomposition rate within surface peat. Subsidence of raised bog can occur because of both drainage and peat cutting." For turloughs (a priority habitat), the Scoping Report acknowledges "The continued maintenance of drainage channels has the potential to continue to degrade the status and condition of turloughs" (OPW, 2021a).

For forestry, the OPW Scoping Report states that the National Council for Forest Research and Development (COFORD), has "demonstrated that forestry is an important economic source in Ireland. They report that Irish wood as a fuel is contributing significantly to mitigating climate change", and further "Arterial Drainage Maintenance Activities can maintain the productivity and soil conditions of forestry land close to drainage channels. Maintenance of embankments preserves the level of flood protection offered to some commercial forestry land. Apart from climate change mitigation, forestry investment also provides a range of other public goods and services, such as biodiversity, recreation, and forests play a role in water protection and flood prevention." No critical assessment or alternative views are presented. The forestry section continues with a promotion of broadleaved forestry, with some very curious language: "Forest management practices, particularly afforestation with a focus on broadleaf and native woodland, have potential to provide environmental and economic benefits if managed sensibly. Potential impacts of afforestation on water quality should be included in forestry schemes such as the Afforestation Scheme, the Forest Environmental Protection Scheme (FEPS), and the Native Woodland Scheme (Forest Service, 2011a, b. c)." No mention is made in the earlier text of many well-known potential impacts on water quality from coniferous forestry in general or in Ireland (Allott et al., 2005).

The key environmental issues at the end of the land-use sections provide a summary of potential impacts from arterial drainage: "There are several issues that should be considered while planning and carrying out the Arterial Drainage Scheme and maintenance works:

- the extent and intensity of land drainage in both the uplands and lowlands could have an impact on the regime of the waterways and increase flood risk;
- inappropriate land management practices, especially on more sensitive soil types could lead to reduced water infiltration into the soil, resulting in an increase in surface water run-off;
- the management of grassland, semi-natural vegetation, wetlands, and woodlands can assist in the storage of rapid surface run-off and floodplain flows upstream of flood risk receptors;
- natural flood storage areas on floodplains including wetlands should be protected from development pressures; and

- inappropriate or intensive land-use practices can result in erosion, modification of channel geomorphology, or discharge of receiving sediments."

In the section on Soil and Geology the SEA Scoping Report (2022-2027) highlights as key environmental issues:

- "natural flood storage and attenuation areas on floodplains, including wetlands, should be further protected from maintenance activities;
- erosion and influence on land-use practices; and
- effect on hydromorphology (i.e., river channel and catchment flow and sediment regimes)."

Under the OPW 'Biodiversity Action Strategy' (OPW, 2022), it is recognised that drainage and flood defences may conflict with optimal delivery for biodiversity", but with the goal to maintain and contribute to its recovery. It then refers to developing strategic partnerships for the protection of biodiversity. This will presumably support the OPW in their stated vision that *"*Biodiversity will be a core consideration in all our plans and operations to deliver our primary functions, ensuring that we are contributors to biodiversity conservation through our policies, practices and people.", and that "Biodiversity will have been fully integrated, alongside climate change measures, as essential to our work." This statement is supported by a fairly extensive list of good intentions, notably including "actively utilising biodiversity conservation as a key consideration in effective hydrological management regimes and will have developed more knowledge and application of Nature Based Catchment Management Solutions such as the use of wetlands for slowing the flow, making a large contribution to restoring ecosystem services."

The strategic action plan for biodiversity is elaborated with specific actions and key performance indicators. The High Priority actions, however, should already be expected in fulfilling statutory obligations. The ambitions have merit but appear to be merely an affirmation of activities already identified under the National Biodiversity Action Plan.

At the formal launch on 12th May 2022 of the Biodiversity Action Strategy (OPW, 2022), a statement from Minister Patrick O'Donovan read:

"We are learning more about nature and our dependency on nature, all of the time. Although the research shows us that 87% of Irish people understand the benefits of engagement with nature for their health and well-being, more than half the adult population don't know or aren't sure how to help support biodiversity. We need to do more. As an organisation, the OPW is committed to doing more to protect and enhance Ireland's biodiversity. The publication of our new Biodiversity Action Strategy is a vital step which will guide our work as we meet this challenge, whether designing or adapting lands, buildings or waterway structures to provide homes for wildlife wherever possible. We also encourage the public to help us as we work across all OPW sites to secure the future for biodiversity in our country."

The strategy is a consequence of the creation of the OPW Biodiversity Steering Group in 2019, to strategically address biodiversity issues. The Foreword to the strategy document includes mention of flood risk management and how "specific work practices to conserve and promote biodiversity; Strict adherence to EIA and SEA requirements where necessary – particularly relevant to major projects and works within catchments that may have wide reach; EIA and SEA requirements where necessary, particularly relevant to major projects and works within catchments that may have wide reach; work(ing) with IFI in freshwater systems to prevent damage from works and build in habitat enhancement where possible.

For the WFD and Flood Directive, the relevance to OPW as stated in the strategy is that: “OPW works extensively within freshwater and coastal environments.” With respect to biodiversity and hydromorphology, the strategy includes the “relevance” to OPW of “Strict adherence to screening and assessment of projects to take account of Natura interests. Consideration of conservation objectives of Natura sites on OPW land and the need to participate in appropriate management.”

The new strategy outlines the responsibilities of OPW in that: “The legal obligations placed upon Ireland are enshrined in the National Biodiversity Action Plan 2017-2021. Public bodies, such as the OPW, are required to implement Government policy and these obligations include the delivery of actions to contribute to the achievement of the NBAP. A biodiversity duty is held within the Habitats Regulations 2011, where Regulation 27 provides that all public authorities have a responsibility to avoid the deterioration of natural habitats and species protected under the Birds and Habitats Directives, and to exercise their functions and statutory powers in compliance with the Directives’ requirements”, and also recognising that “The OPW already engages in positive biodiversity measures, but recognises that it can and should go much further; this strategy aims to build on that understanding.”

This statement has particular resonance with information provided in our report and is encouraging in so far that it indicates a commitment to better practice and consideration of biodiversity, which *de facto* includes the ecological integrity of Ireland’s water bodies. The strategy is explicit in that “duties [are] driven by a statutory responsibility [and] underlying legislative framework may conflict with optimal delivery for biodiversity“, and that “Finding a balance between delivery of core purpose and an effective approach to biodiversity protection or enhancement is challenging.”

The opportunities for a more aware and engaged OPW are clear. In a series of metrics reported on attitudes of OPW staff, on average 63% considered looking after biodiversity as favourable, while this was 71% for staff engaged in flood risk management. Overall, 86% of respondents felt OPW could do more to protect biodiversity. Over 300 staff elected to seek further input into the Biodiversity Action Strategy through direct discussion of biodiversity issues.

Case studies used in the OPW Biodiversity Action Strategy document includes the Clonakilty Flood Relief Scheme as “an example of where a more natural flood solution was feasible that would minimise biodiversity loss while still providing effective protection from flooding. This was achieved through the provision of a storage reservoir that holds flood water and allows slow release to avoid impact on the town.” The OPW self-assessment of the scheme was that: “While this measure does not completely mitigate flood risk, the hard defences required are at a greatly reduced scale. The flood storage area brings some biodiversity gain, but the main gain is a less engineered channel within the town, and more connectivity between nature, people and the river corridor. While this may not be possible in every case, integrating biodiversity into decision-making has helped create a more sympathetic solution.” Our report’s assessment is presented in Section 5.3 below.

A further Case Study presented is the OPW’s ‘Drainage Maintenance & Construction Environmental Guidance’ (Brew and Gilligan, 2019), presented as: “a good example of the OPW setting the national standard for working in rivers and communicating good practice.” It is recognised that: “Ongoing action to identify enhanced training and guidance for operators will be important, alongside examining the systems as a whole to ensure statutory compliance and effective drainage without compromising the best opportunities for biodiversity.”

The cooperation with IFI through the Environmental River Enhancement Programme (EREP) is presented as “providing best practice for work methods that enhance and restore river corridors and fish passage” and “where multiple goals can be achieved by integrating complementary skills and expertise.” However, it has been pointed out in preparation of this section that the Logie fish counter on the River Maigue, Co. Limerick shown on page 3 of the OPW report, can itself act as a barrier to fish migration. IFI produces a report on the operation of all its fish counters claiming that the one on the Maigue River works well, but that “counting of fish in the winter floods is very limited” (IFI, 2021). Other views are that the IFI and OPW fish counters and other barriers hinder migrations of a number of species. See also Section 4.1 below).

The legacy of past actions and communication at the highest level, undoubtedly ‘raises the bar’ for future actions in terms of hydromorphology and the OPW. A series of important and time-bounded actions are presented in Chapter 9 of the OPW Biodiversity Action Strategy (OPW, 2022). As indicated in the Strategy and discussed above (Section 2.2.7) the fundamental remit of arterial drainage and flood defence management leads to conflicts between the implementation of the WFD and the OPW operations, policy decisions on the designation and management targets of HMWBs, and an overall nature-based approach into the future. The demonstration of the OPW Biodiversity Action Strategy will be through the implementation of the third cycle RBMP Water Action Plan, outlined in Chapter 4 below, and published by DHLGH (2024a).

Arterial drainage and Lamprey

The three lamprey species found in Ireland, *Petromyzon marinus*, *Lampetra fluviatilis* and *Lampetra planeri,* are Annex II species, under the Habitats Directive. King et al (2008) concluded the potential for impact on lamprey in any channel subject to drainage works, but also astutely reflected that: “The 1945 Arterial Drainage Act deems that channels within drainage schemes should be retained... ‘in proper repair and effective condition’…” In theory, this could mean that maintenance on channels could cause a recovering or naturalising water course to revert to its immediate post-scheme appearance with perfectly-formed trapezoidal cross-section, removal of any in-stream features or obstructions, removal of any tree growth, and a cross-section and bank slopes devoid of plant cover.” They continue: “A potential difficulty arises in the context of the obligations of National Parks and Wildlife (NPWS) to maintain the favourable ecological status of Annex II species (under the EU Habitats Directive) within SACs with the obligations of OPW (under the Arterial Drainage Act, 1945) to maintain channels in proper hydraulic condition.”

Maintenance of river channels as part of arterial drainage works will have an impact on juvenile lamprey present as these occur in silting habitats at all times of the year. Lamprey transform from juveniles to adults in August – September and could potentially have better chance to avoid lethal disruption of habitat. Migrating lamprey are restricted by chemical or physical, barriers *enroute* from coastal areas to their spawning grounds, although the brook lamprey (*Lampetra planeri*) is less affected by river barriers than the other two species (Cowx et al., 2009). River lamprey (*Lampetra fluviatilis*) migrate in autumn-winter during high flows and can pass weirs and barriers that may be obstacles during low flow (King et al., 2008).

Adult lamprey lay their eggs in nests in gravel, which hatch after 3-4 weeks when they drift downstream to areas of silt in which they burrow. Here, the filter-feeding juveniles remain for between three and seven years and are particularly vulnerable to dredging or any other river

maintenance (King et al., 2008). OPW's maintenance programme, therefore, can have severe adverse impacts on juvenile lamprey.

Mitigation methods following published guidance and adequate training of river crews can reduce impact on the fish, but the extent of achieving that is likely to vary in different settings. The latest Guidance (OPW, 2021a) is: "The presence of Lamprey must be checked using the OPWs Environmental Mapping for previous records of Lamprey before any in-channel work takes place. If new Lamprey are encountered, the machine driver informs the Foreman, and the location and abundance of Lamprey should be noted in a Weekly Record Card. To reduce potential impacts three approaches are suggested: 1) skip a defined stretch of channel; 2) confine maintenance to 2/3 of the channel to retain marginal vegetation; and 3) silt intact and maximise the use of weed cutting buckets."

2.2.9 Summary River Assessment

An overview of the hydromorphological processes and measurable variables for river assessment provided by the REFORM project (Garcia da Jalón, 2013) is shown in Figure 14 and elaborated in Figure 15. It clearly highlights the multidimensional nature of evaluating hydromorphological alteration, and it is not, therefore, surprising that the search for relevant metrics to apply to the WFD has been difficult (see Sections 1.3 and 2.1).

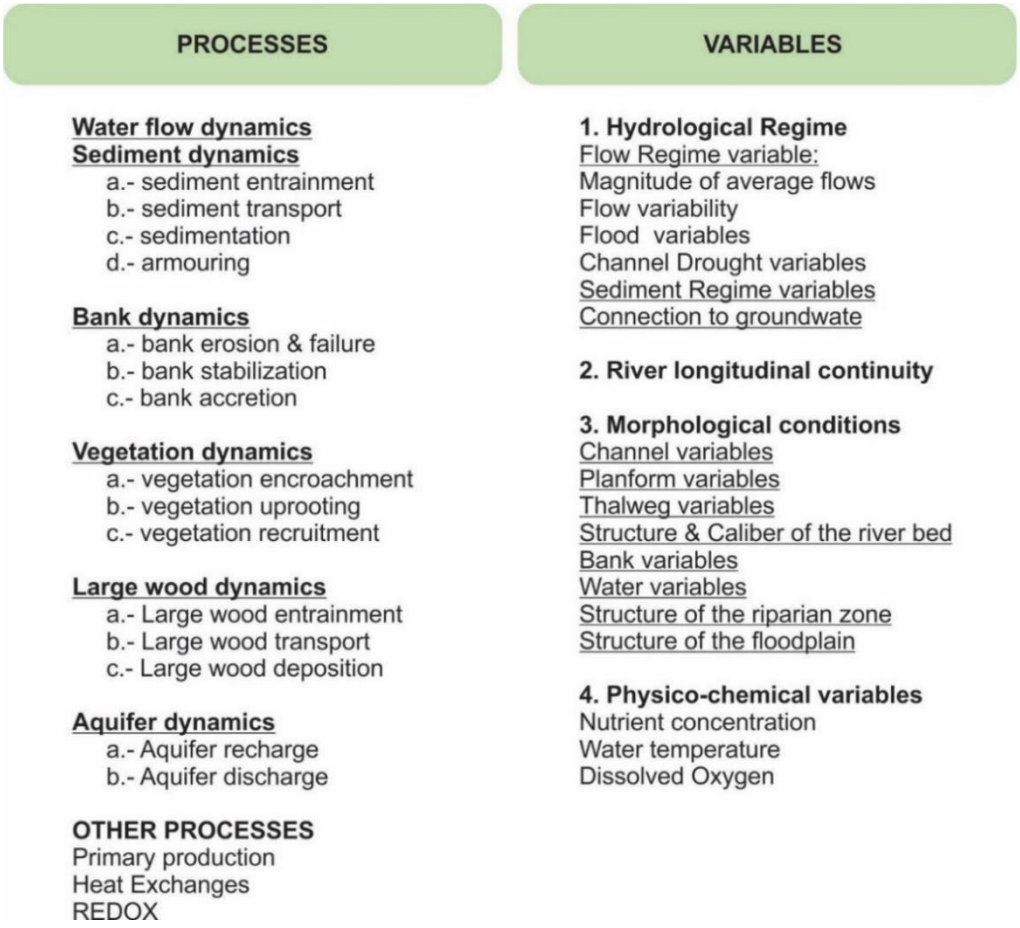


Figure 14. Hydromorphological processes and associated variables (reproduced from Garcia de Jalon, 2013).

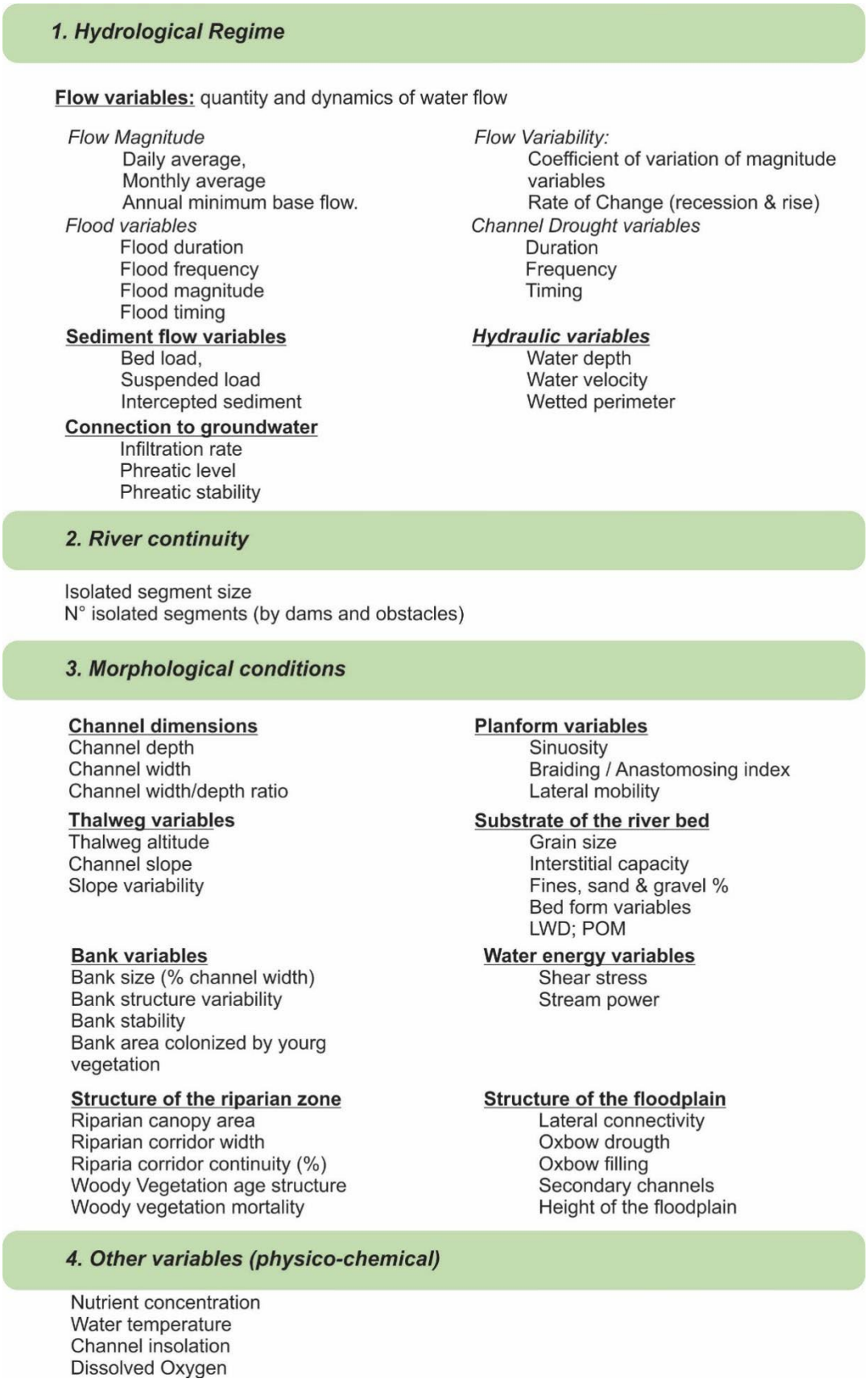


Figure 15. An elaboration of the variables in Figure 14. Reproduced from Garcia de Jalon (2013).

Hydromorphological variables can be recorded at different spatial scales following Feld (2004):

- **"catchment-related** variables consider the whole catchment from the stream source to the sample site. Feld (2004) listed 27 different variables including distance to source, stream order, catchment geology, and catchment land-use;
- **reach-related** variables, whose longitudinal dimension (up-/downstream) depends on the size class of a stream type. For small streams (10-100 km^2 catchment area), a stretch of 5 km up and downstream of a sample site was taken into consideration (= 10 km), whereas in the case of middle-sized streams (100-1000 km^2 catchment area) a stretch of 10 km up-and downstream was analysed (= 20 km). Feld (2004) listed 22 different variables including percent (%) length of impoundments, lack of natural vegetation, or water abstraction; and
- **site-related** variables were recorded for each sampling occasion separately. They refer to a stretch of 250 m up and downstream (= 500 m) of the sample size for small streams and 500 m up and downstream (= 1000 m) in the case of middle-sized streams. Feld (2004) listed 32 different variables including habitat composition and physico-chemical variables."

Given the complexity of interacting factors and geomorphological diversity of a river, difficulties in hydromorphological assessment, even for 'type-specific' ecological assessment, is understandable. Based on the information gathered by the REFORM project, Kemp and Sandin (2022) provide a summary of the recommendations of Rinaldi et al. (2016) on three typologies that could be better used to encompass morphology, flow regime and floodplain character:

- **"morphological typology**: an extended river typology with 22 morphological types, based on confinement – whether lateral movement of a river is constrained by its valley (confined, partly confined, unconfined), dominant bed material calibre – how coarse or fine its substrates are (bedrock, boulder, cobble, gravel, sand, silt), and planform - the pattern it makes in the valley when viewed from above (straight-sinuous, meandering, pseudo-meandering, wandering, braided, island-braided, anabranching);
- **flow regime typology**: based on intermittency, river-aquifer interaction, prevailing type of river-flow source; and
- **floodplain typology**: based on river energy and cohesive or non-cohesive floodplain sediments (Nanson and Croke, 1992; Rinaldi et al., 2016). An additional useful method, published after the REFORM project, is the floodplain evaluation matrix (FEM) (Habersack and Schober, 2020) focusing on floodplain functionality and damage, and considered from a flood-mitigation and hydrograph smoothing perspective."

For critical reaches the following, adapted from Kemp and Sandin (2022), is recommended for four types of hydromorphological assessment:

- **"hydrological** assessment - to understand changes compared with previous or unaltered conditions. Methods are based on "Indicators of Hydrologic Alteration" (Poff et al., 2010);
- **morphological** assessment to consider processes, change and impacts. A number of methods tackle this. The MQI (Morphological Quality Index) (Rinaldi et al., 2015a), applied at the river reach scale (a fairly morphologically homogeneous zone that usually stretches over kilometres – whereas physical habitat surveys are usually carried out at a smaller scale), is probably the most comprehensive, and gaining traction as a useable technique across Europa, including Ireland. MQI uses 28 indicators based on channel forms, processes, sediment and wood fluxes, vegetation, channel mobility, channel adjustment, historical and future changes, and dynamic equilibrium (reference condition) to evaluate the reach in terms of: 1) Geomorphic functionality; 2) Artificiality; and 3) Channel adjustments (morphological changes indicating instability due to human impacts);
- **riparian vegetation** assessment – as vegetation is fundamental to hydromorphological processes, it must be included (e.g. Riparian Quality Index (González del Tánago and García de Jalón, 2011), River Habitat Survey (Raven et al., 2002)). Among other vegetation features, vegetation processes, such as age diversity and plant regeneration are assessed; and
- **geomorphic unit** assessment – assesses the presence and diversity of physical habitats, thereby linking hydromorphology with biology, using e.g. GUS – Geomorphic Units survey and classification System (Rinaldi et al., 2015a)."

In any given catchment and for any given section of the river, multiple pressures and alterations of river hydromorphology can occur, and at different scales of intensity. The ecological response will reflect a combination of pressures, and be modified by local geomorphology. Assessing multiple pressures on aquatic ecosystems and understanding their combined impact on the ecological status is challenging, especially at a large scale, though crucial for the planning of effective policies (Grizzetti et al., 2017).

Alonso et al (2013) provide examples of assessing hydromorphological alteration for a series of scenarios. We reproduce here (Figures 16-20) an example they used for spatial planning and rural development, to illustrate their approach. The metrics used at the site provide a recommendation for the types of measurements needed.

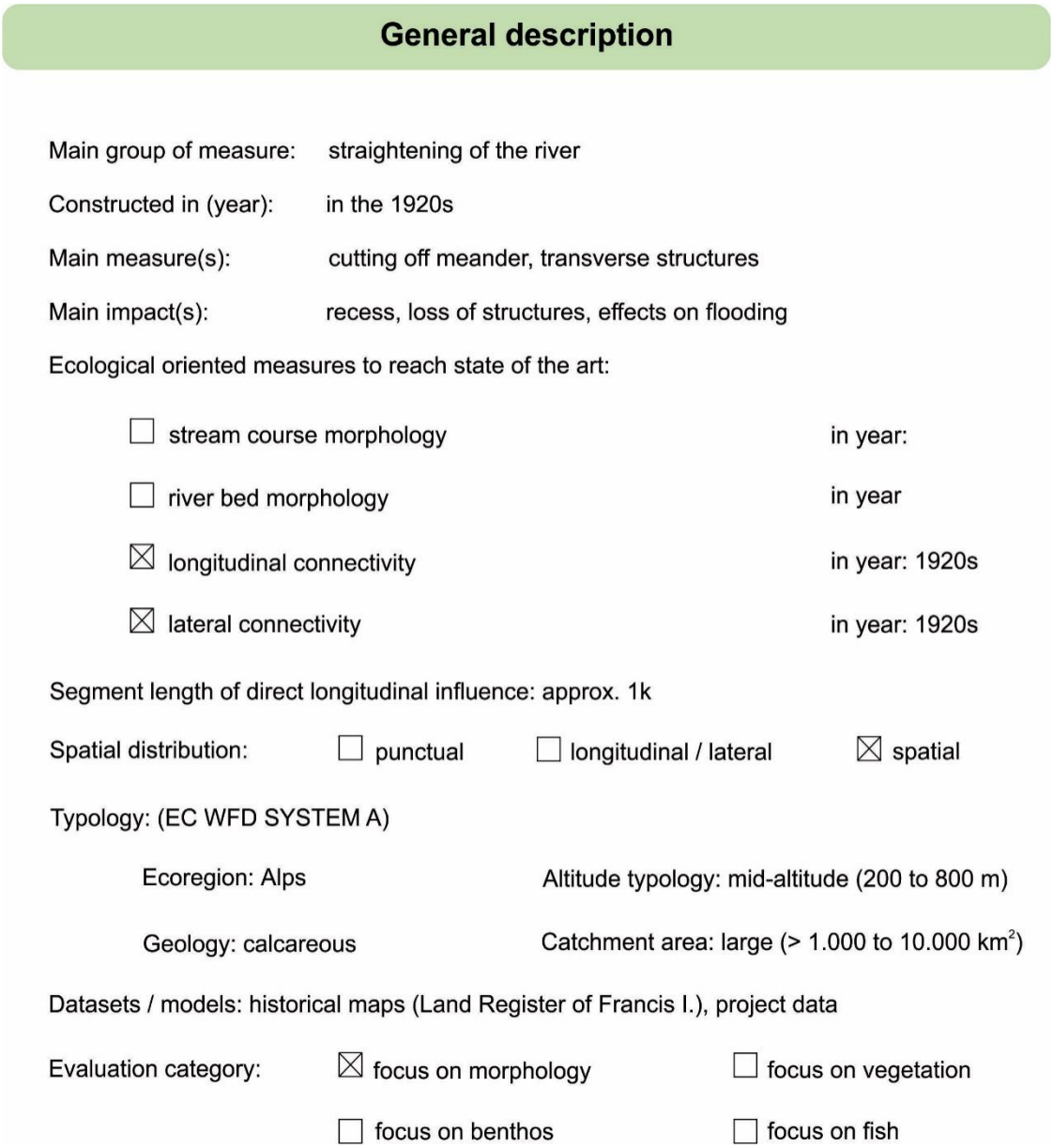


Figure 16. Example of general description and historical record of hydromorphological alteration. Reproduced from Alonso et al. (2013).

Overview - site plan



Key indicators for evaluation scale

List of key indicators:

- Dynamics of flooding
- Slope / gradient
- Length of shoreline
- Water depth
- Flow velocity
- Wetting
- Lateral extension
- Sediment transport
- Structure - geometry

Assessment table

Hydrological indicators

Runoff/discharge	Change of flow regime: ☒ No ☐ Yes Mean annual discharge (m2/s): ☐ 1 to 20 ☒ >20 to 100 ☐ >100 to 500 ☐ >500 Lowflow duration (month, period): winter Occurrence of max. month: June
Dynamics of flooding	Effects on flood peak discharge ☐ no effects ☐ minor interference ☒ modrate interference ☐ high interference

Figure 17. Status of stream morphology: a) in the early 19th century, and b) in 2010. Reproduced from Alonso et al. (2013).

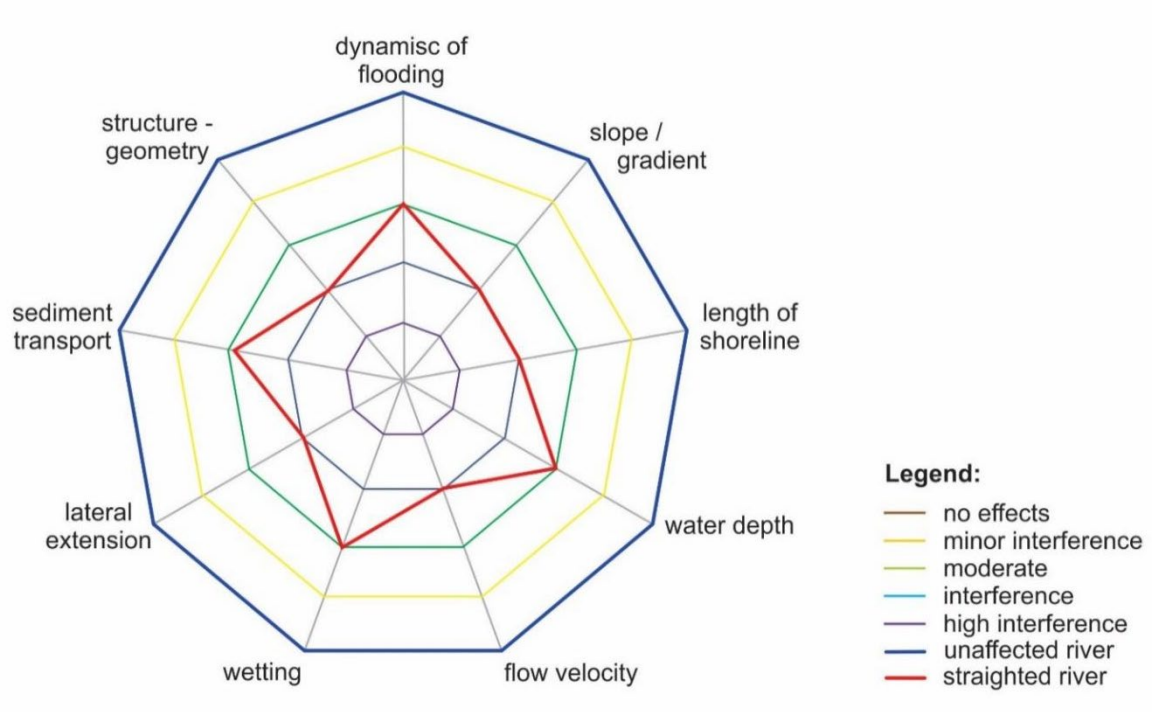


Figure 18. A "spider" diagram of the extent of hydromorphological alteration on a river reach. Reproduced from Alonso et al. (2013).

Hydromorphological indicators				
Fluvial landform	Slope / gradient	☐ no effects	☐ minor interference	☐ moderate interference	☒ high interference
	Length of shoreline	☐ no effects	☐ minor interference	☐ moderate interference	☒ high interference
Water depth	Variation of water depth	☐ no effects	☐ minor interference	☒ moderate interference	☐ high interference
Flow velocity	Flow velocity distribution	☐ no effects	☐ minor interference	☐ moderate interference	☒ high interference
Lateral	Wetting	☐ no effects	☐ minor interference	☒ moderate interference	☐ high interference
	Spatial extension on the aquatic area	☐ no effects	☐ minor interference	☐ moderate interference	☒ high interference
Sediment	Sediment transport	☐ no effects	☐ minor interference	☒ moderate interference	☐ high interference
Structures	Diversity of geomorphic structures	☐ no effects	☐ minor interference	☐ moderate interference	☒ high interference

Figure 19. An assessment of hydromorphological alteration using simple indicators. Reproduced from Alonso et al. (2013).

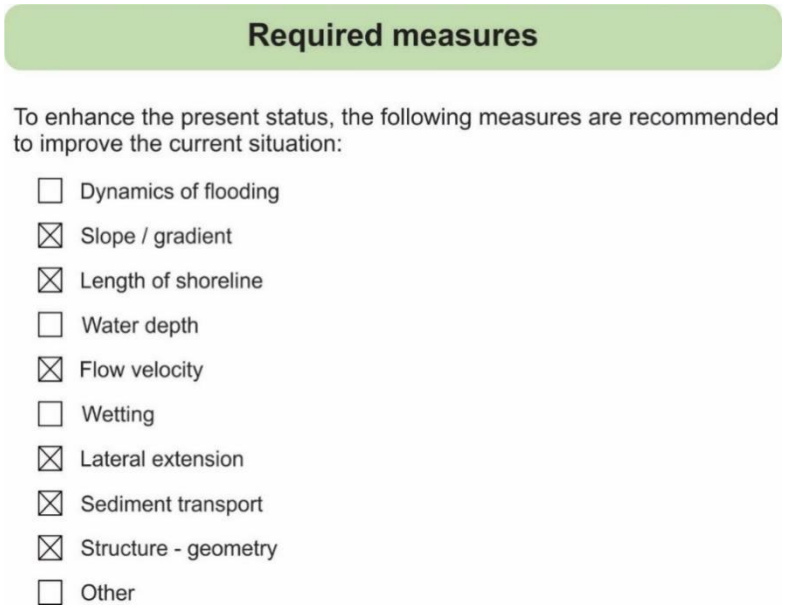


Figure 20. An example of a simple checklist of recommended interventions for restoration of a river reach. Reproduced from Alonso et al. (2013).

2.2.10 Biological trait assessment

The biotic relationship to hydromorphology in rivers is well established, in terms of flow regimes and hydraulics, and which occur within habitat patches across a few meters 'meso-scale' to larger scales of e.g. river flow dynamics. These harbour distinct biotic communities of invertebrates, plants and fish (Chambers et al., 1991; Dawson et al., 1999; Gurnell et al., 2014, 2010; Karr, 1981; Moir et al., 2004), and within identifiable functional habitats (Harper et al., 1998). Models, indices and multimetrics have been developed to assess response of biota to hydromorphological pressures (Hering et al., 2006; Turley et al., 2016), but using them in a general way in complex habitats with a variety of pressures has been generally elusive. While significant correlations between environmental pressures and biological responses over large datasets can be found, using that to guide management, especially across sites and for hydromorphology, is unreliable (Demars et al., 2012; Göthe et al., 2019; Sandin and Johnson, 2004; Woodward et al., 2013).

Macrophytes surveys often reveal a small number of species, and while species may differ across sites they will display similar ecological traits such as growth form. Macroinvertebrates, while sensitive to organic pollution, and through a similar mechanism, nutrient enrichment, have also shown some responses in rivers that could be attributed to hydromorphological alteration (Friberg et al., 2009) or changes at broader ecological level of Functional Feeding Groups (FFGs) (Dolédec et al., 2011; Masese et al., 2014; Statzner et al., 2001). A trait approach to river assessment and response to hydromorphological alterations has potential for use in habitat assessment. Using traits alleviates the need for complex taxa community scores, which also need taxonomic expertise and use of multivariate techniques for analysis. They also have the benefit of being (largely) independent of biogeography (Friberg et al., 2016; White et al., 2017).

2.3 Surface water bodies: Lakes

Under the WFD, hydromorphology of lakes comprises the hydrological regime (quantity and dynamics of flow, residence time, connection to the groundwater) and morphological conditions (depth variation, quantity, structure and substrate of the lakebed, structure of the shore). Traditional views on the ecology and physical structure of lakes have been based very much on open-water physical structure and trophic dynamics, and are strongly influenced by a northern hemisphere paradigm of summer stratification, winter mixing, or isolation by ice. The earliest limnologists focussed on deeper lakes. Shallow lakes were a separate entity, often attended to by a different crew of scientists. The importance of the littoral zone for lake ecological functioning has been largely overlooked (Brauns et al., 2007; Porst et al., 2019; Vadeboncoeur et al., 2002). While these perceptions can be over-simplified, they by and large governed the approach to lake management, with its focus on beneficial use of water supply, fisheries and recreation. A sub-sector of interests paid attention to reservoirs, and their use for water storage, hydroelectric power generation and recreation. The identification and management of impact on lakes were in response to how these ecosystem services were degraded by anthropogenic activity. In Europe, the WFD shifted the thinking dramatically because of the need to assess biological elements as measures of ecosystem health and the necessity to develop the methods to do so. More so than rivers, there was a need to develop techniques to assess hydromorphological alteration, with an additional need to focus on the littoral zone. The starting point for a good understanding of any individual lake is reasonable estimation of lake bathymetry, volume and physical structure.

Hydromorphological alteration of lakes arise mainly from the management of water supply and off-take, water level fluctuations and the structure of lake-side banks and riparian zones (Rowan et al., 2006). Residence times of natural lakes are subject to the use of water, or impoundments upstream. A separate category are the reservoirs themselves, designated under the WFD as AWBs or HMWBs. However, following the creation of a lake-like AWB or HMWB, it would be unwise to equate ecological structure and process with true lakes (Blocksom et al., 2002).

2.3.1 The pelagic zone

Lakes and reservoirs are subject to similar structural features, although the extent and details of these can vary markedly both within and between these categories. Natural lakes exist along a continuum from shallow to deep, with some of the shallower ones being temporary ephemeral water bodies subject to seasonal or longer periods of drying out. Reservoirs, are often subject to more direct management for hydropower of water supply, affecting particularly level fluctuations and internal circulation patterns. Within lakes and reservoirs, habitat structure comprises a littoral zone that moves to a deeper sub-littoral (or demersal) zone and then to the open-water or pelagic zone. Traditional models of lake structure (Figure 21) divided the pelagic into an upper epilimnion distinct, or stratified, from the deeper hypolimnion, separated by a temperature and/or salinity gradient that affects water density, with an intermediate transitional zone, the metalimnion. Under the classic model of Figure 21, the lake went through recognisable seasonal changes, that also were drivers of lake productivity cycles.

While this very simple model has value in describing the physical structure of the lakes, it does not account for very deep lakes with a permanent (and deoxygenated) hypolimnion or for those shallow lakes that are sufficiently shallow so that stratification of, even multiple, temperature layers are infrequent and usually temporary because they are easily broken down by surface wind.

However, even short periods of stratification can have profound effects on the biogeochemical and productivity cycles if these lead to reduction of oxygen concentrations, surpassing some chemical thresholds that release nutrients from the lake sediment. This interaction between nutrient status and physical structure has significant implications for the ecological classification, and restoration, of lakes (Jeppesen et al., 2007). Reduced oxygen concentrations in the deeper water of lakes, the profundal, have direct impact on the organisms that live there, which can also be used as indicators of water quality and ecosystem health (Bazzanti et al., 2012; Saether, 1979; Wiederholm, 1980). The effect of eutrophication on the organisms of the profundal zone is affected by lake hydrology and sediment structure (Jyväsjärvi et al., 2009; Pilotto et al., 2012).

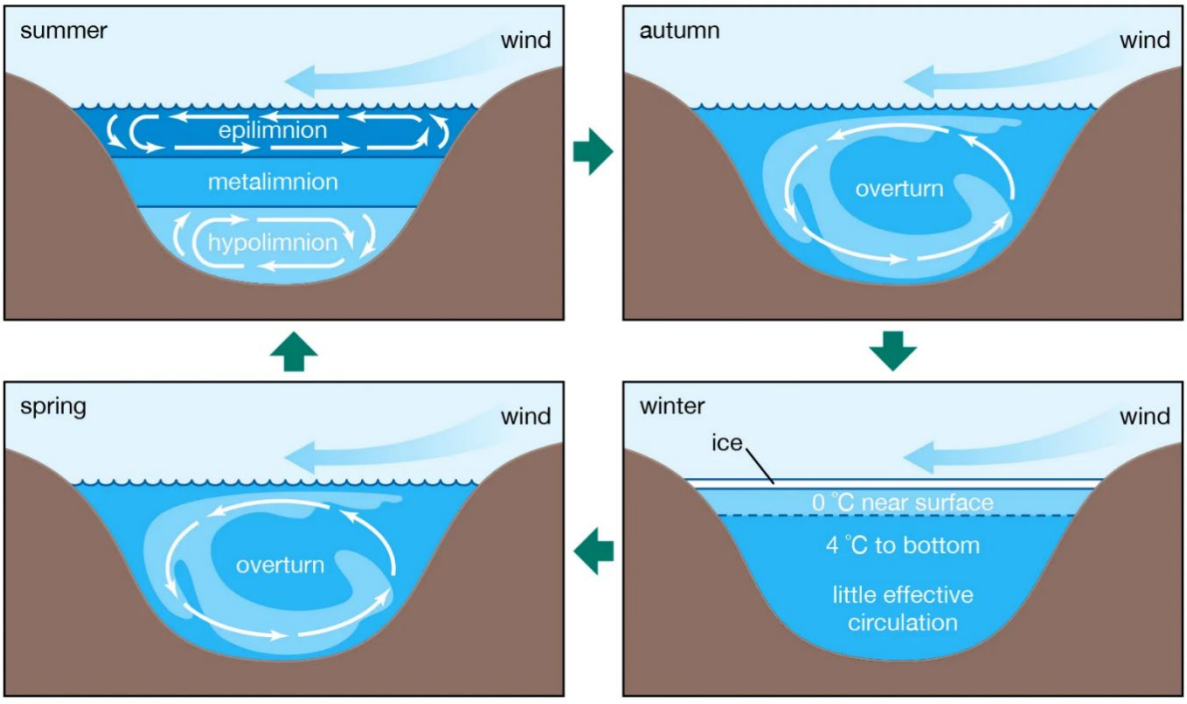


Figure 21. The classic temperate model of lake open water physical structure. Source: Brittanica.com.

The starting point for a good understanding of any individual lake is reasonable estimation of lake bathymetry, volume and physical structure. Hypsographic curves (Rounds et al., 2023) provide a means to visualise bathymetry as the relationship between lake area and water depth, and can be easily compared across lakes. A hypsographic curve also provides important information for modelling processes in lakes that can change with depth, such as nutrient transformations. While measuring lake bathymetry may seem like a simple data collection exercise, it is time consuming and resource intensive.

It is, nevertheless, essential for estimates of hydrological patterns and changes, from e.g. water abstraction. Work by Moe et al.(2016) assessing environmental risks of Unconventional Gas Exploration & Extraction (UGEE), collated bathymetries and lake volumes from 33 lakes, and are available in the public domain. However, a publicly accessible repository of lake bathymetry maps collected by the EPA and other agencies would be extremely useful for lake research and management.

For the WFD, hydromorphological assessment has been stimulated by the WFD in recent years (Argillier et al., 2022; Argillier and Carriere, 2023; Carriere et al., 2024). This has included progress on methods to assess water level regime, although those on changes in stratification, surface/groundwater connection and planform pattern, and estimates of residence time require further development and application. Argillier et al. (2023) observed that "small number of methods considering residence time was surprising since it can be easily approximated." This is from catchment and meteorological data. However, as they point out, estimates of bathymetry and other field measurements can be time consuming. See also Irvine and Katsanou (2024) in their summary of hydromorphological work on Irish lakes.

While reservoirs tend to be sufficiently deep to serve their function, nutrient enrichment and deoxygenation in the hypolimnion, and the proliferation of undesirable algae and cyanobacteria in the epilimnion, is a notable global problem. A common management response is artificial aeration to avoid the release of deoxygenated waters downstream or to safeguard public health. The release of hypolimnetic water from reservoirs can have a consequence, often for many kilometres, for downstream river ecosystems (Kunz et al., 2011).

2.4 Groundwater bodies and GDEs

Groundwater is an important hydrological element for maintaining flow, quality and ecology of many surface waters, and vegetation structure of surface ecosystems connected to it. Groundwater and surface water are mostly interconnected, with many rivers dependent on groundwater for their minimal (base) flow. Groundwater may provide ecologically important chemical environments in a river such as high alkalinity, low nutrient content, low variability of pH and water temperature (Tw) and an oxygenated riverbed. The importance of the groundwater input to the ecological or chemical status of the surface water body can be variable, but generally increases with the percentage of groundwater contribution to the total water supply to the surface water. As a result, even in the aquifers of lower importance in terms of water reserves, the groundwater contribution can be significant, especially during dry periods.

Understanding the interactions between groundwater and surface water is needed for integrated and effective water resources management (Winter, 1995). For example, hydrological exchanges between near-channel and in-channel water, or between the river channel and the hyporheic zones connecting to groundwater can be important for nutrient dynamics. Changes in groundwater quantity or quality can lead to poor chemical status of the groundwater body, with impact on the ecology of connected habitats.

The interactions between surface and groundwater bodies are controlled by groundwater flow systems of different scales, soil and geological composition that the water passes by when seeping back to the ground, and the rate of transpiration that takes place directly from groundwater around the perimeter of the surface water body. Transpiration limits potential

groundwater inflows or consumes water from surface water bodies (Sophocleous, 2000; Winter, 1999).

The interconnection among rivers, lakes, and GDEs with groundwater is governed by the positions of the water bodies with respect to groundwater flow systems, local geology, and climatic conditions (Winter, 1999). Topography can affect hydraulic head, and hence pressure and flow rate. Geology and geomorphology on the other hand regulate the residence time of groundwater mainly through porosity and permeability.

The residence time and geology define chemistry and biogeochemical gradients in an aquifer. Based on predominant regional groundwater flow, Larkin and Sharp (1992) classified stream-aquifer systems into three categories: a) the underflow-component dominated where groundwater flows parallel to the river in the same direction as the river flow; b) the baseflow-component dominated where groundwater flows perpendicular to or from the river; or c) mixed. Hence, the predominant component of groundwater flow can be extracted from their geomorphological characteristics, such as channel slope, river sinuosity, degree of river incision through its alluvium, the width-to-depth ratio of the bank full river channel, and the character of the fluvial depositional system.

While the exchange of water between groundwater and rivers is a key component influencing river processes (Baron et al., 2002), little is generally known about how groundwater/river exchange influences river ecology (Boulton, 2020; Boulton and Hancock, 2006). Disconnection of groundwater affects the hydrological regime of the river and any associated GDEs. Underlying geology plays a crucial role, affecting surface water flow conditions over very large scales, and such that the hydrological catchment is seldom the same as the hydrogeological catchment.

Several pressures can potentially alter the hydrological connectivity of the subsurface habitats from surface water bodies as well as from the underlying aquifer, heavily impacting the hyporheic invertebrate communities. Strona et al. (2019) in their AQUALIFE software introduced a component called the ‘Hydrological Hydromorphological Risk’ (HHR) to identify and score potential risks posed by human-induced alterations of the hydrological connectivity of specific GDE types such as hyporheic zones of streams and rivers and groundwater-fed springs. In order to compute the HHR, the pressures generating effective impacts on GDE invertebrate faunas, with a distinction between those on the hyporheic zones (Table 5) and those affecting springs (see section 2.4.2) were taken into consideration.

Groundwater abstraction, alteration of rivers, urbanisation, and land-use changes are among the pressures that may affect groundwater discharge to rivers. Land clearing results in lower evapotranspiration, higher surface run-off and rate of erosion, and lower groundwater infiltration and base flow in streams (Shen et al., 2013). Large groundwater abstractions have a detrimental effect on rivers and wetlands (Acreman et al., 2000), and springs (Janusz and Pociask-Karteczka, 2017). This may pose significant risks to the respective aquifers, and hence the rivers’ baseflow (Taylor et al., 2013). Groundwater abstractions have been shown in many northern European regions to have a large impact on river baseflow: for example, 11% and 52%, respectively, in Denmark (Fyn region) and Scotland (East Lothian area), and 5-56% in the Netherlands even at what is considered modest abstraction rates (de Louw et al., 2000; Henriksen et al., 2007; Ward and Fitzsimons, 2008). Riparian vegetation is affected by the lowering of the water table (Gurnell et al., 2014). Measures for cross-profile constructions, dykes, channelisation, bank reinforcement and fixations, embankments and deepening change the length and transverse river profile and often disrupt connectivity with

groundwater. As a result, and as an example of the effect of these pressures, specific habitats can disappear (Table 5).

Table 5. Relevant pressures and related impacts for hyporheic habitats as in Guidance No. 35 of the WFD Reporting Guidance 2016, Annexes 1b and 8n (Strona et al., 2019).

Relevant Pressures: Names and Descriptions		**Impacts: Names and Categories**	
Hydrological alteration. Abstraction or flow diversion. Dams, barriers, and locks	Presence of transversal works with reduction of discharge flow rates (detention and/or diversion, dams, weirs) with reduction of discharge flow rates (detention and/or diversion, dams, weirs)	Alteration of discharge flow rates	HHYC-Altered habitats due to hydrological changes
Hydromorphological alteration	Presence of transversal works with reduction of discharge flow rates (detention and/or diversion, dams, weirs) limiting sediment and woody debris transport on the riverbed	Alteration of the longitudinal connectivity in sediment and woody debris in streams/rivers benthic and hyporheic zones	HMOC-Altered habitats due to morphological changes
Abstraction or flow diversion	Presence of solid walls and/or embankments limiting permeability with the alluvial plain of streams and rivers	Alteration of the lateral connectivity in streams/rivers benthic and hyporheic zones	
Dams, barriers, and locks	Concreted riverbed, presence of knick points in rivers or channels where the longitudinal (lengthways) slope of the bed suddenly steepens (incision), artificial riverbed aggradation, clogging, overexploitation of aquifers	Alteration of the vertical connectivity river/aquifer	
Physical alteration of channel/bed/riparian area/shore	Artificially straightened channel	Morphological alteration of the river stretch and riverbed sediment composition	
Groundwater alteration of water level or volume	Removal of perifluvial or riparian vegetation	Increase in riverbank erosion	
	Large woody debris removal	Large woody debris removal	

HHYC: impacts altering habitats due to hydrological changes; HMOC: impacts altering habitats due to morphological changes.

In groundwater-dependent vegetation (phreatophytes), root distribution and function cover a range of water regimes and availability of groundwater (Canham et al., 2012) and if water availability changes suddenly root systems may not adequately adapt (Canham et al., 2015). This results in either mortality or reduced productivity (Figure 22). Water table changes alter the ecosystem structure and community composition of GDEs, often opening up encroachment by invasive species (Froend and Sommer, 2010; Sommer and Froend, 2014).

Underlying geology accentuates the interaction between surface and groundwater. This can be particularly striking in karst regions (Bonacci, 2015), where there is a strong hydraulic connection between surface- and groundwaters (Katz et al., 1997). This is extremely relevant to Ireland (Figure 23), where 40% of total area is underlain by limestones, while 20% has intense karstification. Karst systems cover 30% of Ireland's water supply (Drew, 2018).

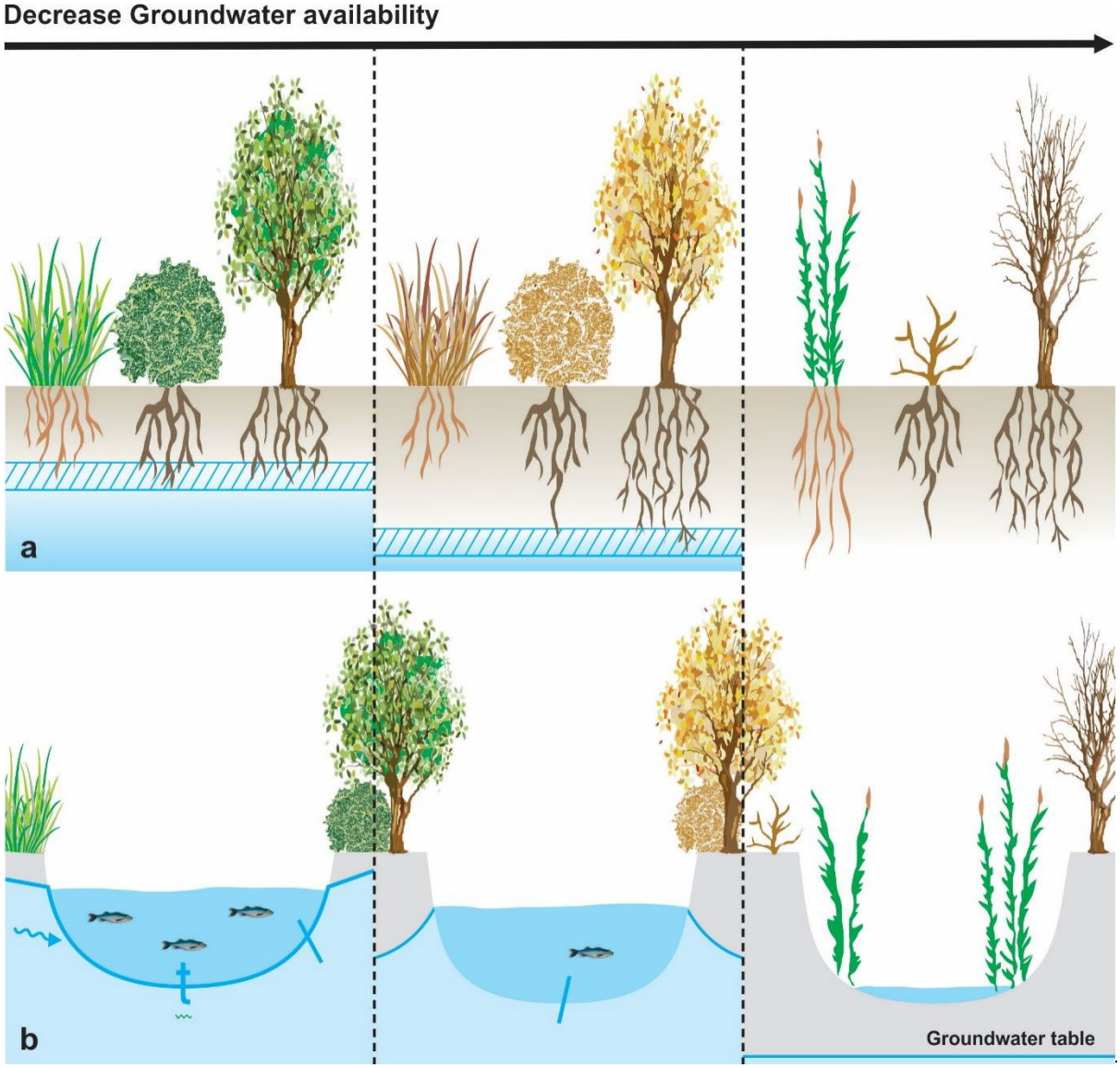


Figure 22. In the shortage of groundwater availability within terrestrial vegetation and interconnected surface water systems figure a. shows high productivity, a healthy population and high species diversity which gradually reduces over time from left to right in the diagram, and b. shows a decline in biodiversity from left to right (Rohde et al., 2017).

Changes in groundwater availability can have a huge impact on structure and function of connected ecosystems (Eamus et al., 2006; Eamus and Froend, 2006). An element of the groundwater that is often overlooked is GDTEs. These often comprise complex habitats adapted to variable water supply, but when water stress becomes extreme or prolonged progressive decline of biodiversity and a shift in the composition and function of vegetation can occur (Figure 22).



Figure 23. Fluvio-lacustrine karst near Gort (County Galway). Complex interactions between surface and groundwater characterise this karst (photo by OPW, Drew, 2018).

A representative example of surface- and groundwater interconnections in Ireland is the Pouladower Spring north of Ennis, studied by Coxon and Drew (2000) and presented graphically by Drew (2018) (Figure 24). The groundwater recharge area varies significantly along the hydrological year depending on the water level of the surface water bodies of the area i.e., the Fergus River and the lakes which lie along its course. In Figure 24, the main recharge area of the spring is given in green colour. During the period that the Fergus River displays high water levels, it supplies the local lakes and in turn, they supply the karst system through “swallow holes.” This results in an extension of the spring’s recharge area by 130 km^2 (orange-coloured area in Figure 24). This area, however, only temporarily feeds the spring (Coxon and Drew, 2000). In the past, the river flow took place underground between Corofin and Ennis (sinking river). Nowadays an artificial channel is constructed, in the frame of drainage works that took place in the broader area, so its current course at this place is artificial.

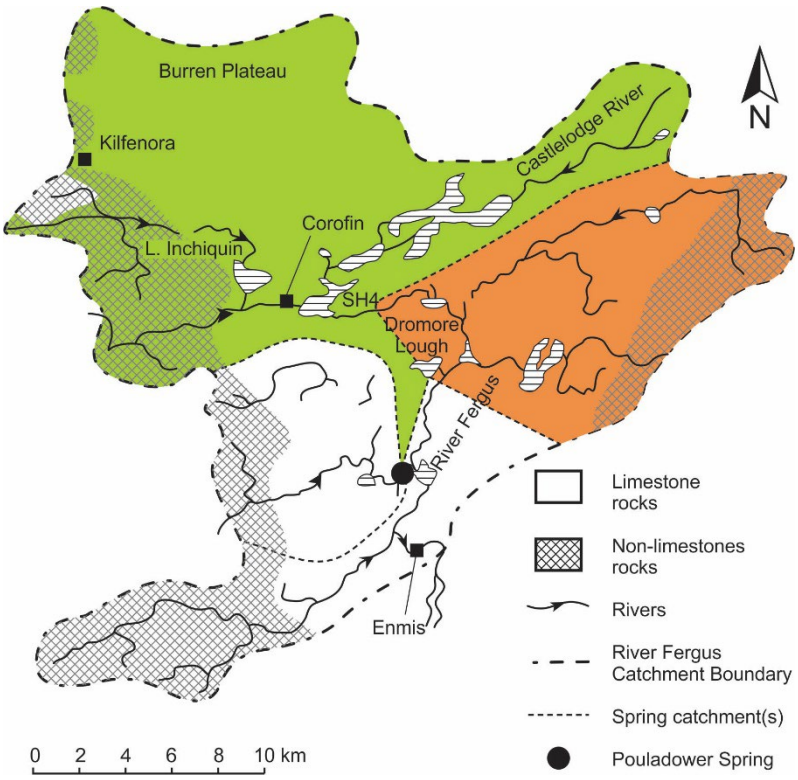


Figure 24. Partial contributing areas to the Pouladower spring under differing water levels in the River Fergus (Coxon and Drew (2000), from Drew (2018)).

Uncontrolled interaction between humans and karst landscapes can result in serious environmental problems (Figure 25). As the soil cover is often very thin in karst regions intense land-use and deforestation can cause soil erosion, and local agriculture can pose high risks of transfer of pollutants from surface to groundwaters. The Irish Burren karst plateau is a typical example of the delicate balance of hydromorphology between land-use and subsurface effects (Coxon, 2011; Drew and Magee, 1994). Groundwaters in karst landscapes are particularly vulnerable to pollution from point recharge through sinkholes or conduits that reach the ground surface, the presence of epikarst zones and the prevalence of conduit flow within karst aquifers. Epikarst allows rapid lateral movement of diffuse contamination to vadose shafts or storage of contaminants that can later on be released during an intense rainfall event that may lead to increased Total Dissolved Solids (TDS), nutrients, pesticides, and microbial contamination (Coxon, 2011; Mellander et al., 2013). For example, Drew (1996) investigated the threat of farm-related effluents on the underlying karst aquifer in the Burren and found that a large proportion of silage piles produced a potent form of effluent, greatly exceeding the other more commonly examined types of effluent in terms of its biological oxygen demand (BOD).

Land-use changes and agricultural intensification, irrigation and drainage schemes may lead to hydrological changes to karst aquifers such as recharge or discharge which in turn might lead to flooding or drying of some GDEs. For example, reduced water levels from drainage operations in the Western Irish limestone lowlands (Drew, 1984; Drew and Coxon, 1988) had serious ecological implications (Sheehy Skeffington et al., 2006). Furthermore, according to Drew (2008) in the Kilcolgan-Lavally catchment in East Galway, the decline in the water level by a couple of meters interrupted water supply to local springs (Drew and Coxon, 1988).

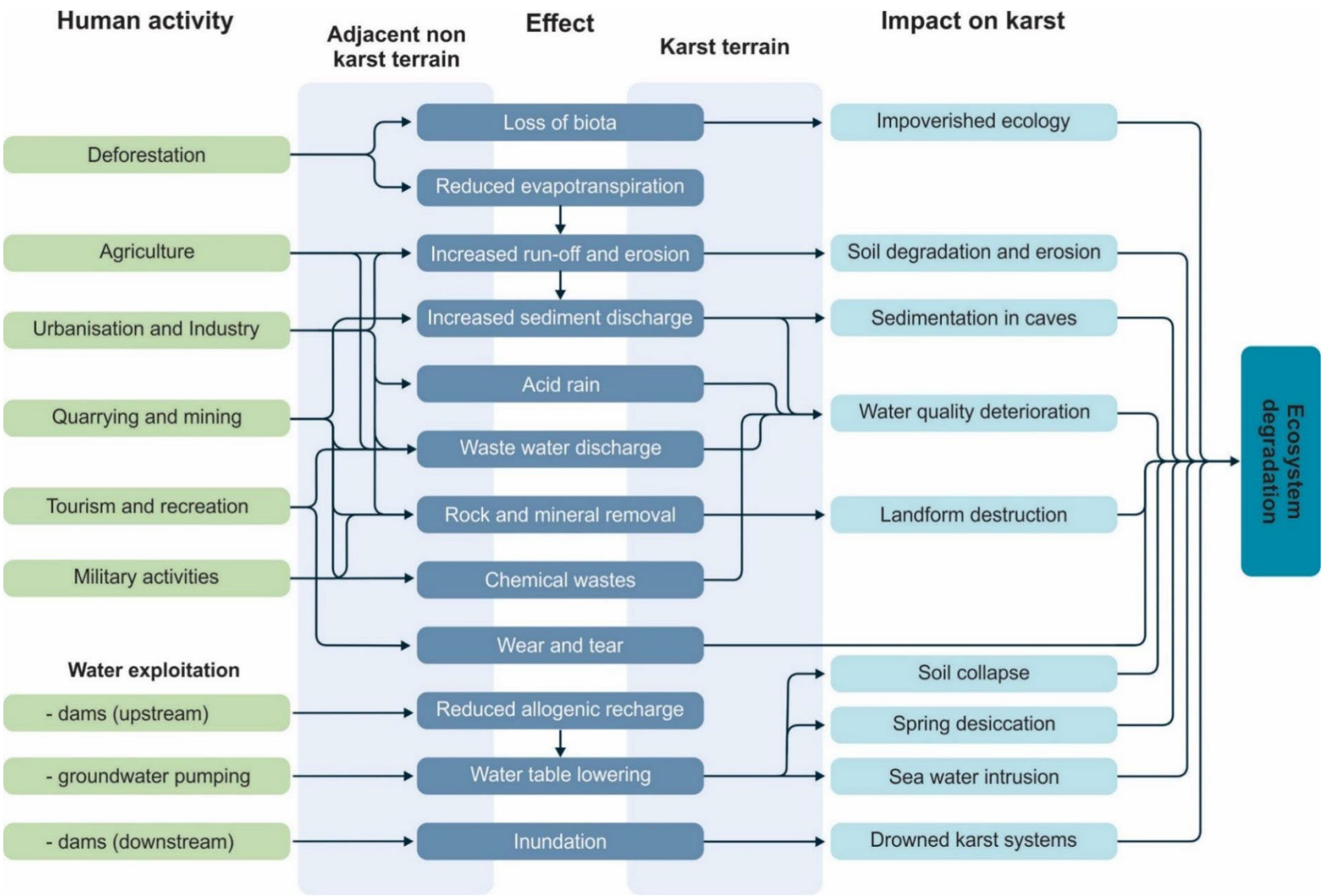


Figure 25. Matrix of anthropogenic activities, effects and impacts on karst terrain. Reproduced from Williams (1993).

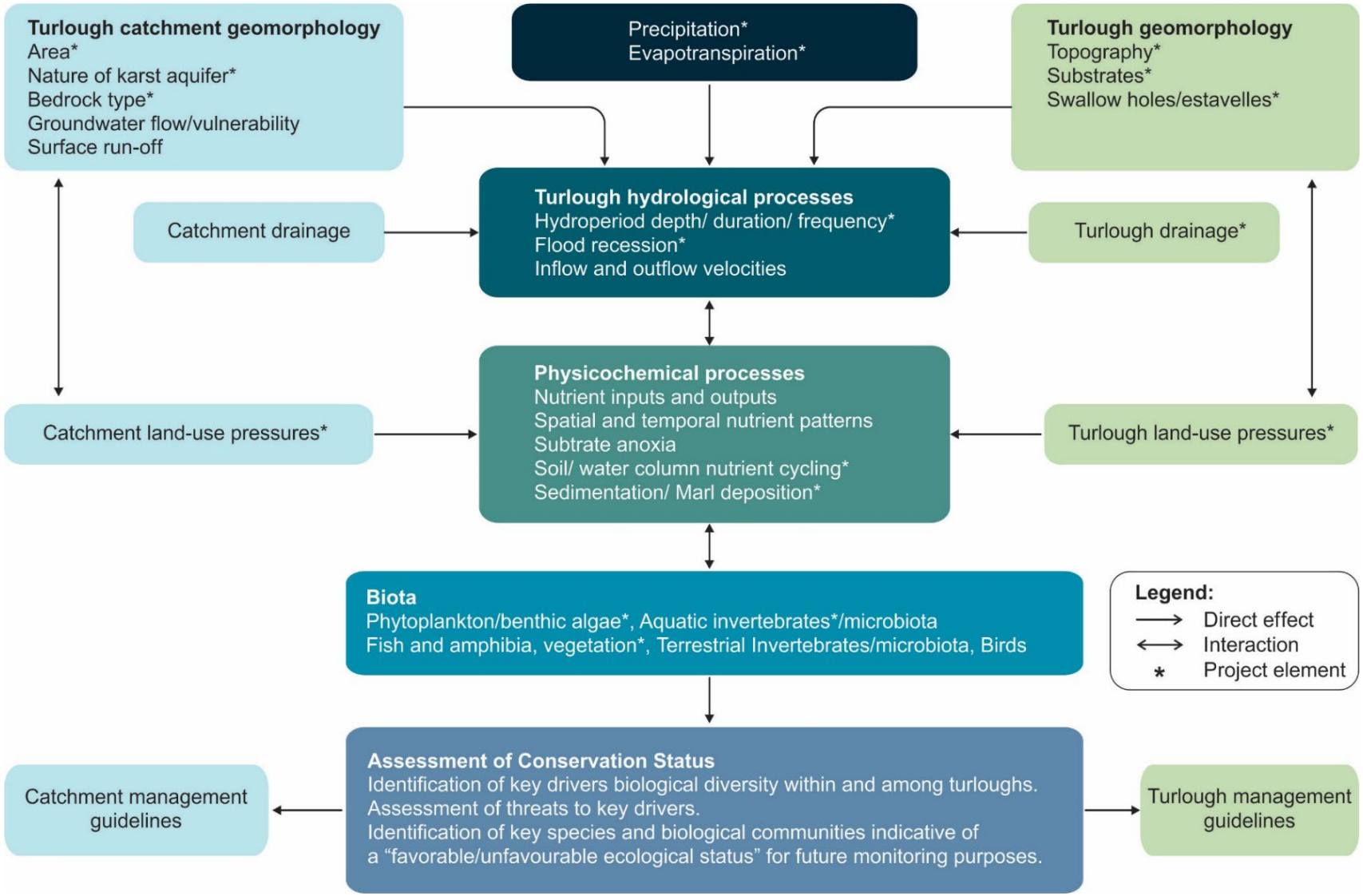


Figure 26. A conceptual model of turlough ecological functioning. Elements investigated as part of the NWPS project (Waldren, 2015) are highlighted by asterisk (*).

In Ireland, the extensive karst systems host the internationally unique turlough ecosystems (Coxon, 1987; Irvine et al., 2018; Naughton et al., 2012; Sheehy Skeffington et al., 2006), which clearly indicates the interconnection between surface- and groundwater bodies. The groundwater emerging from karst, usually rich in its dissolved salts, contributes to the turloughs' characteristic vegetation and faunal communities (Foster et al., 1992; Goodwillie and Reynolds, 2003; Porst et al., 2019). Hence, turloughs are recognised both as wetland habitats in karst and, as ephemeral lakes (Cunha Pereira et al., 2011). They are designated as SACs, classified as GWDTEs under the WFD and protected under Annex I of the EU Habitats Directive. They, therefore, provide a very important interaction between the requirements of the WFD and the Habitats Directive and, in the context of this report, hydrological and ecological interactions (Figure 26) (Griebler et al., 2010; Wheater et al., 2007).

Despite protection under the EU Habitats Directive, turloughs remain vulnerable to new drainage schemes, which may be more strongly advocated as a consequence of climate change. There remains a need for further safeguarding of turloughs from nutrient pollution and the quantification of the surface-groundwater interactions (Waldren, 2015). In karst aquifers, lowering of the water table occurs unevenly with unpredictable consequences. The effect of hydrological alterations can manifest considerable distances from a pressure. In these catchments, high recharge rates and fast flow have strong implications for the functioning of the network of GDEs (Guérin et al., 2009; Hill and Neary, 2012; O'Driscoll and Parizek, 2003, 2008; Pérez-Bielsa et al., 2012; Rodríguez-Rodríguez et al., 2015; Sophocleous, 2002; Wolfe et al., 1996).

2.4.1 Littoral zone

A lake comprises a complex matrix of habitat patches made up of variable sediment size and, where present, supporting a range of plant species and communities of submerged and emergent vegetation. Littoral zones can be extremely biologically productive, but also very vulnerable to anthropogenic pressures from especially nutrients (Vadeboncoeur et al., 2003, 2002) and hydromorphological alterations (Brönmark and Hansson, 2017; Rasmussen, 1988).

Morphologically intact littoral zones provide habitat supporting a large biodiversity and dispersal pathways (Brauns et al., 2011; Strayer and Findlay, 2010) sequestering nutrients and other pollutants (Hes and van Dam, 2019; Mickle, 1993; Sollie and Verhoeven, 2008), and dissipating wave energy that reduces erosion (Gabel et al., 2017; Schmieder, 2004; Strayer and Findlay, 2010). Heterogeneity of littoral habitats is high within and among similar habitat features such as stony substrata, sand and macrophyte beds (Cyr and Downing, 1988; Tolonen et al., 2001; van den Berg et al., 1997; White and Irvine, 2003). There is commonly a positive relationship between taxa richness and structural complexity in rivers (O'Connor, 1991; Schneider and Winemiller, 2008) and lakes (Miler et al., 2013; Porst et al., 2019).

Submerged plants and reed beds can also act as both a refuge from predation (Timms and Moss, 1984) and a cover and source of food for, particularly, small fish (Diehl and Kornijów, 1998; Okun and Mehner, 2005). White and Irvine (2003) found that variation *within lakes* was nested *among* variation across a range of lake types. Other ecosystem services include opportunities for recreation, flood mitigation and local water abstraction.

Littoral zones are also subject to a wide range of pressures and impacts. Alterations in water levels, a prominent feature of reservoirs, can have a notable impact on the littoral biotic communities (Carmignani and Roy, 2017; Evtimova and Donohue, 2016, 2014; Jurkiewicz-Karnkowska, 1989; Mjelde et al., 2013; Smith et al., 1987; Wilcox and Meeker, 1991). In the work by Smith et al. (1987) in 27 Scottish lochs, water level drawdown was up to 30 m, exposing about 100 m length of shoreline. In one of the lochs, Stuart (1953) found dense littoral vegetation before the commission of the hydroelectrical scheme, whereas Smith et al. (1987) found it to be one of the most impoverished sites (Miler, 2022).

Shoreline development is a severe threat to many lake ecosystems (Schmieder, 2004). This includes replacement of natural habitats by anthropogenic structures, such as retaining walls and rip-raps, recreational beaches, docks, marinas and boat houses can reduce biodiversity (Brauns et al., 2011; Strayer and Findlay, 2010). Physically complex habitats such as coarse woody debris, tree roots, as well as submerged and emergent macrophytes tend to be reduced in anthropogenically altered degraded lake shores (Brauns et al., 2007; Elias and Meyer, 2003; Marburg et al., 2006; Miler et al., 2015; Ostendorp et al., 2020). A reduction of fringing vegetation increases impact of natural and boat-induced wave action via boat and ship traffic. This is also amplified by retaining walls (Gabel et al., 2017; Ostendorp et al., 2020). Submerged vegetation is often removed or cut back at recreational beaches, or trampled by users (Liddle and Scorgie, 1980). Shorelines with simplified habitats are usually related to some kind of human activity (Jurca et al., 2021; Whittier et al., 2002). Urbanised shorelines reduce the input of terrestrial insects inhabiting riparian vegetation to a water body, with potential reduction of food supply for fishes (Francis and Schindler, 2009). This is just another example of pressure leading to the general and widespread decline of insects (Wagner et al., 2021). In the very upper eulittoral lake zone both Pilotto et al. (2015) and Miler and Brauns (2020) found greater influence of hydromorphological alterations on invertebrate communities than compared with eutrophication. It is, however, clear that many pressures interact to diminish the ecological quality of the lake as a whole. Disentangling these is difficult (Vaughan and Ormerod, 2010). A number of lakeshore assessment techniques have attempted to do this, or developed and tested multimeric methods to assess hydromorphological alteration on the littoral zone of lakes (Jurca et al., 2021; Kaufmann et al., 2014; Miler et al., 2015, 2013; Rowan et al., 2012).

Many of these techniques have developed from the original work of Kaufmann and Whittier (1997) and Rowan et al. (2006). The applicability of the Lake Habitat Survey (LHS) hydromorphological variables (Rowan et al., 2006) for macroinvertebrates was demonstrated by Jurca et al. (2012), McGoff and Irvine (2009) and McGoff et al. (2013). The LHS has been applied to many lakes across Europe (Ciampittiello et al., 2017). Lake-MImAS, a simplified version of the LHS developed for assessing pressures on lakes (Rowan et al., 2012), has been incorporated in WFD monitoring in Scotland, N. Ireland and the Republic of Ireland (EPA, 2021a). Littoral invertebrates, advocated by a number of workers (Miler et al., 2013; Ostendorp et al., 2020; Pätzig et al., 2015), were considered by Poikane et al. (2020b), in a review of assessment of hydromorphological pressures on lakes, to be the most sensitive BQE to assess hydromorphological alteration in European lakes, but further standardising and application of methods require further development (Boon et al., 2019; Poikane et al., 2020b). Less work has occurred on other Biological Quality Elements, although Mjelde et al. (2013) developed a macrophyte index sensitive to water level fluctuations and drawdown in Scandinavian lakes and reservoirs.

Connection between lakes and groundwater is important for the functioning of many lakes, but its assessment remains largely qualitative (Argillier et al., 2022). Quantifying groundwater discharge as a substantial source of freshwater and nutrients to lakes is important for nutrient management of lakes and implementation of WFD programmes of measures. In particularly limestone dominated catchments, there can be a strong groundwater connection with a lake. In Ireland during summer, groundwater discharge is identifiable in satellite imagery through cooler thermal signals. (Jean Wilson et al., 2016), using remote sensing to map surface water temperature, identified cold anomalous plumes along the shoreline of Loughs Owel and Ennell indicating significant inputs of groundwater. The extent of groundwater discharge to lakes in Ireland is generally under-studied, and most probably under estimated.

As part of the categorisation of Irish water bodies required for the WFD, Dublin City Council (2009) identified potentially groundwater-dependent lakes nationally. Nearly all of these are low-lying lakes (less than 200 masl), with hard water and high alkalinity, occurring particularly in the karst limestone area of central and western Ireland. Table 6 illustrates characteristics of 13 lakes with likely important groundwater supply also used for water abstraction. Ten have karst conduits, four are surrounded by bedrock with karstic features, and three are surrounded by bog. Recharge mechanism of Bofinna Lough was hard to define.

Table 6. Physical Attributes of 13 Groundwater-dependent Lakes. (Dublin City Council, 2009).

Lake Name	County	Surface Area (m^2) [1]	Shoreline Length (m) [1]	Mean Depth (m) [2]	Lake Volume (m^3)	Abstraction Volume (m^3/d)	Estimated 50%ile Surface Inflow (m^3/d) [3]	Net Abstraction: Surface Inflow Ratio	Existing Hydrometric Gauge?	Water Level Fluctuation	Inflow Points	Hydrological Assessment Available
Ballycar	Clare	26,675	843	na	na	418	605	0.69	No	No info	No springs, seeps or streams visible.	No
Bekan	Mayo	208,864	2,576	na	na	382	1,987	0.19	No	Limited	No springs, seeps or streams visible.	No
Bleach	Limerick	178,909	2,129	na	na	932	1,728	0.54	No	Anecdotally significant	Springs	No
Bofinna	Cork	86,763	1,399	3.7	319,289	1,500	2,074	0.72	No	Anecdotally significant (>1 m)	Small seeps	No
Cavetown	Roscommon	642,345	4,299	3.8	2,440,910	797	6,739	0.12	No	Anecdotally significant (>2 m)	Small spring, 4 inflowing small streams	No
Gorman	Donegal	74,527	1,660	na	na	740			No	No info	No springs, seeps or streams visible.	No
Grange	Roscommon	78,038	1,720	na	na	4,941	3,024	1.63	No	Anecdotally significant (>1 m)	No springs, seeps or streams visible.	Yes
Holan	Mayo	29,915	683	7.3	217,484	115	518	0.22	No	No info	No springs, seeps or streams visible.	No
Labe	Sligo	55,367	1,120	4.8	265,208	180	1,296	0.10	No	No info	Small seeps visible, one small stream.*	No
Lene	Westmeath	4,162,496	14,444	na	na	5,216	21,946	0.24	Data logger	approx. 0.5 m/yr	Springs	Yes
Spring	Monaghan	102,532	1,480	na	na	1,800			No	Anecdotally significant (>1 m)	Springs	No
Owel	Westmeath	10,217,811	18,237	na	na	19,548			Data logger	approx. 0.6 m/yr	Springs, small streamlets	Yes
Bane	Meath	754,474	4,999	5.2	3,953,446	4,000			Data logger	Significant - zero outflow from lake periodically	Springs	No

[1] measured in GIS; [2] from bathymetric surveys; [3] from Stage 2 * Bathymetric survey suggests the lake may be a collapse feature.

2.4.2 Springs

Springs are considered to be a key part of the water cycle and they reflect changes that are taking place in groundwater both in terms of quality and quantity. They are vulnerable resources that can indicate environmental and land-use changes as well as the occurrence of environmental pollution (Zuber et al., 2008). The most important anthropogenic pressures which may affect springs occur in the spring recharge area, i.e., urbanisation, growing demand for groundwater, overexploitation of aquifers, or agriculture and can lead to an increase in nutrient content (fertilisers), decrease in discharge (or even drying of springs), or even loss of habitats.

In many European countries, spring casing and/or concretion take place to cover the drinking water needs, and/or for aesthetic reasons (Dedić et al., 2012). For example, the effects of human-induced changes, which are shown in Table 7, are evident for many springs in the Dinaric karst in S.E. Europe. Differences in hydromorphological features of springs manifest as various transitional ecohydrological forms from human impact, from heavily modified 'dammed' to weakly or moderately modified 'cased' springs (Pešić et al., 2019). Most springs in the Dinaric region, even the springs in National Parks, are not in a natural state, while in certain areas of Bosnia & Herzegovina and Montenegro around 40% of springs are heavily modified (Pešić et al., 2019). This phenomenon is expected to be enhanced by climate change.

The ecological importance of springs is often overlooked, while they also represent important cultural sites (Misstear, 2021). In the EU Habitats Directive (92/43/EEC), not every type of spring is recognised as a specific habitat (Dedić et al., 2012), except for the type of Limestone Precipitating Springs (Natura code: 7220) which is recognised as an Annex I habitat.

Table 7. Relevant pressures and related impacts for groundwater-fed springs in Guidance No. 35 of the WFD Reporting Guidance 2016, Annexes 1b and 8n (Strona et al., 2019).

Relevant Pressures		**Impacts**	
Hydrological alteration Abstraction or flow diversion Dams, barriers, and locks	Presence of transversal works with reduction of discharge flow rates (detention and/or diversion, dams, weirs) downstream the spring emergence	Alteration of discharge flow rate	HHYC-Altered habitats due to hydrological changes
	Overexploitation of aquifers	Alteration of the vertical connectivity	
Physical alteration of channel/bed/riparian	Spring is used for different purposes or concreted at its emergence	Morphological alteration of spring habitats with loss of the ecotonal nature of groundwater-fed springs	HMOC-Altered habitats due to morphological changes area/shore
	Riparian vegetation removal	Habitat and microhabitat losses, nutrient dynamics alteration, current velocity alteration	

2.4.3 The management and assessment of GDEs

Annex V of the WFD defines GDEs as terrestrial ecosystems directly dependent on groundwater and where the groundwater body can significantly damage the GDE. Hydromorphological pressures commonly arise from changes in land-use affecting surface run-off, and water abstraction. Impacts can be local or extremely widespread. GDEs in Ireland are mainly upland bogs in carbon-rich (peat) soil, or lowland marshes and fens, and across the large area of karst and turloughs. Deeper aquifers in Ireland are mainly “unconfined” covering large subterranean areas.

Connectivity of the hydrosphere means that groundwater contributes to surface and transitional water bodies. While abstractions from surface- or groundwater in Ireland may be considered as significant pressures locally, droughts like those that occurred in Ireland in 2018 or 2020 might occur more often in the future as a consequence of climate change. For GDEs such as turloughs, local abstraction may have far-reaching effects. Protection of the water balance in GDEs depends heavily on recharge character and the extent that ecosystem is fully or partially dependent on groundwater.

An overview of the inclusion of GDEs in the characterisation and risk assessment of the groundwater bodies under the WFD (European Commission, 2015c) is shown in Figure 27. Identifying the connections of GDEs requires further understanding to provide estimates of relevant threshold values of possible impact (European Commission, 2015c; Kløve et al., 2011), although further consideration is still needed when the GDEs constitute protected sites under the Habitats Directive.

Since GDEs vary with local hydrogeology and climate, local and regional studies on their quantitative and chemical interactions are recommended to be done before the WFD status assessment (European Commission, 2015c; Kløve et al., 2011), with specific characteristics and associated surface water bodies conditions incorporated in their further characterisation; including considerations of climate change, which is expected to have a negative effect on the recharge of groundwater bodies, remains a significant issue.

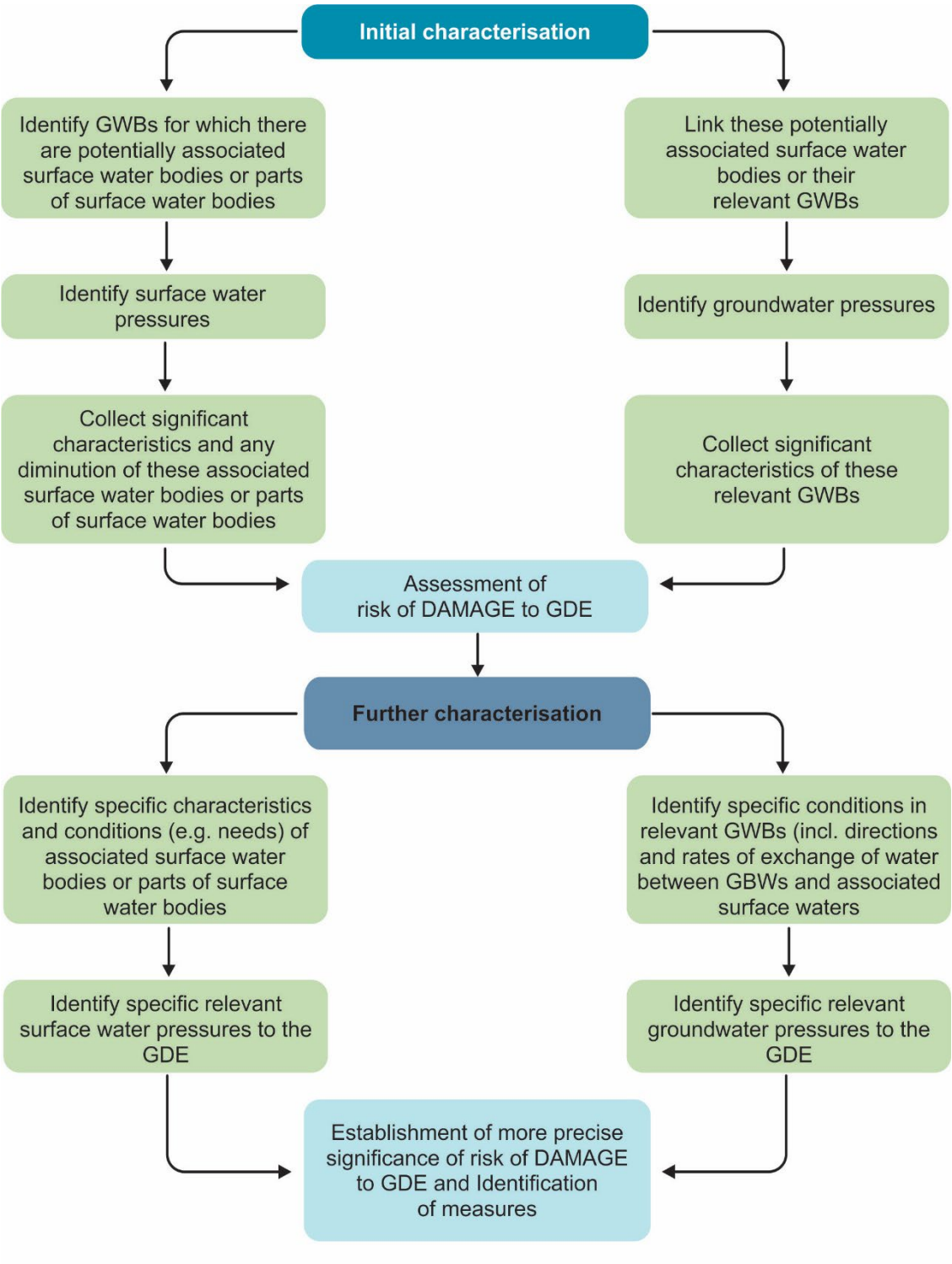


Figure 27. Flow chart of inclusion of GDEs considerations in GWB characterisation and risk assessment. Modified from European Commission (2015c).

The response of GDEs to hydromorphological alterations of recharge rate vary (Boulton and Hancock, 2006). The dependency of GDEs on groundwater investigated by the GENESIS (Balderacchi et al., 2013; Kløve et al., 2011) and REFORM (García de Jalón et al., 2013) projects were included in European Commission (2015c), and are especially relevant where the chemical quality degradation of either the surface or the groundwater body contributes to failing to meet WFD objectives (Figure 28).

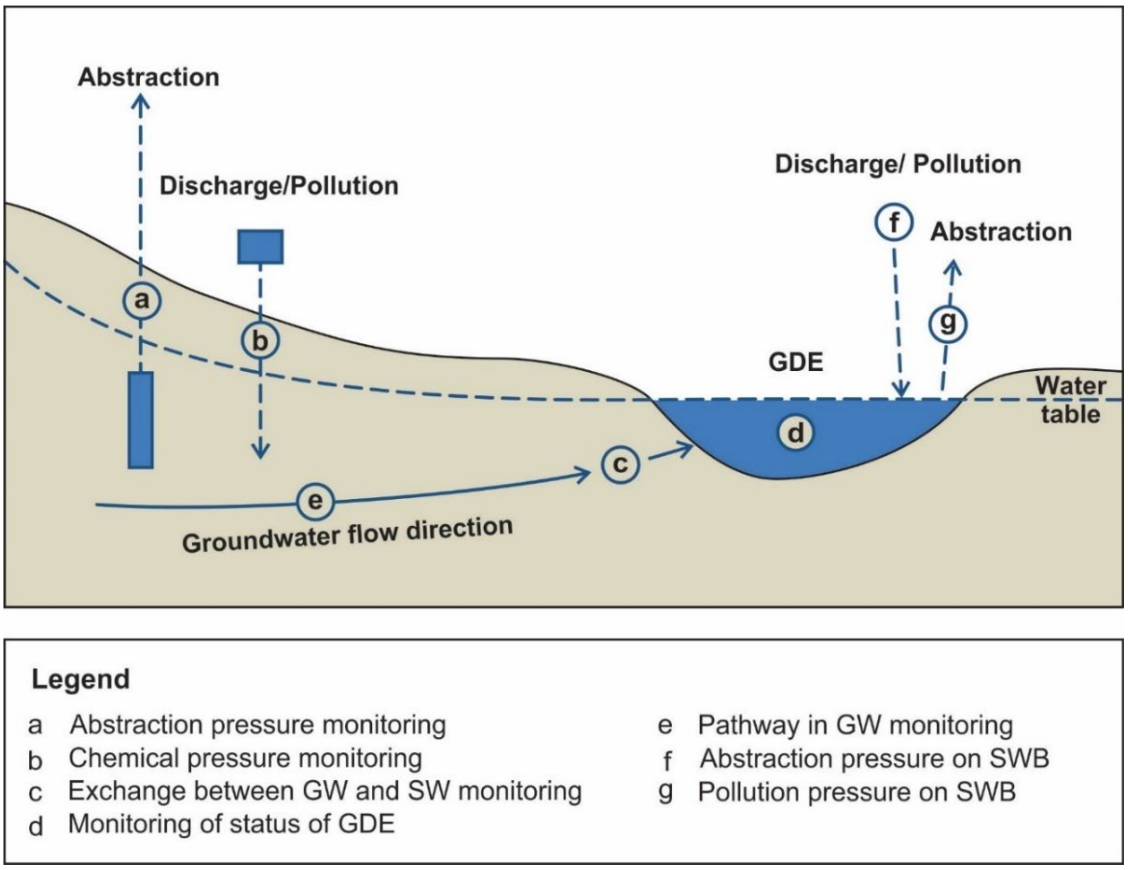


Figure 28. Schematised relationship between GWB and GDE showing potential monitoring locations. Modified from European Commission (2015c).

Despite hydrological, ecological, economic, and social importance, studies on the conservation of groundwater bodies are much less than those on surface waters (Boulton, 2020). Many groundwater species depend on hydrological and ecological connections between surface and groundwater bodies. Where these have been severed can lead to long-lasting effects even following restoration (Boulton, 2009). While there is a strong need for more attention to groundwater conservation, both in terms of legislative protection and public and policy awareness, there is a deficit of methodologies that assess GDEs, affecting their protection and management (European Commission, 2015c; Strona et al., 2019). Addressing this gap, the AQUALIFE software (Table 14) was developed to assess the ecological, hydrological and hydromorphological risks to GDEs (Strona et al., 2019). It focused on threats posed by: pollutants to GDE invertebrates; hydrological and hydromorphological alterations on the subsurface zone of lotic systems and groundwater-fed springs; and the conservation priority of GDE communities (Groundwater Biodiversity Concern index, GBC).

It aims to assist in managing GDEs for: 1) the ecological risk; 2) the hydrological-hydromorphological risk; and 3) the identification of conservation priorities. Spring casing and/or embedding in concrete, so that the outlet or the geological formation cannot be seen anymore, is taken into consideration in the Hydrological-Hydromorphological Risk.

Policies on GDEs management intermesh between the WFD and the EU Habitats Directive (Irvine, 2009). The WFD does provide specific guidance on wetlands, although there is an extensive body of management literature produced by the Ramsar Convention Secretariat. Unfortunately, attention to the Ramsar Convention in Ireland has been very much overshadowed by that given to the legally binding WFD and Habitats Directive. Compliance with the Habitats Directive in Ireland has been under-resourced, and Ireland's reporting to the EU under Article 17 has shown steady declines over the last 30 years in the metrics of quality across the majority of habitat types. There is also a lack of definitions of significant impact on GDEs. Greater understanding of the impacts of groundwater pressures on wetlands is needed (Kilroy et al., 2008). For freshwaters in general, the WFD relies on estimates of reference state. Determining baseline or reference conditions for the hydrologically dynamic turloughs and vegetated wetlands, and hence thresholds of hydromorphological pressures is, however, extremely difficult (Irvine et al., 2021).

In Australia, a comprehensive state-wide approach has been adopted for managing GDEs (Tomlinson, 2011). Adaptive management strategy initiates monitoring programmes to fill knowledge gaps and remove uncertainties. Effective management and decision making is required to minimise adverse impacts. In order to reduce risk, knowledge about susceptibility of a GDE to groundwater use, and understanding of their respective ecological value is needed. Valued attributes of the ecosystem can be protected by better understanding of the activities which have any impact on GDEs. Management prioritisation is not only important from a viewpoint of inventory but also for the reason that management efforts can target GDEs. Ecological monitoring is a two-way process that begins with a 'desktop approach' heading towards more in-depth analysis. In the first stage, there is identification of GDEs that have: a) highly conservative environment (like critical locations endangered or threatened species); b) those that are under protection through other legislative programmes; and c) environmental obligate species. In the second stage, a very detailed approach is devised to identify the ecological value of GDEs.

There is a need for more focused research on GDEs. Modern monitoring methods include ecological isotopic tracers, plant water-use models, numerical groundwater models, in-stream flow criteria, water quality metrics, and vegetation growth patterns. These concepts help to implement water management policies. Ecosystem protection and conservation is a part of water management in e.g. the EU, California, and South Africa. GDEs management can be improved by adopting the same strategies as that of Australia using a risk-based adaptive management framework (Kingsford et al., 2021). Similar legislative work (the Sustainable Groundwater Management Act) has been adopted by California to protect GDEs, and it is recognised that local agencies need to acquire more knowledge on this crucial issue (Rohde et al., 2018, 2017).

2.5 Transitional and coastal water bodies

Hydromorphological alterations affect transitional and coastal ecosystems by changing the salinity, suspended sediments, water movement, and tidal balance. This can have significant effects on ecological status of fish, angiosperms, plankton, and benthic invertebrates (Recio et al., 2013). It is broadly accepted that the different chemical and biological variables vary in their sensitivity to specific morphological and hydrological processes (Keogh et al., 2020; UKTAG, 2012). The BQEs angiosperms and benthic invertebrates are mainly used in the assessment of both coastal and transitional waters (Orlando-Bonaca et al., 2012; Recio et al., 2013), with greater reliance on fish in transitional waters (Lepage et al., 2016).

Hydromorphology plays a major role in the hydrodynamics and sediment dynamics of transitional and coastal waters, as these provide the link between sediments and suspended sediments, water movement and tidal balance. These influence the biota and are, in turn, connected to the underlying sea bed geology, sediment characteristics, morphology and water depth (Elliott and Whitfield, 2011) (Figures 29 and 30).

Like other water bodies, under the WFD transitional water bodies' status should be assessed based on their biological, chemical and hydromorphological quality elements. Many attempts have been made to develop relevant indicators (García et al., 2009; Table 8), and some intercalibration attempts were made among indicators (Lepage et al., 2016; Poikane et al., 2020a).

The European Environment Agency Report (EEA, 2018) considered that hydromorphological pressures were the main significant pressures on transitional water bodies across Europe, accounting for 40% of failure to achieve environmental objectives, slightly higher than the pressure input from diffuse pollution sources (38%). Although hydromorphological alterations are identified as among the biggest threats in the coastal and transitional water bodies, they are not well studied (Ioana-Toroimac, 2018; Orlando-Bonaca et al., 2012). For example, two of the five coastal water bodies in the Baltic region of Germany, and 50% of the coastal water bodies in the Black Sea are designated as HMWBs (EEA, 2019).

Poikane et al. (2020a) estimated that 75% of European countries do not have any assessment method for the hydromorphological pressures acting on coastal waters. Moreover, in transitional and coastal water bodies, a lack of clear definition of hydromorphological elements presents more difficulties for using an ecological assessment than in the other surface water bodies (Camp et al., 2016). A recent overview of hydromorphological features used in WFD classification is shown in Table 8.

A list of pressures and potential impacts on transitional and coastal waters assessed by Burdon et al. (2009), and shown in Table 9, concluded that:

- "few studies have attempted to tackle the three-way interplay between chemical, biotic and hydro-geomorphological processes at a large spatial or temporal scale. Thus, there is limited quantitative material on which to base measures;
- it is difficult to consider the role of hydro-geomorphological processes in isolation from other processes driving ecosystems such as climate and the physico-chemical factors influenced by hydrographic and geomorphological factors. Managing for pressures in isolation might also exacerbate rather than reduce human pressures on ecosystems;

Table 8. Hydromorphological characteristics of transitional and coastal waters as listed in this table of the guidance document (CEN, 2014) and the metrics for each generic feature (Keogh et al., 2020).

Assessment categories	No.	Generic features	Examples of attributes assessed	Metric
Morphology	1	Physiography/ Depth/ Elevation	Topography, bedforms, mouth width, intertidal area: subtidal area ratio; tidal volume; linear coastlines, beach types, shore armouring	Metric 1a. Shoreline alteration
	2	Connectivity	Presence of adjoining physical features and links within and between water bodies, and between transitional and coastal waters and wetlands; mouth width, presence of artificial structures (e.g. dams)	Metric 2a. Presence or absence of barriers within and between water bodies
	3	Geology	Substrate type, bedform patterns	Metric 3a. Bed disturbance Metric; 3b. Change in habitat
	4	Biogenic structures	Presence of aquatic macrophytes and biogenic reefs	Metric 4a. Change in the spatial extent of Saltmarsh and Seagrass beds
Hydrodynamic regime	5	Tidal regime, water level and current	Current velocity and direction, water level variability, tidal range, tidal prism, presence of tidal wave/bore	Metric 5a. Change in tidal regime
	6	Wave regime	Exposure, wind speed and direction, fetch, wave height	Metric 6a. Changes in wave regime
	7	Freshwater inputs and run-off	Residence time/flushing rate (transitional waters), retention time (enclosed bays), freshwater discharge	Metric 7a. Change in river flow Metric 7b. Change in residence time
	8	Sediment dynamics	Sediment supply, erosion/ deposition/ transport cycles	Metric 8a. Change in dominant fraction particle size Metric 8b. Change in turbidity
	9	Stratification or degree of mixing	Salinity, turbidity, density, temperature	Metric 9a. Change to stratification; Metric 9b. Change in salinity

Table 9. Anthropogenic pressures and their generic impacts on hydrological and morphological processes in transitional and coastal waters from Burdon et al. (2009).

Activity	Impact on hydrological and morphological processes
Agriculture	An increase in sediment supply (increased turbidity) and nutrients (potential for blooms to develop) has an impact on phytoplankton production in transitional waters (La Jeunesse and Elliott, 2004).
Aquaculture	Aquaculture structures (e.g. fish cages and trestles) could have an impact on both the hydrological and geomorphological features of estuaries and coasts by impeding water flow (La Jeunesse and Elliott, 2004). Grazing of phytoplankton by filter-feeding organisms such as mussels has an impact on phytoplankton populations. Localised, increased organic loading may result in eutrophic symptoms.
Changes to the physiography of the system through infrastructure and activities	Changes in the physiography of a river basin or estuary will influence the nutrient supply to estuaries and coastal waters. For example, alterations in the lower part of the Rhine River basin led to a decrease in flushing time of the system and thus a relative increase in the discharge of nutrient loads to the Dutch Wadden Sea (de Jonge and Elliott, 2001).
Changes in water supply upstream water use	Change in freshwater input (e.g. through abstraction) will influence the supply (loading) and concentrations of nutrients, the location of the FSI (which changes phytoplankton community structure), the residence time (that has an impact on nutrient supply in estuarine and coastal zones) and the mixing of the estuary (affecting phytoplankton growth). All these impacts may also have a knock-on effect on phytoplankton production in estuarine and coastal waters.
Construction of harbours, barrages etc.	Impact on both hydrological and geomorphological features of estuaries and coastal waters. For example, construction of a storm-surge barrier and two-compartment dams completed in the Oosterschelde, The Netherlands resulted in reduced flow velocities, reduced suspended matter content and decreased freshwater loads (Wetsteyn and Bakker, 1991).
Dredging/navigation	An increase in water depth will have an impact on light availability for photosynthesis by phytoplankton. Increased localised turbidity is a limiting factor for phytoplankton production in estuarine ecosystems, which are generally limited by light availability for photosynthesis.
Organic pollution	An increase in nutrients from diffuse (agricultural run-off) and point source discharges (wastewater treatment plants) leads to the potential for increased phytoplankton production depending on other factors such as light availability and residence time (La Jeunesse and Elliott, 2004).
Urbanisation/deforestation	Impact on the supply of nutrients into estuarine waters. It has been shown that phytoplankton growth may be iron-limited in deforested areas. This is consistent with the hypothesis that organically bound iron from coastal forests plays an important role in supplying iron for the growth of estuarine phytoplankton (Lewitus et al., 2004).

- some biological elements are more sensitive to either hydrographic (e.g. phytoplankton) or geomorphological processes (e.g. saltmarshes), while most are responsive to the combination of hydro-geomorphological processes (e.g. benthic invertebrates) coupled with other environmental and biological forcing factors (e.g. seagrasses, fish); and
- it is often difficult to separate human activities from natural process dynamics, although it is clear that human activities (including hydromorphological pressures) do impact on ecological function of the WFD-relevant biota."

2.5.1 Transitional water bodies

Under the term transitional water bodies, a wide range of aquatic ecosystems is classified, such as estuaries, fjords, lentic lagoons, river mouths and deltas. The boundary between one type of transitional water body and another is not always clear (Lucena-Moya and Duggan, 2017). The most important threats to the transitional water bodies are hydromorphological alterations (Facca et al., 2020) causing substantial changes to the hydromorphology and biota of many transitional water bodies throughout Europe (Chainho et al., 2008; Gutperlet et al., 2015; Orlando-Bonaca et al., 2012; Pitacco et al., 2018; Recio et al., 2013).

Estuaries

Estuaries are considered as transitional water bodies under the WFD. They are one of the most productive ecosystems in the world, but also highly threatened and modified (Branch, 1999). Estuaries do not have a regular form in terms of shape and size and are difficult to define because, as an interface between land and sea, they incorporate a gradient in conditions from predominately riverine to predominately oceanic (Hume et al., 2007). They are both affected by pressures in their immediate surroundings and from inland areas (Figure 29). Moreover, any changes in the inflowing river catchments will also affect their ecological character (Cooper et al., 1994).

The Estuary Environment classification (EEC) aimed to group estuaries according to their physical characteristics (Figure 30). It is based on the consideration that a number of factors i.e., climate, ocean, river conditions and catchment characteristics define a sequence of processes and their physical and biological characteristics. Hydromorphological alterations influence estuarine structure and function by changing the salinity, suspended sediments, water movement, and tidal regime (Borja et al., 2011). Hydromorphological pressures affect physical structure and chemical variables (e.g. temperature, salinity, nutrient composition, pollutants), with effects on BQEs (fish, plankton, plants, and benthic invertebrates) (Kennish, 2002; Recio et al., 2013). A survey by Phellan et al. (2021) among Member States indicated a considerable need to develop effective pressure-response methods for transitional and coastal waters. A lack of clear distinction between hydromorphological and biological/biogenic assessment suggests insufficient attention to either hydromorphological or biological elements, with an over-reliance on expert judgment.

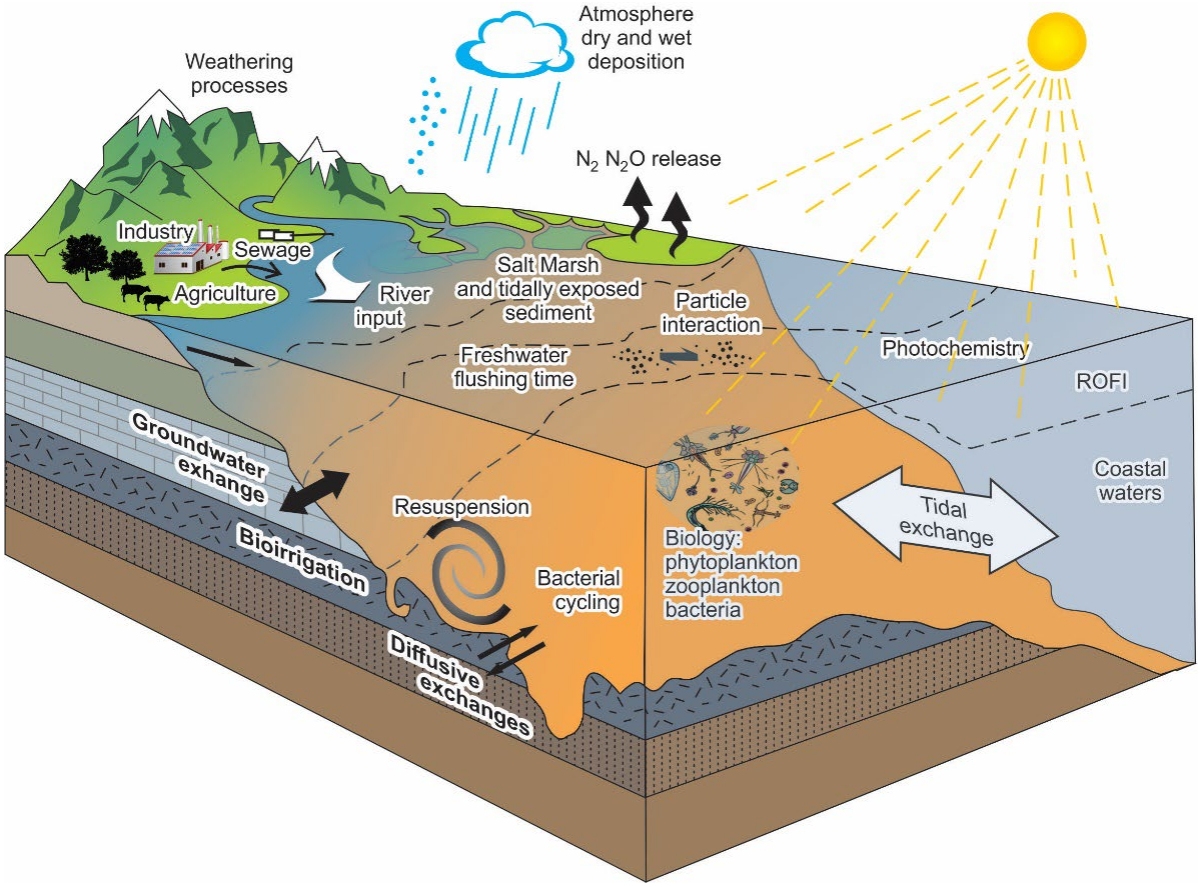


Figure 29. Schematic view of physical, chemical and biological processes occurring in estuaries (Statham, 2012). Reproduced from (Cochran, 2014).

A number of methodologies employed to assess pressures and impacts on European estuaries (Table 10) were introduced before the WFD. For example, the Estuarine Health Index (EHI) is based on physical, chemical and biological aspects of estuaries along with an additional aesthetic component to provide an integrated measure of estuarine health (Cooper et al., 1994). Furthermore, the EHI assesses the loss of intertidal areas due to land reclamation, the relative area with hydrodynamic changes and the presence of constructions, and detects variations in the tidal regimes, as well as morphological characteristics. It was applied in nine estuaries in northern Spain to assess the relation of hydromorphological stresses and vegetative quality indicators such as seagrasses and salt marshes (Recio et al., 2013). Extensive alteration of water velocity was evident, and richness of indicators decreased as a result of hydromorphological modification either from land reclamation, hydrodynamic changes, or longitudinal structures (Recio et al., 2013).

Landscape alterations from human-induced pressures in coastal water bodies impact both the littoral and the sublittoral conditions and hence the biological accumulation (Orlando-Bonaca et al., 2012). Annex III of the Habitats Directive (92/43/EEC) mentions that: “In the event of significant construction works or significant changes in the infrastructure in or in the vicinity of the bathing water, the bathing water profile is to be updated before the start of the next bathing season.” Climate change through global warming and sea level rise is expected to have a severe impact on estuaries (Al-Nasrawi et al., 2018).

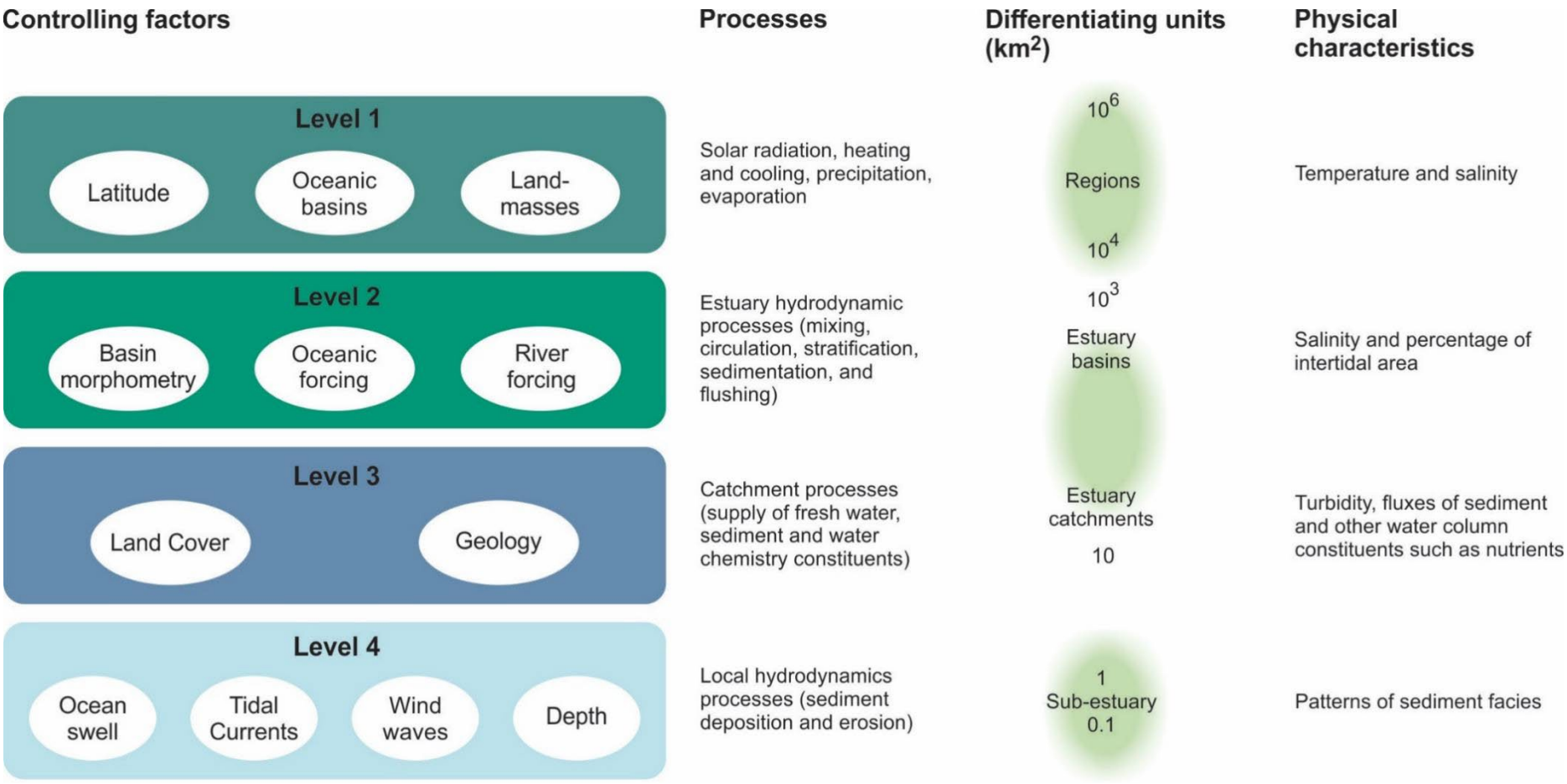


Figure 30. Conceptual model of the hierarchically related physical processes that determine the physical and ecological characteristics of estuaries at four system levels. Each level is associated with a specific set of processes that are controlled by 'factors' (Hume et al., 2007).

Coastal Lagoons

Lagoons are mixing zones between water from the sea and river run-off, and comprise high-risk water bodies due to their unconsolidated soft sediments, low relief and wide inland exposure. The geomorphology of the coastal lagoons is constantly changing due to the variation in the sediment supply and the sea level due to water level and ground level changes. Their salinity may vary depending on precipitation and evaporation rates, but also due to seawater contribution during storms, floods and tidal exchange (Facca et al., 2020). Coastal lagoons are a priority habitat type under the Habitats Directive (92/43/EEC) and are facing increasing and significant impacts, which include physical and chemical modification, habitat destruction, and changes in biodiversity (Halpern et al., 2008, 2007) due to land reclamation, dredging, pollution, tourism, alien species, and climate change. For example, two of the nine coastal lagoons on the Maltese islands are classified as HMWB due to the construction of freeport and oil terminals around the lagoons. They have a long history of anthropogenic pressures i.e. the construction of weirs, platforms which were used as a defence zone in the 16th century. Similarly, the port of Marsaxlokk in Malta was subjected to intensive land degradation by the effluents coming from the oil terminals making dredging a common practice. The increasing pressure on the water bodies of Port Marsaxlokk from tourism, large-scale construction, and loss of coastal land makes it very difficult to restore the physical characteristics of the lagoon to meet WFD standards (Malta Resources Authority and Malta Environment and Planning, 2011). Coastal lagoons are considered extremely vulnerable to climate change and the expected sea level rise which, in turn, is expected to affect their geomorphology and hydraulics, or even lead to their disappearance (de Wit, 2011).

Especially in the Mediterranean countries, the productivity of coastal ecosystems largely depends on the health of coastal lagoons, which play a central role in providing habitat for fish but are also under pressure from anthropogenic pressures (dams and land loss). Across Europe, lagoons are degrading for a number of reasons. For example, the impact of anthropogenic pressures on the Venice Lagoon in the last century is a striking example of hydromorphological alteration in a transitional European water body. In the 15th century, harbour activities and navigation patterns in the lagoon were altered due to the rising load of sediment transported from the river. To reduce the impact of transported sediments, the depth of the navigation channel in the lagoon was increased by 20 m (Molinaroli et al., 2007). Carniello et al. (2009) found that the water depth in the navigation channels was increasing rapidly with time, making it easy for the incoming waves to erode the bed. To make the situation worse, the hydromorphology of the lagoon became heavily altered between 1927 and 1970 by construction for urban settlement, groundwater discharge for industrial use, and dock dredging for navigation. These anthropogenic pressures resulted in the exploitation of the natural resources of the lagoon and the extent of salt marshes in the Venice lagoon decreased from 68 to 32 km^2 between 1927 and 2002. The increase in depth of the water column from unregulated infilling of wetland areas and most notably from the harvesting of Manila Clams (*Venerupis philippinarum*) with mechanical dredges converted the Venice Lagoon into a sediment-starved water body (Sarretta et al., 2010).

The discharge of sediment and fertiliser from agriculture is the most common threat to the hydromorphological status of the lagoons in Ireland. To study the consequences of changing the natural morphological process of lagoon ecology and its impact on hydromorphology, Orford et al. (1988) studied Tacumshin Lake (see also Section 5.2.1) on the southeast coast of Ireland.

The lagoon which was separated from the sea by a gravel barrier and provided fine sand to the beach through an outlet stream in that barrier, is of high ecological importance. The study found that the natural outlet of the Tacumshin lagoon was dammed in 1974 when a sub-barrier drainage culvert was constructed right on the lagoon to convert it into agricultural land. The result of these extensive pressures on the lagoon reduced the natural supply of fine sand to the beach which ultimately led to the removal of the already present fine-grained sediments by longshore currents, and steepened the natural angle of the face of the, increasing susceptibility to erosion.

2.5.2 Assessment methods for transitional and coastal water bodies at European level

Salas Herrero (2018) lists the methods used in the assessment of both coastal and transitional water bodies that were reported for fourteen European countries. In Table 10 the methods used and the water bodies in which they are applied are shown. Most of them are applied in the context of the WFD to assess ecological status. The report from Phellan et al. (2021) on their survey of Member States summarised hydromorphological assessment and monitoring methodologies in EU coastal and transitional waters.

In Ireland, a risk-based assessment tool known as the Transitional and Coastal Waters Morphological Impact Assessment System (TraC-MImAS) was developed as a decision support tool assessing potential impact of new projects on the hydromorphological status of transitional, estuaries, and coastal water bodies (UKTAG, 2013). A limitation is that it cannot fully characterise the hydromorphological structure and functions of certain transitional water bodies. These limitations include characterising and incorporating geology of the sea bed, the sediment features, the depth of water and its morphology, and the overall dynamics of sediments. This has been superseded by the Hydromorphological Quality Index (HQI) developed by Keogh et al. (2020). This connects the hydromorphological alterations with the ecological status of the water bodies. Although some of its metrics use certain information that is also assessed by TraC-MImAS (shoreline alteration, presence of barriers, bed disturbance, change in habitat, wave regime), it also uses in-situ collected data (change in extent of saltmarsh and seagrass, tidal regime, change in river flow, change in residence time, change in dominant sediment fraction, change in turbidity, change to stratification, change to salinity) (Keogh et al., 2020; Strona et al., 2019). Although developed independently from the techniques designed to support implementation of the WFD, the outcome of the HQI index uses the same classification as the WFD classification.

Keogh et al (2020) conducted a study to address these limitations and developed a new hydromorphological assessment approach for transitional water bodies in Ireland. The hydromorphological status of each study was examined under nine metrics originally devised by the hydromorphology guidance document (CEN, 2014). These metrics are morphological (alterations along shorelines, disturbance of coastal waters by barriers, disturbance in bed geology, special changes in saltwater) and hydrodynamic (change in tidal pattern, wave regime, overall river flow changes with time, unregulated sediment built up in saltwater and stratification changes). GIS layers were used to examine the extent of, for example, barrier absence and presence, and land loss by anthropogenic factors, in each water body. Finally, the score for each metric in each water body was given following the River Habitat Assessment Scheme (RHAT) method (DEARA, 2009).

Table 10. Overview of the methods and their components for transitional and coastal water bodies (Salas Herrero, 2018).

Member state	Name of the method, or acronym/abbreviation	Water category	Hydrology	Morphology
UK	Risk assessments, cumulative impact	CWTW	x	x
	TraC-MImAS	CWTW	x	x
ES Galicia	No name	CWTW		x
ES Catalonia	ECELS	TW	x (indirectly)	x
FR	No name	CWTW	x	x (indirectly)
PT	No name	CWTW		
RO	Princeton Modell (POM)	CWTW	x	
	Granulometric	CWTW		x
BG	No name	CW	x	x
	No name	TW	x (indirectly)	x
NO	Size of pressures	CW		
FI	Voimakkaasti muutettujen ja keinotekoisten pintavesien tunnistaminen ja tilan arviointi	CW	x	x
DE	HyMo Assessment Matrix for Coastal and Transitional Waters of Germany	CWTW	x (indirectly)	x
DK	National RBMP and national monitoring programme	CW	x (indirectly)	x (indirectly)
IE	HQI	CWTW	x	x
	TraC-MImAS	CWTW		x
NL	Handboek Hydromorfologie 2.0 (Oste et al. 2013)	CWTW	x	x
PO	Monitoring hydromorfologiczny wód przejściowych i przybrzeżnych	CWTW	x	x

BG: Bulgaria. DE: Germany, DK: Denmark, ES: Spain, FR: France, FI: Finland, IE: Ireland, MT: Malta, NL: Netherlands, NO: Norway, PL: Poland, PT: Portugal, RO: Romania, Trac: Transitional and Coastal waters, TW: Transitional waters, CW: Coastal waters.

Table 11. Use of the methods in the WFD planning process for transitional and coastal water bodies (Salas Herrero, 2018).

Member state	Method	WB delineation	Typology	Pressures & impacts	EQS classification only for		Risk analyses	HMWB designation	Definition of GEP	Design of program of measures	Exemptions
					high status	good status					
UK (Hymo assessment)	Amix/ combination of risks assessment, cumulative impact, TraC-MImAS			x	X	x	x	x			
UK (Hymo designation)	A combination of risk assessment categories, cumulative impact, TraC-MImAS			x			x	x			
ES Galicia		x	X	x			x	x	x	x	
ES Catalonia	ECELS			x	X	x	x	x	x	x	
FR	No name			x	X						
PT	No name			x	X		x	x	x	x	
RO	Princeton Modell (POM)	x	X	x					x	x	
	Granulometric		X		X				x		
BG	No name			x				x			
NO	Size of pressures	x		x			x	x	x	x	x
FI	Voimakkaasti muutettujen ja keinotekoisten pintavesien tunnistaminen ja tilan arviointi	x		x		x	x	x	x	x	x
DE	HyMo Assessment Matrix for Coastal and Transitional Waters of Germany	x	X	x		x					
DK	National RBMP and national monitoring programme	x	X	x		x		x	x	x	
IE	HQI										
	TraC-MImAS										
NL	Handboek Hydromorfologie 2.0 (Oste et al. 2013)										
PL	Monitoring hydromorfologiczny wód przejściowych i przybrzeżnych					x		x			

BG: Bulgaria. DE: Germany, DK: Denmark, ES: Spain, FR: France, FI: Finland, IE: Ireland, MT: Malta, NL: Netherlands, NO: Norway, PL: Poland, PT: Portugal, RO: Romania, Trac: Transitional and Coastal waters, TW: Transitional waters, CW: Coastal waters.

Table 12. Pressures considered for hydrological alteration of transitional and coastal water bodies (Salas Herrero, 2018).

Country	Method	Abstraction	Flood defence	Land claim	Flood mitigation	Artificial waves from navigation	Urbanisation	Agriculture	Hydro peaking
UK	Classification methods use a combination of risk assessment categories, cumulative impact, TraC-MImAS	x	x	X	x				
UK	Hymo designation method	x	x	X					
ES Galicia	No name								
ES Catalonia	ECELS	x	x	X	x				
FR	No name	x	x		x		x		x
PT	No name		x	X	x		x		
RO									
BU (CW)	No name		x						
BU (TW)	No name		x				x		
FI	Voimakkaasti muutettujen ja keinotekoisten pintavesien tunnistaminen ja tilan arviointi		x	X	x		x	x	
DE	HyMo Assessment Matrix for Coastal and Transitional Waters of Germany	x	x		x	x	x	x	x
DK	National RBMP and national monitoring programme		x		x				
IE	TraC-MImAS								
	HQI			X					
NL	Handboek Hydromorfologie 2.0 (Oste et al. 2013)		x	X	x		x		
PL	Monitoring hydromorfologiczny wód przejściowych i przybrzeżnych	x	x	X	x	x			

BG: Bulgaria. DE: Germany, DK: Denmark, ES: Spain, FR: France, FI: Finland, IE: Ireland, MT: Malta, NL: Netherlands, NO: Norway, PL: Poland, PT: Portugal, RO: Romania, Trac: Transitional and Coastal waters, TW: Transitional waters, CW: Coastal waters

Most of the methods given in Table 10 are also used for Environmental Impact Assessment (Directive 85/337/EEC), as well as for PoMs to support the WFD planning process (Table 11). The pressures that are considered by the methods that are listed in Table 10 are shown in Table 12. Finally, those methods help towards the designation of HMWBs.

2.5.3 Coastal water bodies

Activities such as dredging and land reclamation strongly impact hydromorphology and hence the biological diversity of coastal water bodies (Crain et al., 2009; Orlando-Bonaca et al., 2012). Besides dredging and land reclamation, numerous other pressures lead to hydromorphological alterations which include sand and gravel extraction, flooding protection constructions along the coast, flood barriers in estuaries, dams and diversion structures; marine constructions including offshore wind farms and harbours (Fehér et al., 2012). Such activities in most cases involve channelisation and straightening, coastal defence walls, bank reinforcement, embankments or even land claim and/or impoundment. Moreover, the inland waterways can assist invasive species intrusion into an area. Fehér et al. (2012) summarised these as leading to:

- "the physical removal of habitats or species;
- changes to physical processes (erosion, accretion and sediment transport); and
- barriers to movement of species or the loss of connectivity between habitat sites (e.g. due to impoundment or reclamation)."

Climate change is expected to have a strong impact on coastal areas due to expected sea level rise and due to increased probability of storm waves, as well as the receptors of floods arriving from upstream extreme events, and associated coastal floods. Moreover, increased 'grey infrastructure' for flood protection of coastal areas is expected to have an environmental impact (OSPAR Commission, 2009).

A common problem in all harbours is the accumulation of sediments. In this case, dredging needs to take place to maintain the required water depth, and hence the navigation access, which raises the operational costs due to the dredging but also for the need to dispose of the dredged material. These costs might even be higher in case that these sediments have high pollution loads (Lawler et al., 2017). The dredged material is at the borderline of water, soil and waste policies and the European legislation for handling it is complex. The WFD does not specifically address sediment management, and EU legislation, although developing, does not yet deal adequately with it (Bussettini and Schmidt, 2022).

For inland navigation and ports, the World Association for Waterborne Transport Infrastructure (PIANC) has introduced guidelines on sustainable inland waterways and navigation. The guidelines suggest an integrated approach for inland and maritime water transport design. According to these guidelines, any new project should be assessed before it is carried out to make sure that the morphological (erosion, sediment transport and sedimentation), hydrological (e.g. flood pulse), sediment balance, ecological, biological and chemical (nutrient cycles) processes and functions are maintained.

Finally, for developments on the coast and estuaries (e.g. ports, flood defences, marinas) specific attention should be paid to the dynamic nature of the environment in achieving ecological objectives, established by the WFD and/or for water-dependent Natura 2000 sites, of achieving "favourable conservation status." This requires close coordination with the implementation of the Birds and Habitats Directives.

Given that industrial ports are often rich in biodiversity and important migration sites there should also be coordination of the WFD with the Birds and Habitats Directive. A classic case of how ports and industrial sites can protect migratory wetland birds can be found in Teesside in NE England, where the Tees Estuary is one of the most heavily modified estuaries in the UK and has lost the majority of its former intertidal habitat to land claim. The semi-natural habitats that remain are nestled among significant industrial development, including the third busiest port in the UK accompanied by chemical processing industries, and surrounded by urban settlements. Despite the enormous impact of industry on the area, the Teesmouth National Nature Reserve is part of the Tees Estuary. Its boundaries encompass two Sites of Special Scientific Interest (SSSI), together with parts of a further four, these make up the Teesmouth and Cleveland Coast Special Protection Area and Ramsar site, which is of international importance for wildlife.

2.6 European Case Studies employing ecosystem to mitigate hydromorphological pressures

Widespread impact on ecosystems from traditional hard engineering has been recognised for decades but is often considered an unavoidable cost in the interests of economic development or flood defences, or both. In many cases, ill-considered planning decisions have allowed or even encouraged the building of structures on the floodplains. Although the risks of this have been discouraged in long-standing legislation such as the UK Town and Country Planning Act of 1947, poor practice continued (Parker, 1995). As a corollary, the impact itself of the loss of natural habitat in increasing flood risk was often not factored into decisions. In general, the economic and social importance of retaining ecosystem functions and services has been a major global failing, and in some parts of the world active development still occurs on wetlands, resulting in serious consequences for communities, as well as a loss of protected habitats (Irvine et al., 2021).

The importance of hydromorphology for functioning ecosystems has been covered extensively in the previous sections. In this section, we provide four examples from Europe that cover the management of providing more space for water, a major river restoration project, and how Nature Based Solutions (NBS) are increasingly used in order to provide flood protection alongside multiple other ecosystem services (WWDR, 2018).

2.6.1 Room for the River Project, The Netherlands

One of the most well-known examples of providing space to prevent and mitigate flooding is the Dutch Room for the River. Details are summarised by van Alphen (2020). It involves the restoration of floodplains on the upper and middle sections of the Rhine, so that the height of flood waves reaching the Delta area is reduced. At the lower end of the River Rhine, management during flood events acts to maximise drainage to the delta. The operations when needed involve coordinated management across a number of agencies.

The Rhine Delta plays an integral role in characterising the landscape of the Netherlands and is the point where three rivers i.e. Rhine, Meuse and Scheldt connect to the sea. Room for the Rhine project was initiated in the Netherlands in 2006, in response to the intensive flooding events in Rhine Delta between 1993 and 1995. Flooding reached historically high levels in the Delta and led to the evacuation of 250,000 people. The project was a ten-year flood management project that aimed to protect the Netherlands from high water discharge during extreme floods in the delta, using detailed spatial planning for hydraulic effectiveness (Klijn et al., 2013). The measures adopted to achieve these objectives (Figure 31) primarily comprised:

- “relocation of dikes to enhance water flow between them during floods;
- increasing the depth of the river channel to provide room for water discharge during floods, with dredging also ensuring navigation in the main river channel;
- where relocation of dikes was not possible in areas of high populated areas, strengthening existing dikes was carried out;
- the effective lowering of the floodplain to provide room for water flow to reduce silt depositions during seasonal floods. Moreover, groynes were lowered below the water level to avoid water flow beyond the groynes as they are the structures that hold water in the channel; and
- the removal of obvious obstacles to the water flow in the floodplain, the storage of high incoming water from the Rhine Delta to the Volkerak-Zoommeer Lake and depoldering to ensure smooth water flow in areas located behind the dike by removing small dikes” (van Alphen, 2020).

The impacts of flooding in the Rhine River are not confined to the Netherlands. In fact, the rise in the water level of the southern-mid part of the Rhine River caused massive flooding in Germany in 2021, which is considered the highest in the past six decades and led to the death of 180 people (Fekete and Sandholz, 2021). In the past decade there has been a loss of the natural floodplain in the Rhine River and much of this is characterised by the impacts of climate change. Hydromorphological alterations in the upstream catchment have played an important role in increasing the intensity of flooding in the Rhine River (Pinter et al., 2006).

The success of the Room for the River project is characterised by the involvement of old and new flood management practices that mainly include river widening and dike relocation. This project therefore indicated a paradigm shift in the Dutch flood management practices and the need for the development of new policies and practices to cope with the impacts of changing climate (De Conto and Pollard, 2016).

The Room for the River project involved a strong element of public participation and a negotiated settlement with some land owners and urban municipalities to release water into previously reclaimed land when flood risks are high. The Room for the River project involved a break of traditions in a country built on keeping water off the land.

The project was subject to a Strategic Environment Assessment (SEA) because of the integrated nature of the proposal and potential effects of upstream and downstream measures affecting each other and the need for high-level political approval and compliance with the Dutch Planning system.

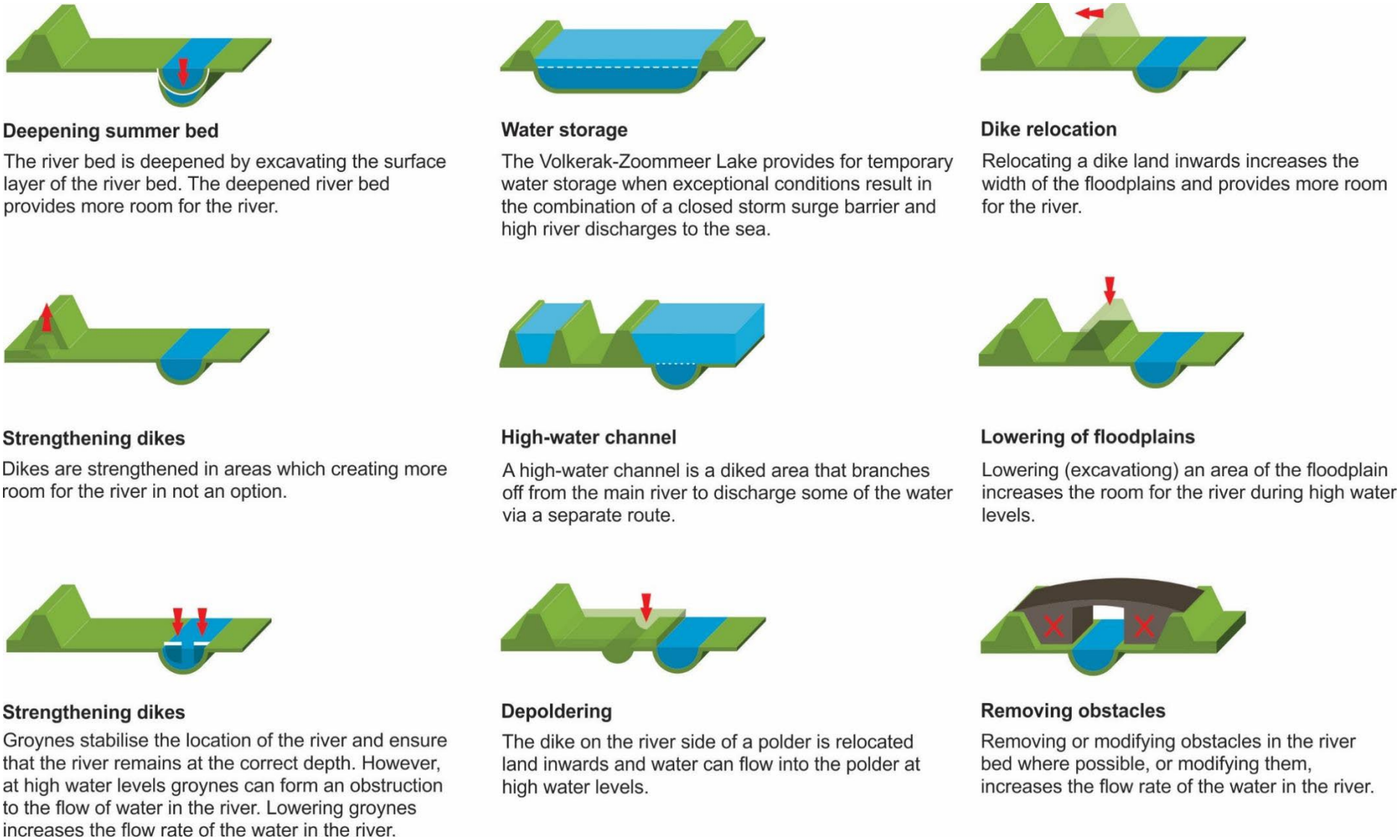


Figure 31. Actions taken to gain Room for the Lower Rhine. Reproduced from:Dredging.org

The SEA included detailed assessment of alternatives and intense public and stakeholder participation. Under Dutch law, the SEA process requires a quality review by the Netherlands Commission for Environmental Assessment (NCEA). Then NCEA also advised on the Terms of Reference of the Plan (Bobbi Schijf, NCEA, pers comm 2012). The conclusion of the NCEA on the SEA (Verheem and Laeven, 2009) was that the SEA significantly influenced the final design of the plan, which fully considered environmental issues. The SEA and plan were developed interactively and in parallel with the negotiations between stakeholders, and because of the scale and controversial nature of the plan, involved the creation of a so-called 'project-directorate' within the ministries coordinating and involving the key responsible ministries in the 'messy world of policy making'. The NCEA acknowledged that it was "hard to identify exactly how influential the SEA" , but also that the "open and positive attitude towards participation and environmental integration of the main responsible ministries clearly also contributed significantly to the final outcome."

The paradigm shift that the Dutch Room for the River programme has adopted goes back to much older traditions of flood protection, of "not with force, but with sweetness" (Bijker, 2007), and the opportunities gained from controlled flooding (van Alphen, 2020). In the sixteenth century, the dike builder and polder creator, Andries Vierlingh, advised the Dutch to fight the water "with a soft hand"–that is, to regulate the floodwater, "instead of applying brute force."

2.6.2 Space for river and management in the Loire/Allier River, France

The Loire River is the largest in France, running for over 1,000 km, with a catchment area of 117,054 km^2 draining a fifth of the country (Figure 32). It rises in the Massif Central at 1,350 m, flows north and then west, before discharging to the Bay of Biscay at St Nazaire. Its main tributaries, upstream to downstream are the Allier, Cher, Vienne and Maine. It supports two-thirds of the livestock and half of the cereal production in France, with approximately 350,000 ha irrigated . In every sense of the word, it is an historic river. The hydromorphological dynamics of the Loire and one of its major tributaries, the Allier, were considered by Gautier et al. (Gautier et al., 2000) as relatively natural, with active fluvial dynamics maintaining the character of the vegetation in the middle sections. They did, however, identify the river as artificially controlled in parts, with extensive levees or bank protections in places. Navigation structures, such as groins, restrict channel width considerably in certain places (Fourchambault and Charite-sur-Loire). Gravel mining intensified in the middle of the 20th century, leading to channel degradation.

Modification of the Loire Valley and its tributaries developed over centuries, with numerous hydromorphological alterations and flood control schemes. Its multiple uses extend to navigation, generation of hydro- and nuclear power from 38 dams and four power stations, recreation, and an estuary and coastal zone used for fishing, shellfish farming and tourism, with a major commercial port at Nantes. Where reaches were affected by thermal discharges, oxygen can be depleted to lethal levels for fish (Kondolf et al., 2006).

The Loire provides an important case study because management over the last ca. 30 years has taken account of the river's hydromorphology, including interventions to alleviate flooding to provide more space for the river and dam removals. It is also a highly relevant case study because of its scale, involving the entire river basin many years ahead of the WFD.

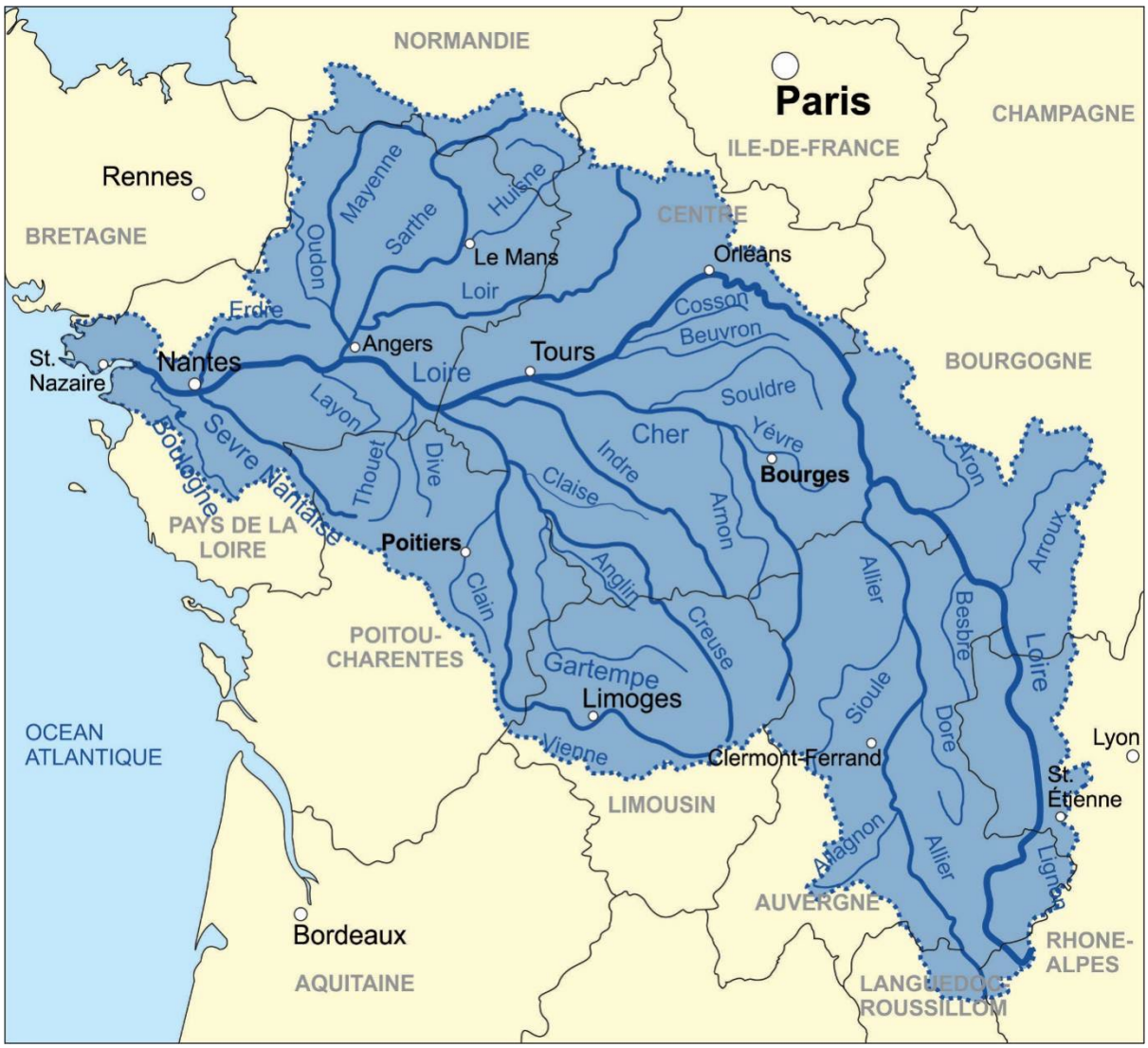


Figure 32. The Loire River Basin. Modified from Wikipedia.

In 1986, catchment authorities and the Loire-Bretagne Water Agency embarked on plans for four new dams (Serre de la Fare on the Upper Loire, Chambonchard on the Cher River, Naussac II and Le Veurdre on the Allier River) and several hundred kilometres of new dikes. These drew opposition from the 'Loire Vivante committee' comprising local NGOs and supported by WWF and French environmental action groups). The banner *SOS Loire Vivante* was used to protect what was labelled as the 'last wild river in Europe'. The campaign, involved multiple actors, with large civil demonstrations attracting extensive media coverage, as well as some intensive scientific research and conservation planning. This enabled the *SOS Loire Vivante* to provide credible alternatives for river management and flood control, with a focus on river restoration and biodiversity protection. The Atlantic salmon (*Salmo salar*), which had disappeared from most of the rivers of France, symbolised the Loire as a 'Living River', galvanising a very positive public image (Germaine and Lespez, 2017).

The civil activities led to a successful lawsuit in 1991 against the Serre de la Fare Dam that would have flooded upper catchment gorges of high scenic and conservation value. This occurred against a policy backdrop of emerging approaches to water management in France in the early 1990s with the Schema directeur d'amenagement et de gestion des eaux (SDAGE; Basin water development and management plan) and Schema d'amenagement et de gestion des eaux (SAGE), with a requirement for management plans to be drawn up by regional and local administrations. The discussions over the controversies for the management of the Loire led to the “Plan Loire Grandeur Nature”, launched in 1994. This was the first Government initiative for a long-term management strategy for a whole river . It set out to be an integrated plan to provide security from floods within, as far as possible, the natural hydrological regime, as well as promote and where necessary rehabilitate the ecosystem health of the river.

Coinciding and connected to this government-supported initiative was a ca 8 million ECU (equivalent to the euro) ‘Loire Nature’ project from 1992 to 1999, funded under the EU’s LIFE programme. This project included the purchase of land to demonstrate better approaches to floodplain management and more environmentally sustainable agriculture. A second Loire Nature project initiated in 2002 (without LIFE funding), covered the whole Loire Basin and planned for the purchase of ca 4,500 ha of land, with a total budget of ca 16 million euros. Funding came mainly from government and public bodies, including the Établissement Publique Loire, a public institution that formerly promoted large dams.

A further consequence of the Plan Loire Grandeur Nature was the removal of two dams to improve salmon migration in 1998. The Maisons-Rouges Dam (Figure 33), built for hydropower in 1922 for about 800 m downstream from the confluence of the Vienne and Creuse rivers, was a major obstacle, closest to the sea, that restricted fish migration, particularly salmon, already with reduced access to spawning grounds. Interestingly, the removal was delayed for four years because of local opposition. Its eventual removal was the first major operation of its kind in France, leading also immediately to shad and sea lamprey recolonising the Vienne and Creuse rivers upstream. Allis Shad (*Alosa alosa*) recolonised 35 km of water courses including spawning sites that were now accessible (11 km along the River Creuse and 24 km along the Vienne). The Vienne Basin now holds 80% of the Loire Basin’s sea lamprey (*Petromyzon marinus*) population. According to the European Rivers Network re-colonisation by salmon led to an increase from zero to ca 15 – 20% of the Loire’s Atlantic salmon population in the two basins.

Following removal of the dam, riffles, small gravel islands and natural banks re-emerged, with establishment of a more natural water flow and sediment regime. Monitoring of the river under the WFD by the Agence de l’eau Loire-Bretagne (Loire-Brittany Water Agency) has shown that not only connectivity improved, but the overall ecological status gradually moved from moderate in 2010 to high status in 2015. Nevertheless, the approach even in Loire-Bretagne drew criticism from the European Environmental Bureau (2010), because it was argued that the extension of time to meet WFD deadlines related to water quality was justified on the basis of disproportionate costs due to changing agricultural policies, and that awareness-raising measures were considered too difficult and time-consuming.

Notwithstanding the general challenges in relation to agricultural pollution of European water bodies, there has certainly been progress in relation to identifying many of the environmental problems in the Loire and trying to address them.



Figure 33. The former Maison Rouge dam on the Loire.
Source: Dam removal portfolio ©*Roberto Epple, ERN*

The scale of the issues of river management and continuity in the Loire are, however, immense with estimates of over 10,000 barriers with potential negative impacts on ecology, of which 90% are obsolete and with an ongoing plan for their removal, involving a budget of tens of millions of euros (European Environmental Bureau, 2010). Meanwhile, other developments involving hydromorphological alteration in the Loire were allowed, including dams for water supply, and options for recreation, in the upper reaches. Associated with these changes were strategies for flood prevention, resulting from periodic heavy rain. In France, local flood risk management plans, 'Stratégies Locale de Gestion des Risques d'Inondation' provide flood response strategies for local populations and economic interests. In the middle reaches of the Loire, an improved flood alarm system and improved evacuation plans have been put in place.

The Plan 'Loire Grandeur Nature' has instigated special protection for the important cultural and natural heritage of the middle Loire through:

- development of a network of nature reserves;
- protection and extension of riverine meadows using traditional extensive grazing habits and agri-environmental measures; and
- designation in 2000 of 280 km area from Sully-sur-Loire (Loiret) to Chalonnes-sur-Loire (Anjou) as an UNESCO World Heritage Site.

In the middle reaches, action against the further sinking of the riverbed as a result of channelisation and aggregate mining in the floodplain led to reduced dredging and stopped aggregate mining in the floodplain .

In the coastal zone, the Plan Loire Grandeur Nature has developed management plans for the estuary; protecting the wetlands and bird habitats, and managing water outflows that are sensitive to the protection of the intertidal zone. An arrangement with the Nantes-Saint-Nazaire Autonomous Harbour led to expansion from the port in exchange for safeguarding ecologically important areas between the Brière wetlands and the Grandlieu Lake, with the harbour involved in habitat restoration. The Estuaire de la Loire is a Natura 2000 site protected under the Habitats Directive (Le Dez et al., 2021).

The Plan Loire Grandeur Nature entered its third phase (2007-2013) financed with about 300 million euros by the European Union, and the French national, regional and district governments. It had the aims to:

- assure sustainable living conditions in the regularly flooded plains of the Loire River and its affluents;
- restore and maintain common goods such as the water resources, natural areas and biodiversity;
- improve and promote the natural, cultural and landscape heritage for tourism and sustainable development; and
- increase and disseminate the knowledge and appreciation of the river and floodplain ecosystem services.

It continued to Phase 4 (2014-2020) and 5 (2021-27), with further plans to extend to 2035. . The European Regional Development Fund has been an important source of finance, with e.g. EUR 226,204 provided under the 'Interregional Operational Programme for the Loire Basin' cooperation programme for the 2014-2020 period, and coming under the 'preserving biodiversity and ecological continuity' priority which part-funded a EUR 425,408 study on the restoration of the riverbed and ecological, morphological and usage trajectories in the lower Loire region.

A key element of the Plan Loire Grandeur Nature is the commitment to a long-term plan and the involvement of multiple agencies and stakeholders. This has required vision and purpose, and the successful mobilisation of funding. Such commitment could be applied to any river basin in Ireland, including at the largest scale such as the Shannon system.

The progress of the Plan Loire Grandeur Nature is also manifest in that it provides a platform for research to better understand the hydromorphological processes. The Loire was a case study in the EU REFORM project (Table 14, Deliverable 2.1), with the objectives to:

- “delineate the river and its catchment into spatial units;
- characterise the hydromorphological condition of those spatial units; and
- characterise some representative reach and morphological units using hydraulic parameters.”

The EU AMBER project (Table 14) also worked in the with the dam operators and the National Wild Salmon Conservatory [Conservatoire National du Saumon Sauvage] to maximise gains and minimise the impacts of water abstraction for hydropower, while facilitating fish migrations.

In general, the French government has adopted a multidisciplinary approach to river management that took into account hydromorphological and ecological processes and was adopted by several regional administration bodies (Gautier et al., 2000; Guzelj et al., 2020). The lessons learned from this, in a suitable pedagogical approach, are an important feature

of sustainable development in addressing complex environmental problems (Sahlberg and Oldroyd, 2010).

2.6.3 Restoration of Skjern River, Denmark

Skjern River is a medium-sized lowland river with a catchment area of 2,490 km² (Figure 34). It is the largest river in Denmark and drains the western part of the Jutland Peninsula before flowing into Ringkøbing Fjord (Andersen et al., 2005). The subsurface geology in western Jutland is dominated by Quaternary outwash plains of sand and gravel. The average yearly measured precipitation in the catchment is 89 cm/yr (1961–1990) and the precipitation reaching the surface is 108 cm/yr. The climate is oceanic temperate (annual mean temperature 8°C) (Pusch et al., 2009).

In 1960 a drainage project was designed to provide agricultural land, and between 1962 and 1968, the Skjern River, a meandering river was straightened and deepened. Embankments, dikes and drainage channels were built to lower the groundwater level. The disruption of the connection between river and wetlands owing to the presence of barriers led to the drainage of 4,000 ha of wetlands, meadows and heaths in the floodplain.

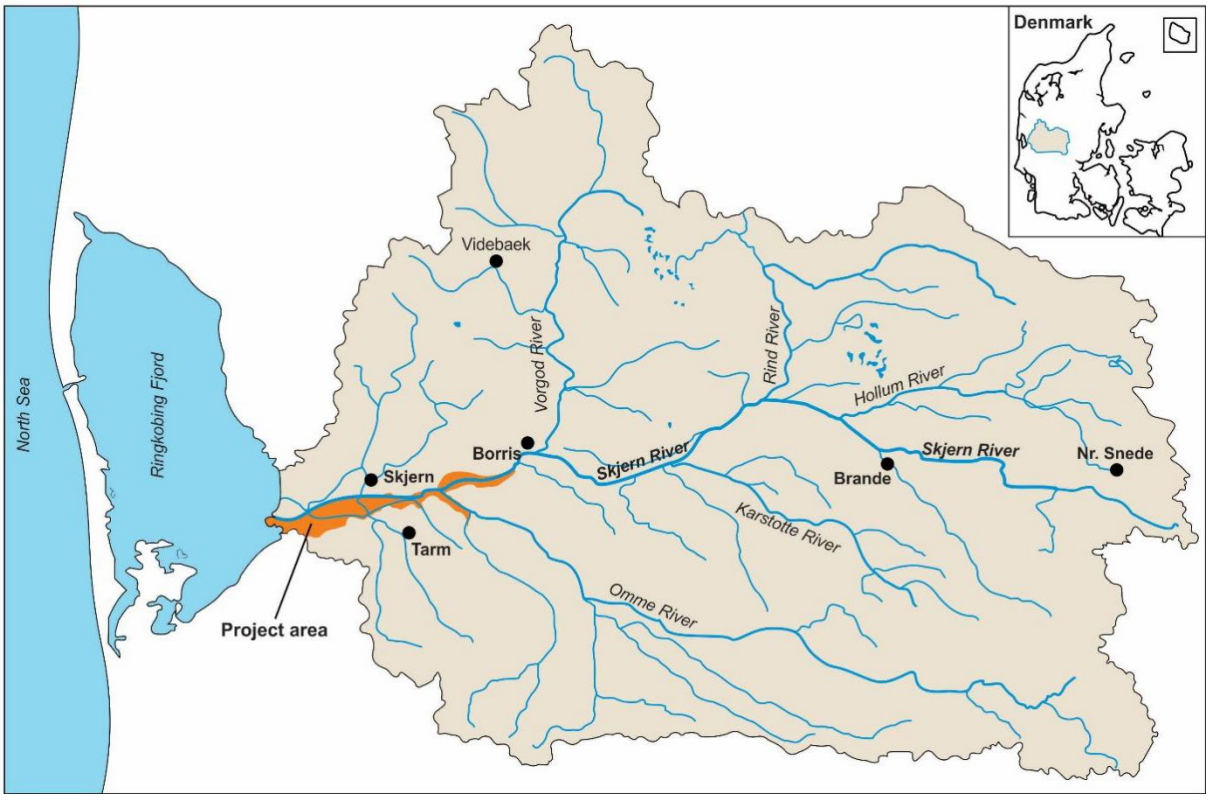


Figure 34. Map of the Skjern River catchment and the restoration project area (Pedersen et al., 2007).

In 1987, the Danish government launched a major strategy to restore marginal areas to their former natural state and to introduce more compatible land-use. As part of it, the restoration of the Skjern River took place between 1999 and 2002, implemented through the Danish Ministry of Environment and Energy (Kronvang et al., 1998).

The Skjern River (Figure 35) is considered to be one of the largest restoration projects in N. Europe. In 2003 it was awarded the prestigious Europa Nostra Prize for conserving European cultural heritage (Clemmensen, 2014). Its total budget reached 38 million euros, with financing

provided mainly by the Danish state and LIFE programme (LIFE00 NAT/DK/007116). Among others, an amount of about 13.5 million euros was used for land purchase for inclusion in the project. The Danish Ministry of Environment and Energy purchased 2,200 ha of the river valley from 300 private farmers in three land-consolidation schemes (Neilsen, 2002).

The project aimed to restore 25 km of the river and the natural water levels and their fluctuation in the river and its valley. It also targeted the restoration of the nutrient retention (nitrogen and phosphorus) capacity of the river and its valley, as well as the wetland and habitats for migratory birds by restoring the physical and hydrological dynamics of the river and its floodplain. As there was no dilution from flood water following the original drainage works, the fertilisers affected the Ringkøbing Fjord which became silted up and polluted. There was a decline in numbers and diversity for e.g. salmon and migratory birds. Problems also arose within the catchment area. Cultivation and drainage led to the peat subsiding due to oxidation and loss of water, in a number of places more than 1 m, also affecting the effectiveness of the drainage (Mitsch, 2005). Furthermore, the water turned red because the drained pyritiferous soil layer leaked ferrous substances, which were converted into ochre (Dubgaard et al., 2003). The presence of ochre sediments (FeO(OH)) in the river led to the formation of ferrous phosphate ($FePO_4$) particles that settled in the channel (Pusch et al., 2009).

The project focused on restoring a natural, meandering river channel that would periodically inundate adjacent areas and thereby re-create the former habitat types. Restoration measures included the re-meandering of the main river and tributaries, the recreation of wetlands and lakes and the removal of barriers. The restoration also aimed to promote fisheries in the downstream estuary and increase the recreational and tourist values of the project area.

In the frame of the restoration project, 2,200 ha natural area and more than 4 km of meandering water courses i.e., parts of Skjern, Omme and Gundesb Rivers have been created following, whenever possible, their previous natural routes (Figure 35). These changes were expected to improve ecological conditions.

Description of Project Activities

During the first stage of the restoration (1987-1999) public debate, scientific and technical surveys, land acquisitions, land allocations, legislation, planning, and environmental information took place. An EIA report was published in 1997 (Andersen et al., 2005). Ideas and proposals derived from the public within this stage were included in the Parliament Act on the Restoration of the Skjern River (Act no. 493, 1 July 1997).

During the second stage (1999-2002) the construction part took place. During this stage, dikes around the long, straight water courses were removed, and the old channels were filled with soil. A new, meandering river course was excavated, increasing 19 km of straight channels to 26 km in the lower sections of the river. The restored river included several outflows into the fjord so that in time this would create a delta of approximately 220 ha. Removal of five drainage bridges and two pumping stations allowed periodic natural flooding once again, re-establishing contact between the river and adjacent riparian areas.

In order to protect surrounding fields and towns from the natural floods expected to occur inside the natural area, 1.5 km of new dikes have been built. Some sections of original dikes have also been preserved, the most important being Skjern River's North Dike, which now forms the northern boundary of the natural area. As soon as the construction phase was finished, there was already an abundance of birds, fish, insects, and aquatic plants returned to inhabit the site. The final stage of the project (2002-2005) included the dissemination of information and the establishment of facilities for the public. This included 17.4 km of trails and the observation stations/towers, attracting a growing number of visitors.

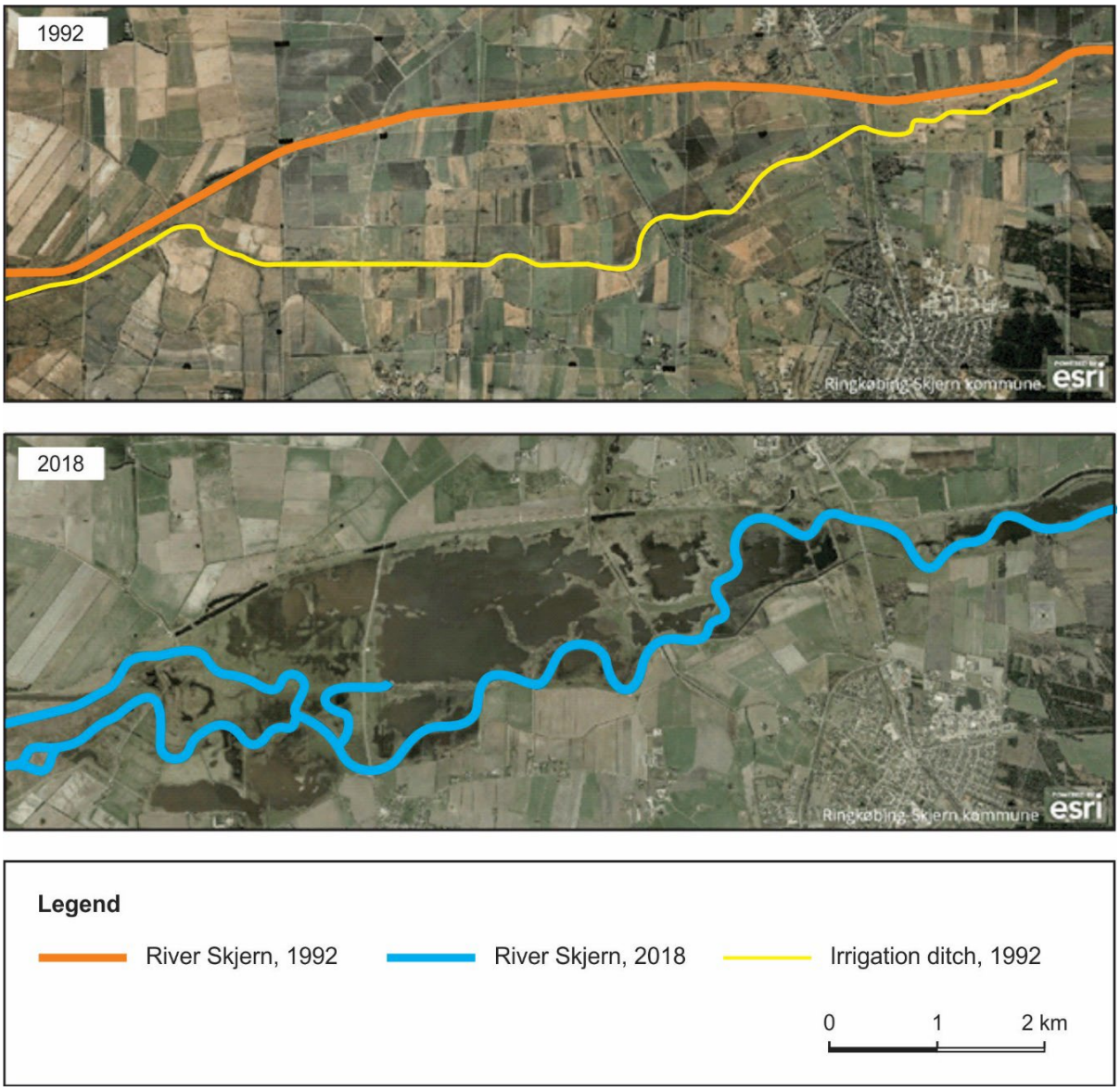


Figure 35. Skjern River before and after its restoration. Source: https://www.eea.europa.eu/data-and-maps/figures/river-skjern-denmark.

Monitoring programme

The Skjern River Act introduced the obligation to carry out a monitoring programme in cooperation between the Ministry of Environment and the regional environmental authority, Ringkjøbing County to evaluate the outcomes of the restoration (Andersen et al., 2005).

The programme was established and carried out in cooperation between the National Environmental Research Institute, Ringkjøbing County, the Danish Institute for Fisheries Research, and the Danish Nature and Forest Agency (Andersen, 2005). Major elements covered by the monitoring programme were effects on nutrient transport and retention in the project area, river morphology and habitats for macroinvertebrates, fish and macrophytes, vegetation in the river valley and amphibians, otter and migratory and breeding birds during the period 1999-2003; but initial monitoring indicated only minor changes of the overall biodiversity of the restored river (Pedersen et al., 2007).

Project outcomes

Cessation of the pumping of water and changes in the watercourse profile for Skjern River have raised the water level in the project area. As the water table is not lowered anymore by pumping, there is no more leaching of ochre sediment (SER, n.d.). According to Andersen (2005), there has been a gradual increase in the water level in the project area as a result of the closure of the two pumping stations and the reorganisation of the streams. Although there are no concrete measurements, there has probably been an increase in the water level in the part of Råddensig Kær that is closest to the river. This increase led to the formation of Hestholm shallow Lake which has an extent of about 5 km^2 (Figure 36). During high water discharges (more than about 40 m^3/s) further flooding of the river valley occurs.

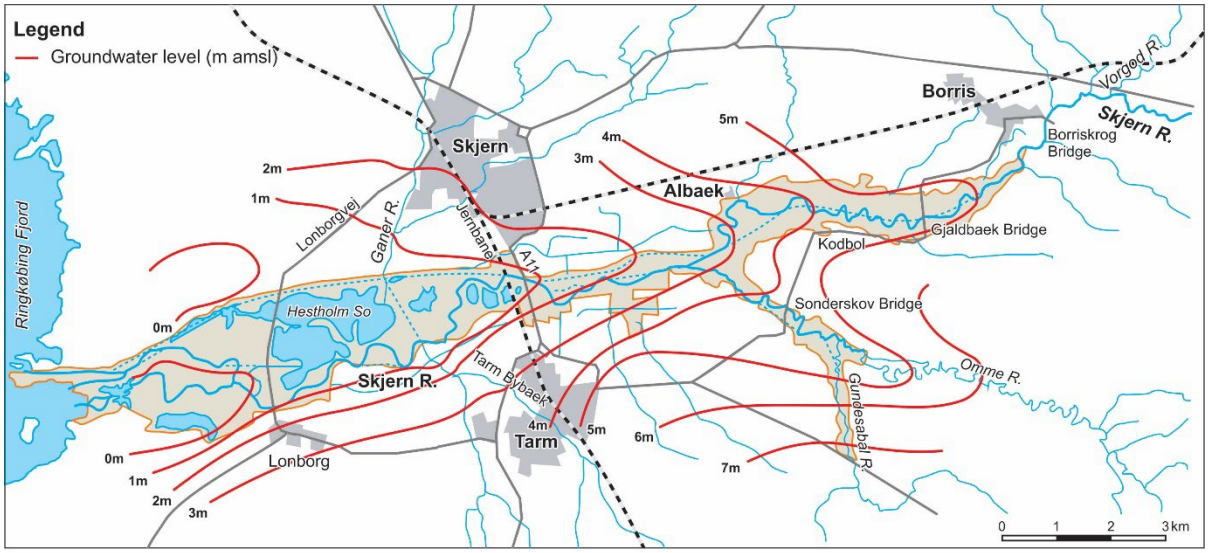


Figure 36. Piezometric map of the restored area for March 2002 (Reproduced from Andersen, 2005).

One of the main purposes of the restoration project was to restore the river valley's ability to retain nutrients and hence improve the water quality in Ringkøbing Fjord. Prior to the project implementation, it was calculated that the restoration would reduce the phosphorus supply from the Skjern River system by approximately 12% (8.4-22.3 ton/yr) and the nitrogen supply by approximately 6% (270-600 ton/yr). However, these calculations assumed that the Skjern River flowed through Hestholm Lake. With the chosen solution Skjern River flows around the lake, and hence only a small part of the water flow in Skjern River flows out and floods the

river valley. The retention of nutrients and iron in the project area is, therefore, expected to be less than anticipated. According to SER (n.d.), when the water table exceeds the ground surface, floods inundate the surrounding meadows, depositing nutrients derived from agriculture, which are filtered and prevented from entering Ringkøbing Fjord.

The overall conclusion from the early monitoring programme indicated that the transport of nutrients was not reduced significantly (Figure 37) as a consequence of the restoration (Andersen, 2005). According to the findings of the REFORM Programme (Pedersen et al., 2007), between 1999 and 2003 the nutrient load in the restored area was reduced by more than 200 ton/ha/yr for nitrogen. Pedersen et al. (2007) concluded that the restored wetlands regained their natural function and were able to purify the water before it was discharged into Ringkøbing Fjord. Moreover, the transport of nutrients through the Skjern River into Ringkøbing Fjord is largely determined by the size of the nutrient sources in the entire catchment. However, the expected results were not fully achieved since, as a consequence of the restoration, nutrient retention was less than 10%.

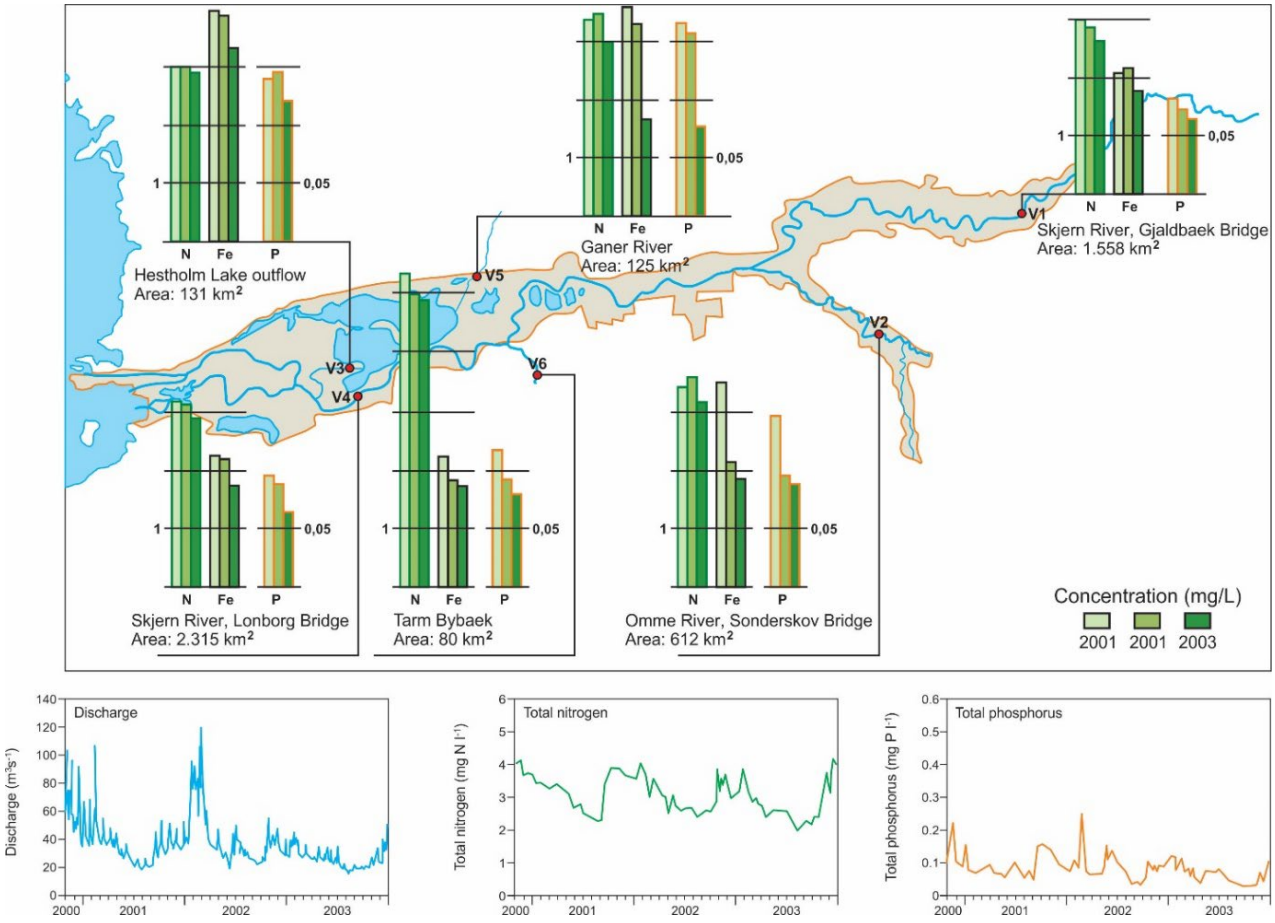


Figure 37. a. Annual average concentrations of total nitrogen, total phosphorus and total iron in the water at the 6 water quality monitoring stations (Reproduced from Andersen, 2005); b. Discharge (at the Skjern-Tarm road), total nitrogen (in the outlet from Hestholm Lake) and phosphorus (in Skjern River at Lønborg Bridge) changes 2000-2005. Reproduced from: Pedersen et al. (2007).

Andersen (2005) concluded that the overall effects of substance transport were that: a) the inputs of nutrients and iron to Ringkøbing Fjord are mainly controlled by nutrient inputs to water courses throughout the Skjern River catchment area; b). the retention of these

substances in the project area is small compared with the total transport through Skjern River; and c) the retention cannot be determined from measurements of the substance transport because of high uncertainties. The annual uncertainty of the measurement of substance transport in water courses is often calculated to be about 5-10%.

In the Skjern, the average cross-sectional area was reduced by 20-30%, the dominant depth interval decreased from 100-160 to 40-140 cm, and velocities increased to around 30-60 cm/s in the mid-channel (Feld et al., 2011). The restored water courses created better conditions for spawning fish and habitats for fish fry, and removal of barriers has allowed access to other sections of the river system for certain species of fish. Several species live in the fjord and spawn in the river. The increasing number of Atlantic salmon (*Salmon salar*) in the Skjern is a positive sign.

A very positive result is that the Skjern River restoration works improved the hydrological needs of diverse habitats for biodiversity (Bregnballe et al., 2014). Birds began arriving at the project area almost as soon as soon as the construction work finished. Since then, about 212 different bird species have been reported in the area, which is becoming an important migration staging post for many bird species. Bregnballe et al. (2014) suggested that better breeding pair density and diversity could have been achieved but at an additional cost. Additionally, otter (*Lutra lutra*) populations, which are threatened in most of Denmark, were reported present, since the river is now providing food, as well as good places to hide and breed (Andersen et al., 2005).

In the Skjern Enge (meadows), among others, three species of great international importance, the Green Snaketail (*Ophiogomphus Cecilia*), the mayfly *Baetis calcaratus*, and the stonefly *Isoptena serricornis,* were reported. The river waterdropwort (*Oenanthe fluviatilis*), floating water plantain (*Elisma natans*), and arrowhead (*Sagittaria sagittifolia*) became abundant in the restored area. Finally, about 1,200 ha of grassland has been successfully established. Although the restored grassland is not as extensive as originally planned (1,600 ha), it is expected that the increase in wetland area will benefit birds such as the spotted crake (*Porzana porzana*), avocet (*Recurvirostra avosetta*) and Eurasian bittern (*Botaurus stellaris*).

Kristensen et al. (2014) evaluating the hydromorphological outcome of the restoration in terms of in-stream, channel morphology and re-connection with the floodplain, found that relatively stable stream channels were created during restoration, but subsequently limited further improvement. For erosion and sedimentation they found a slow rate of change and, hence, the creation of islands, backwaters and oxbow lakes will take centuries to develop. Furthermore, although the restoration project had reconnected the river with its floodplain, they concluded that if the purpose of restoration was to bring back lost habitats, and the flora and fauna associated with these, then the restoration was not yet a success. It is, however, unrealistic to expect restoration to fully reconstruct a modified ecosystem to its original state, apart from the difficulties in making an accurate estimation of that.

The Danish Stream Fauna Index (DSFI), a metric of general biological quality of rivers, but originally developed to assess sensitivity of invertebrates to organic pollution, was calculated as 7, respectively, in 2000 and 2003, before and after the restoration (Andersen et al., 2005). Normally DSFI allocates a value of 1 for very badly polluted and a 7 for unpolluted streams, with a diverse fauna. Although Kristensen et al. (2014) did not assess the biological recovery, they mentioned that recently collected data indicated that many macroinvertebrates and macrophytes associated with islands, backwaters and other slow-flowing areas have not returned to the River Skjern, partly because the habitats have not been re-created.

2.6.4 Nature Based Solutions and the Cityscape

Nature Based Solutions (NBS) are increasingly recognised of vital importance for global water security (EEA, 2017; WWDR, 2018). There are also increasingly promoted of being cost- and ecologically effective for water management and protecting and enhancing multiple and simultaneous ecosystem services, that provide resistance and resilience to ecosystem shocks. The UN World Development Report (WWDR, 2018), involving contributions from a large and multidisciplinary group of water professionals, emphasised the importance of "working with nature rather than against it" (foreword by Director-General of UNESCO). It is in the area of risk reduction that NBS are often considered most effective, especially in preparedness for flooding in both rural (Addy et al., 2016; Collier and Bourke, 2020; EEA, 2020), and urban environments, especially for flood management (Costa et al., 2021; EEA, 2017; Vörösmarty et al., 2021). Burek et al. (2012) using simulation models, estimated that while NBS could reduce 1:20 year flood peaks by up to 15% locally, at a regional level, peak flow reductions were only 4%. A "few percentage points can make the difference between a flood and a disaster" (WWDR, 2018).

Dadson et al. (2017), analysing flood risk management options (Table 13) concluded that:

- "appropriately chosen land-use and land-cover interventions can reduce local peak water flows after moderate rainfall events;
- the evidence does not suggest that these interventions will have a major effect on nearby downstream flood risk for the most extreme events;
- the evidence available for the downstream effects of upstream land-use changes at large catchment scales is more limited, but at present it does not suggest that realistic land-use changes will make a major difference to downstream flood risk; and
- long-term monitoring is needed to separate the effects of land management from those of climatic variability, without this it is unwise to extrapolate the findings from individual studies to larger scales, or settings with different soil and vegetation types."

While NBS may have limited mitigation for the most extreme events, they can moderate more frequent (and smaller) flood events. Moreover, they can reduce the cost of conventional (grey) infrastructure, when used in combination with it. Sayers et al. (2015) from a UK study showed comparable flood defence benefits from conventional and natural flood management, with the latter increasing in effectiveness in more extreme climate futures (Sayers et al., 2015). At the catchment scale, there is clearly more understanding needed, and informed choices to be made about the type and location of interventions for flood management.

Adaption to flooding is only one aspect of NBS, which can offer multiple other human and conservation benefits (Breslow et al., 2017; Millennium Ecosystem Assessment, 2005; Shwartz et al., 2014). These include sustainable food production, sustainable human settlements, access to water supply and sanitation services, improved water quality, and economic benefits, all at multiple scales. The current dominance of grey infrastructure for water management is reflected in public policy and landscape and urban practices (WMO, 2007). This is perpetuated by the "orientation of economic markets, expertise of service providers, and consequentially in the minds of policymakers and the general public… resulting in a general inertia against the development and use of NBS and a bias against NBS, which are often perceived as being less efficient than anthropogenic/built systems" (WWDR, 2018).

Table 13 Types of flood risk management reviewed by Dadson et al. (2017).

Flood Risk Management theme	Specific measure	Examples
Retaining water in the landscape: water retention through management of infiltration and overland flow	Land-use changes	Arable to grassland conversion, forestry and woodland planting, restrictions on hillslope cropping (e.g. silage maize), moorland and peatland restoration
	Arable land-use practices	Spring cropping versus winter cropping, cover crops, extensification, set aside
	Livestock land practices	Lower stocking rates, restriction of the grazing season
	Tillage practices	Conservation tillage, contour/cross slope ploughing
	Field drainage (to increase storage)	Deep cultivations and drainage to reduce impermeability
	Buffer strips and buffer zones	Contour grass strips, hedges, shelter belts, bunds, riparian buffer strips, controls on bank erosion
	Machinery management	Low ground pressures, avoiding wet conditions
	Urban land-use	Increased permeable areas and surface storage
Retaining water in the landscape: managing connectivity and conveyance	Management of hillslope connectivity	Blockage of farm ditches and moorland grips
	Buffer strips and buffering zones to reduce connectivity	Contour grass strips, hedges, shelter belts, bunds, field margins, riparian buffer strips
	Channel maintenance	Modifications to maintenance of farm ditches
	Drainage and pumping operations	Modifications to drainage and pumping regimes
	Field and farm structures	Modifications to gates, yards, tracks and culverts
	On-farm retention	Retention ponds and ditches
	River restoration	Restoration of river profile and cross-sections, channel realignment and changes to planform pattern
	Upland water retention	Farm ponds, ditches, wetlands
Making space for water: floodplain conveyance and storage	Water storage areas	On- or off-line storage, washlands, polders, impoundment reservoirs
	Wetlands	Wetland creation, engineered storage scrapes, controlled water levels
	River restoration/retraining	River re-profiling, channel works, riparian works
	River and watercourse management	Vegetation clearance, channel maintenance and riparian works
	Floodplain restoration	Setback of embankments, reconnecting rivers and floodplains

Regrettably, the importance of NBS often manifests when ecosystems have been degraded and conventional practices are shown to be insufficient (Russi et al., 2013; WWDR, 2018). Currently, it is estimated that globally less than 1%, and probably closer to 0.1% of total investment in water resources infrastructure and management is devoted to NBS (WWDR, 2018). The awareness and discussion on the societal benefits of NBS compared with, or in combination with, grey infrastructure is an important need, from communities to regional planners and national policymakers (WMO, 2006). That discussion can be hindered when poor designs or high hopes for NBS fail. These situations can arise from what WWDR (2018) describes as myths and/or uncertainty about how natural infrastructure functions, and the practical application of, especially regulating ecosystem services. A more informed discussion and integration of ecosystem services and their valuation into planning and decision-making remains a major challenge in addressing policy inertia (Kremer et al., 2016; Liquete et al., 2016; Russi et al., 2013). The social and conservation value of urban streams and small water bodies remains underplayed, and the WFD focus on the catchment can, ironically hinder an appreciation of urban waters and the associated educational opportunities (Schanze et al., 2012).

The European Commission (2013) adopted the 'Green Infrastructure Strategy' to promote green infrastructure in rural and urban areas, but achieving such as vision requires greater awareness among multiple sectors. Management interventions as part of a wider integrated approach to mitigate water risks affecting water quantity and quality, and enhancing biodiversity and social needs necessitate formalised integration offered by 'System thinking'. NBS can play a role in the source (e.g. through wetland restoration or land-use practices) and pathways (e.g. through various ways of increasing conveyance and storage capacity) (Figure 38). *Ad hoc* interventions bring many risks and potential disappointments.

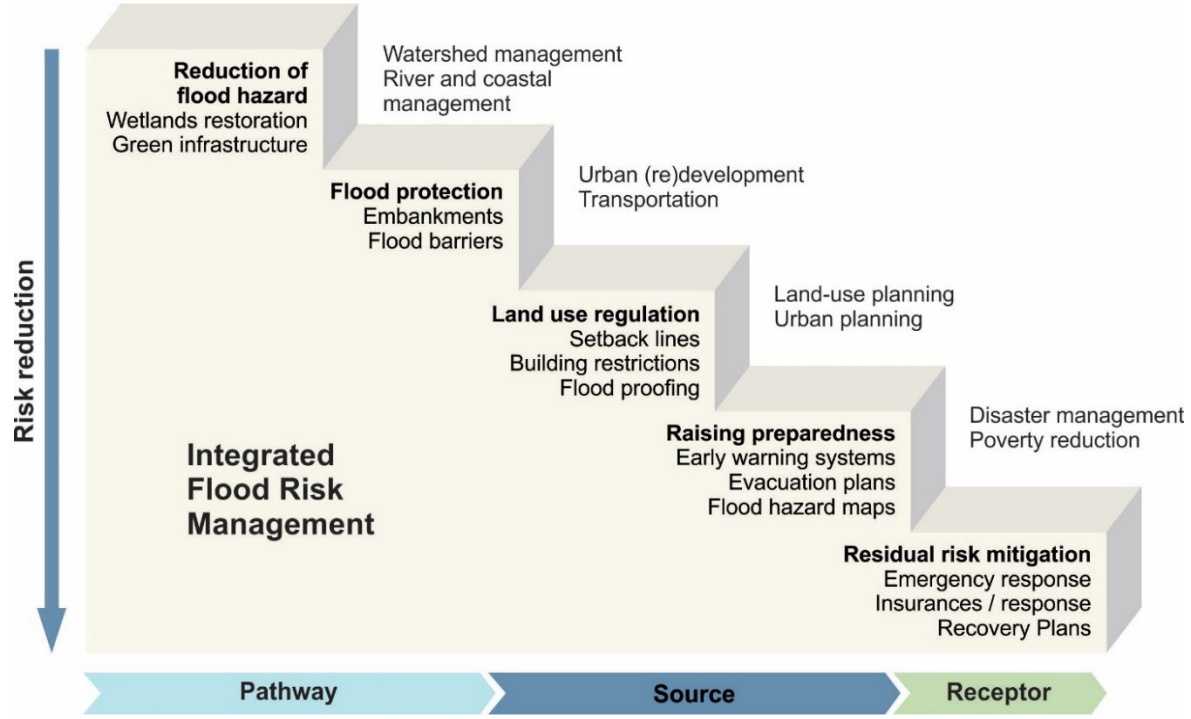


Figure 38 Schematic of flood risk management from pathway to receptor. Reproduced from: WWDR (2018).

WWDR (2018) report on NBS identified a number of key information gaps and research needs. These included “improving the:

- understanding of the hydrological performance of different ecosystem types and sub-types, including under different management regimes, to enable improved projections of NBS performance in locally specific sites;
- knowledge of the hydrology of land-use and change, particularly its impacts at scale;
- understanding of the impacts of ecosystem loss and degradation on hydrology;
- understanding of the links between ecosystems, water and ecosystem services to better underpin predictions of the impacts of (positive or negative) ecosystem change on human well-being;
- assessments of the hydrological and socio-economic performance of NBS applications, and sharing this knowledge, including NBS failures. Raymond et al. (2017) suggest a potential roadmap for assessing the performance of NBS;
- indicators for the effectiveness and efficiency of NBS and in particular those that enable ecosystems, hydrology, and economic and social outcomes to be linked;
- guidelines for conducting holistic cost-benefit analyses that include non-water-related co-benefits;
- communication tools for NBS;
- integration of ecosystems into land-use planning and IWRM; and
- understanding of the socio-political drivers of water resources policy and management to better understand and identify effective triggers to stimulate transformational change.”

Urban case study

This case study focuses on the urban-scape which by its very nature requires an integrated approach to water management and where hydromorphology is a key element. Increasingly there are rehabilitation programmes for urban rivers, and developing methodologies for doing that, across Europe (Schanze et al., 2012). Urban green infrastructure, employing a range of techniques, including re-vegetation of impermeable surfaces, constructed wetlands, bioswales and green roofs can improve water availability during dry periods, reduce flood damage from extreme events, and improve water quality. Individual or combined techniques can contribute majorly to provisioning, regulating and cultural ecosystem services, and enhancement of biodiversity and its connectivity in cities (Casado-Arzuaga et al., 2013; Kelly-Quinn et al., 2014; Newcastle Gateshead Green Infrastructure, n.d.; Palliwoda et al., 2017; Soga et al., 2015; Tezer et al., 2012).

In New York City, lower costs of green infrastructure compared with conventional Combined Sewer Overflow (CSO) retention led to a programme for rain gardens, bioswales, green roofs, constructed wetlands and other nature-based approaches (The City of New York, 2008). Like many cities in the world, this requires an adaptive and somewhat opportunistic approach to retrofitting green infrastructure into the city fabric. This can be a particularly technical and psychological challenge for city planners because regulatory approaches for city water management are largely a legacy of reliance on grey infrastructure (Davis et al., 2015; WWDR, 2018).

Nevertheless, the idea of using green infrastructure in cityscapes is gaining traction (Willems et al., 2020). It is recognised for the potentially high economic and social benefits it brings, but also for the policy instruments needed for meaningful citizen engagement (Lovell and Taylor, 2013; Mees et al., 2019). A case in point is how partnerships have developed in the municipality of Amsterdam in the Netherlands on how to apply NBS for better water management. It includes interactions among a range of stakeholders, from individual citizens to municipality departments, a process best facilitated by government (Osborne, 2006; Willems et al., 2020).

While new urban areas can incorporate green infrastructure for water management from a blueprint, as is occurring in a number of new 'sponge cities' (Xu and Horn, 2017) in China, for established cities a more adaptive management and multisectoral approach is needed (Nickel et al., 2014; WWDR, 2018). The 'rainproof initiative' in Amsterdam is developing the 'sponge effect' potential of the city, using public and private spaces such as streets, gardens and rooftops. The philosophy is described by Henk Ovink:" What is unique about the Dutch way of working with water is that we think and work systemically. With a comprehensive approach knowing everything is ultimately connected to water. We see this complexity as strength, an opportunity." Given the history and culture of the Netherlands, the Dutch have a very intimate connection with water. The Rainproof initiative is a semi-independent programme building a broad coalition. It came about after 150 mm of rain fell in the city of Copenhagen in just an hour and a half (the average equivalent of two months of rainfall in the city) in July 2011, causing one billion euros in damage and that stimulated the Dutch action.

In Amsterdam, the water management agenda is strongly aligned with the city's Green Space policy, designed to enhance and promote the use and availability of urban parks and forests for multiple uses. The city recognises the importance of using green spaces to help meet its 'Climate Proof' targets for 2050 with forward planning. This combined nature-water-people approach aims to create an additional 50,000 m^2 of green roofs, increased rainwater absorbance, maximising potential for this in industrial areas, car parks, and along motorways; increased protection of trees, linking up nature through wildlife corridors and providing more habitat for nesting birds in buildings, urban farming and promotion of 'green neighbourhoods. To meet the city's goals a key concept is integration. This involves partnerships between public services and citizens, and using various mechanisms across the life-cycle of projects (Sharp, 2017; Willems et al., 2020). While early motivation of citizen groups can be strong, this often wanes later on affecting delivery. Similar findings have been found for citizen science projects (Wehn and Almomani, 2019).

The experience of Amsterdam is shared with other municipalities in the Netherlands through a 'coalition of the willing', supported by the public service authorities and engaging with a broad spectrum of other stakeholders. The success of the programme is "all about the dialogue" (Kasper Spaan Beleidsadviseur Klimaatadaptatie, RESILIO, pers comm.). There are many similarities with the other case studies in that the success is dependent on both the technical engineering innovations and the enabling social processes.

Chapter 3

3 Knowledge development in hydromorphology through the WFD

3.1 EU projects to support WFD implementation

The WFD has stimulated research on how hydromorphological alterations affect ecological communities and the methodology needed to assess that. It also motivated connecting the more physically orientated research communities with those working on biological systems, and with increased attention to research across all water body types. In parallel, it has drawn attention to ecosystem functions and processes that underpin assessment techniques used for the WFD. Management is dependent on the understanding of how complex and integrated biogeophysical processes drive the structure of biological communities (Moss, 2008b; Vadeboncoeur et al., 2002). Identifying, and more particularly quantifying, processes as causal agents of ecosystem properties involve varying degrees of uncertainty in measurement and non-deterministic stochasticity. For a Directive that is rooted in the assessment of cause and effect, this requires a degree of mental agility in those charged with its implementation. An added dimension superimposed on this is the challenge of determining reference conditions. For HMWBs and AWBs, the problem of determining a reference state on which to base ecological potential may be a 'moot point' because they are fundamentally altered in many different ways, such that determining any sort of consistent baseline may be impossible, or at least highly contested. It merely accentuates the difficulties that occur with determining reference condition for water bodies that are subject to minimal pressures and impact (Bailey et al., 2004). Furthermore, the widespread occurrence of hydromorphological alterations affecting a small part of a water body, or considered historical such as medieval water mills, makes the inclusion of these in ecological assessment not only difficult but highly contentious. It could also be argued that a river downstream of a water storage reservoir is, *de facto,* heavily modified and that reduced flows exacerbate water pollution. These considerations highlight both the inevitability of extensive knowledge gaps in the assessment of the ecological impact of hydromorphological alteration, as well as the need for a pragmatic, using best available knowledge, approach to that assessment. For reasons such as this, an EU ECOSTAT group is further considering the how to assess HMWBs and the relevant baselines to use (Martina Bussettini, ECOSTAT pers comm.)

A number of the findings and development of research to better understand the relationships between hydromorphology and ecosystem integrity have been covered in the previous sections. This includes the difficulties in understanding and assessing how pressure-related stressors may have synergistic, additive or antagonistic effects (Townsend et al., 2008). Hydromorphological pressures can act in concert with other pressures, increasing the vulnerability of freshwater communities to impact. The following sections provide a summary of EU and Irish projects that have attempted to unravel the cause and effects of hydromorphological alterations.

This research stimulated by the WFD also built a community of scientists and practitioners and opportunities for training among a new generation. Key EU projects that were accessed up to April 2024 that included important findings related to, or with a focus on, hydromorphology are summarised in Table 14.

Table 14. EU Projects including important hydromorphological elements, with links to reports, publications and a list of publications where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
The Development and Testing of an Integrated Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates	AQEM	2000-2002	EC FP5 Energy, Environment & Sustainable Development, Key Action 1: Sustainable Management and Quality of Water, Contract No: EVK1-CT1999-00027	AQEM Website Link	Full List of Publications Special Issue Hering et al. (2004) Buffagni et al. (2004) Taxa database List of taxa key values Software: ASTERICS/PERLODES	The objectives of AQEM include the development of an assessment framework for streams in Europe based on the ecological quality of benthic invertebrates. Through this assessment framework, the classification of stream stretches occurred. Another objective was to provide information on the extent of stream degradation and its impact on the macroinvertebrate population. It was an early EC funded project to be created to provide technical support for WFD implementation.
Development, Evaluation and Implementation of a Fish-based Assessment Method for the Ecological Status of European Rivers. A Contribution to the Water Framework Directive.	FAME	2000-2002	EC FP5 Energy, Environment & Sustainable Development, Key Action 1: Sustainable Management and Quality of Water, Contract No: EVK1-CT-2001-00094	FAME Website Link	Summary Report Final Report EFI Software	The objectives of FAME were to develop, evaluate and implement a fish-based assessment method for the ecological status of European rivers hence contributing to the implementation of the WFD. A fish-based ecological assessment method was developed in this project for the implementation of the WFD to improve the ecological restoration of rivers. Fish monitoring was conducted through the type-specific and site-specific development approaches integrated with the FAME assessment method: the European Fish Index (EFI). Under EFI, reference conditions were set and ecological assessment was carried out by identifying and measuring the deviation from reference conditions.
Standardisation of River Classifications: Framework method for calibrating different biological survey results against ecological quality classifications to be developed for the Water Framework Directive	STAR	2002-2005	EC FP5 Energy, Environment & Sustainable Development, Key Action Water, Contract No: EVK1-CT-2001-00089	STAR Website Link	WPs Deliverables Software Furse et al. (2006)	Standardise river classification systems and intercalibration of existing ecological assessment methods for European rivers. The main objective of the project was to classify the suitable assessment method for streams and rivers on the basis of standardisation. The project successfully intercalibrated existing methods based on the benthic invertebrates that helped in the classification of river water quality. Moreover, a matrix of class boundaries exhibiting an Ecological state was established associated with different methods and the intensity of pressures on the river. Sampling in the STAR project was based on the method devised in the FAME project to test the protocols highlighted in the FAME project

Table 14. (continued) EU Projects including important hydromorphological elements, with links to reports, publications and a list of publications where available

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
Ecological quality and functioning of shallow lake ecosystems with respect to the needs of the European Water Framework Directive	ECOFRAME	2000-2002	EC FP5 Energy, Environment & Sustainable Development, Key Action 1: Sustainable Management and Quality of Water, Contract No: EVK1-CT-1999-00039	Defunct ECOFRAME CORDIS Tab Link	Moss et al. (2003) Ketola et al. (2005) Montagud et al. (2019)	The objectives of ECOFRAME were to: a) test the sampling frequencies given for lakes in the WFD; b) determine the degree of change in each lake and relate it to their present ecological status; c) discover possible merge of ecotypes using collected data and existing databases; d) test developments of the WFD parameters which may prove more easily comparable among different ecoregions; and e) decide with statutory stakeholders on the best criteria for determination of ecological status of shallow lakes, and determine their ecological quality with the WFD criteria. ECOFRAME adopted palaeo-ecological and diatom methods for recognising the status of water in shallow lakes. Addressed the practical implementation of WFD towards shallow lakes through the identification of common features among ecotypes and ecoregions. A pan-European typology and ecological classification system for shallow lakes was developed. Moreover, the biological features were refined and tested for suitable reproductivity among ecoregions.
Relationships between the ecological and chemical status of surface waters	REBECCA	2003-2007	EC FP6 Specific Targeted Research or Innovation Project Contract No: SSPI-CT-2003-502158	Defunct REBECCA EUGRIS Tab Link	Summary Report Lyche Solheim et al. (2008) Moe et al. (2008)	The objectives of REBECCA were to: a) collect spatial and temporal data of EU rivers, lakes and coastal water bodies; b) carry out chemical and biological sampling of lakes and rivers in 19 EU counties and identify habitats under hydromorphological stress. Phytoplankton was an indicator of eutrophication while macrophytes were better indicators of hydromorphological pressures on the lakes. A toolbox of methods was produced, but the link is no longer functional. There have, however, been many developments since then.

Table 14. (continued) EU Projects including important hydromorphological elements, with links to reports, publications and a list of publications where available

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
North South Shared Aquatic Resource	NS SHARE	2004-2008	EU INTERREG IIIA Programme for Ireland/Northern Ireland	Defunct	Final Report Curtis et al. (2009) RHAT Manual	The objectives of NS SHARE were: a) the inter-regional improvement and monitoring at the three RBD levels; and b) the involvement of the public to raise awareness towards aquatic ecosystems conservation and management. This project resulted in the development of a field evaluation approach for WFD categorisation. The method was developed using the USEPA Rapid Bio-Assessment Protocols and the Environment Agency's River Habitat Survey. Following additional consultation and advice from the European Committee for Standardisation (CEN), the approach developed under NS Share was updated and adopted as the River Hydromorphology Assessment Technique (Toland and Murphy, 2013).
Restoring Europe's rivers	RESTORE	2008-2013	EU LIFE^{+} Programme for Nature and Biodiversity	RESTORE Website Link	RiverWiki	The objectives of RESTORE were to: a) bring people together and establish networks through its website, events and conferences; and b) share and promote the exchange of knowledge on river restoration to give professionals the information they need to restore rivers and improve habitats for wildlife. Its key result is a website/database that serves as a focal point for knowledge exchange within the European river restoration community.

Table 14. (continued) EU Projects including important hydromorphological elements, with links to reports, publications and a list of publications where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
Water Bodies in Europe - integrative systems to assess Ecological Status and Recovery	WISER	2009-2012	EU FP7 Theme 6: Environment including Climate Change Contract No: 226273	WISER Website Link	Full List of Deliverables Deliverable D3.3-4 Deliverable D3.4-2 Deliverable D3.4-4 Full List of Publications Special Issue (ISSN:1573-5117) Hering et al. (2010) Feld et al. (2011) Hering et al. (2013) Moe et al. (2013) Schmidt-Kloiber et al. (2013) Clarke (2012)	The objectives of WISER were to: a) develop tools for the hydromorphological status assessment of lakes, river and coastal water bodies in 16 EU countries; b) develop specific assessment methodologies for different groups of organisms i.e. fish, invertebrates, aquatic flora and fauna; and c) evaluate existing assessment methods and modelling the improvement in hydromorphological status of the river, and coastal ecology in those countries by using more than 90 databases. The project developed methods for assessing and restoring aquatic ecosystems. It also summarised the importance of, and reviewed the progress on, the restoration of water bodies from eutrophication, pollution from organic sources and unregulated land-use.
Action for the Reinforcement of the Transitional Waters' Environmental Integrity	ARTWEI	2010-2013	INTERREG IVA South Baltic Programme 2007-2013	Website Link	Case studies Project media & publications	The objective of ARTWEI was to strike an operational balance between EU requirements for the Maritime Spatial Planning framework, Water Framework Directive and Integrated Coastal Zone Management, which often overlap or contradict each other. In the frame of this project, the 'South Baltic Transitional Waters' partnership network of the key institutions was based on the long-term cooperation agreement and supported by the regional activity network of EUCC – The Coastal and Marine Union.

Table 14. (continued) EU Projects including important hydromorphological elements, with links to reports, publications and a list of publications where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
DOLMANT-The development of lake management tools	DOLMANT	2011-2014	EU INTERREG IVa	DOLMANT Website Link	Report	DOLMANT aimed to develop lake management tools that integrate the biological, hydromorphological and physiochemical properties of lakes with lake and lake catchment variables in cross-border catchments, to improve and maintain the ecological status of lakes. This project defined ecological relationships in large Irish lakes – Lough Neagh and Lough Erne – and smaller cross-border lakes focusing on the relationship of the BQEs with external pressures e.g. eutrophication and climate change.
REstoring rivers FOR effective catchment Management	REFORM	2011-2015	EU FP7 Theme 6: Environment including Climate Change Contract No: 282656	REFORM Website Link	Full List of Deliverables Deliverable 1.1 Deliverable 1.2 Full List of Publications Belletti et al. (2018) Belletti et al. (2017) García de Jalón et al. (2017) Rinaldi et al. (2015) Rinaldi et al. (2016)	The objectives of REFORM were to: a) provide a framework which addresses the relevance of dynamic processes at various spatial and temporal scales for improving the success of hydromorphological restoration measures; and b) assess more effectively the state of rivers, floodplains and connected groundwater systems. A key result was a hydromorphology framework incorporating multi-scale spatial and temporal aspects.
DEVelopment Of innovative Tools for understanding marine biodiversity and assessing good Environmental Status	DEVOTES	2012-2016	EU FP7 Theme 6: Environment including Climate Change Contract No: 308392	DEVOTES Website Link	Full List of Publications Andersen et al. (2014) Teixeira et al. (2016) Full List of Deliverables	The objectives of DEVOTES were to: a) gain an understanding of the impact of human activities and climate change on marine biodiversity; b) identify the barriers and bottlenecks that prevent GES from being achieved; c) test indicators and develop new, innovative ones to assess biodiversity in a harmonised way throughout the 4 regional seas; d) develop, test and validate innovative integrative modelling and monitoring tools about ecosystem and biodiversity changes, for integration into a unique and holistic assessment; and f) propose and disseminate strategies and measures for ecosystems' adaptive management, including the active role of industry and relevant stakeholders.

Table 14. (continued) EU Projects including important hydromorphological elements, with links to reports, publications and a list of publications where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
Development of an innovative and user-friendly indicator system for biodiversity in groundwater dependent Ecosystems	AQUALIFE	2013-2018	LIFE12 BIO/IT/000231	AQUALIFE Website Link	Fattorini et al. (2020) Di Lorenzo et al. (2018) Petitta et al. (2015) Iannella et al. (2020)	AQUALIFE project aimed to: a) develop and validate a set of indicators for the assessment and map construction of the status and trend of GDE biodiversity, and b) develop and disseminate the AQUALIFE Package, an indicator system to assess the biodiversity of GDEs.
Managing the effects of multiple stressors on aquatic ecosystems under water scarcity	GLOBAQUA	2014-2019	EU FP7 Research, technological development and demonstration Contract No: 603629	GLOBAQUA Website Link	Toolbox Toolbox Manual Deliverable 011 (D5.11) Full List of Publications Von Schiller et al. (2017) Liu et al. (2018) Giakoumis & Voulvoulis (2018)	The objectives of GLOBAQUA were to: a) analyse the relationship between certain pressures and biota and their influence on water scarcity by applying an integrated approach on six basins in EU countries; b) define/analyse policy gaps and alternative restoration practices under the WFD; c) investigate the impact of ecosystem services on socio-economic development; and d) identify hydromorphological pressures and study the interactions responsible for ecological and chemical modification in aquatic ecosystems. The project found that water scarcity in the studied basins has increased due to intensive land-use and climate change. Moreover, the chemical analysis conducted indicates a high possibility of pollutants on biota under hydromorphological pressures.
SOLUTIONS for present and future emerging pollutants in land and water resources management	SOLUTIONS	2013-2018	EU FP7, Research, technological development Contract No: 603437	SOLUTIONS Website Link	Full List of Outcomes Brack et al. (2015) Brack et al. (2017) Van Gils et al. (2019) Faust et al. (2019) Deliverable 9.1	The objectives of SOLUTIONS were to: a) identify risk substances mainly chemicals and devise measures to prevent their inflow in the European water bodies; b) provide a coherent framework for the assessment, monitoring and prioritisation of pollutants to minimise the ecological impact they cause on water bodies; c) provide tool-based assessment methods for the identification of emerging water pollutant; and d) identify obstacles caused by pollutants towards achieving the WFD targets and aiding the policy development. This project successfully identified river basin-specific pollutants through a model-based monitoring approach in the Danube River. It also highlighted water scarcity elements as a result of compound prioritisation in the Ebro and Llobregat case studies.

Table 14. (continued) EU Projects including important hydromorphological elements, with links to reports, publications and a list of publications where available.

Programme	Acronym	Duration	Funder	website	Reports/papers	Key objectives/key outputs
HydroMorphological assessment and management at basin scale for the Conservation of Alpine Rivers and related Ecosystem Services	HyMoCARES	2016-2019	European Regional Development Fund Interreg TN Alpine Space Action Group 7: Green infrastructure	HYMOCARES	Full List of Deliverables Deliverable D.T.1.3.1 Deliverable D.T1.2.1 Deliverable D.T2.3.1 Toolbox	The objectives of HyMoCARES were to: a) integrate ecosystem services in the alpine river basin by developing novel methods of planning to focus on the river hydromorphological factors; b) identify operational and planning activities and ensuring the integration at basin scale by analysing the continuity of sediments; c) identify indicators that influence the hydromorphological quality of rivers and monitor their physical and ecological impact of restoration efforts taken; and d) identify the operational and management areas where HyMoCARES method can be applied for hydromorphological restoration. HyMoCARES provided a methodological framework for the assessment of Alpine river's eco-services. It also provided guidelines for the assessment of hydromorphological indicators through sectorial guidelines and legislative recommendations.
Managing Aquatic ecosystems and water resources under multiple stress	MARS	2014-2018	EU FP7 Theme 6: Environment including Climate Change Contract No: 603378	MARS Website Link	Full List of Publications Final report	The objectives of MARS were to: a) understand the chemical and biological changes in ground- and surface water due to the impacts of natural and anthropogenic stressors; b) explore large datasets and understand the impact of stressors by targeting environmental flows, fish and benthic habitat in lakes and rivers; c) advocate river basin management for the restoration of lakes and rivers highly affected by stressors; and d) address gaps in RBMPs and implementation of measures and tools to achieve ecological restoration. MARS addressed basic stressors caused by climate change and hydromorphological alterations and informed stakeholders about necessary action plans.

Table 14. (continued) EU Projects including important hydromorphological elements, with links to reports, publications and a list of publications where available.

Programme	Acronym	Duration	Funder	website	Reports/papers	Key objectives/key outputs
Fish friendly Innovative Technologies for Hydropower	FIThydro	2016-2020	EU Horizon 2020 H2020-EU.3.3.2. Contract No: 727830	FITHYDRO Website Link	Full List of Publications Full List of Deliverables Deliverable 2.1 Deliverable 2.2 Policy Brief	The main objective of FIThydro was the decision support in commissioning and operating hydropower plants by use of existing and innovative technologies. It concentrated on mitigation measures and strategies to develop cost-efficient environmental solutions, and on strategies to avoid individual fish damage and enhance population development. A risk-based Decision Support System was developed to enable operators to fulfil the requirements of cost-effective production while also meeting environmental obligations and targets under EU legislation, such as the WFD.
Adaptive Management of Barriers in European Rivers	AMBER	2016-2020	EU Horizon 2020 H2020-EU.3.5.2. Contract No: 689682	AMBER Website Link	List of deliverables Full List of Publications Belletti et al. (2020) Jones et al. (2020) Sun et al. (2021) Policy Brief	The main objective of AMBER was the effective restoration of stream connectivity by addressing the impacts of river fragmentation and the establishment of comprehensive distribution maps in 11 EU counties. Key output includes the adaptation of effective barrier management strategies to reduce river fragmentation as it largely impacts rivers in the Balkan, Scandinavia and Baltic regions.

Further details of some of the EC funded projects are provided below. A sub-set of the hydromorphology research community was involved in the WFD intercalibration process, where the national assessment techniques for determining quality status of water bodies were compared, co-designed and, as far as feasible, aligned across Member States (Poikane et al., 2014) (see Section 2.1). The focus of many of the early EU projects (e.g. AQEM, FAME, ECOFRAME, STAR) did not include a large element of hydromorphological assessment, although aspects of hydromorphology were often included as important for influencing the ecological assessment. The REBECCA project included hydromorphology in assessment of pressures and impacts on surface waters with a pan-European hydro-ecoregion approach (Wasson et al., 2006). The WISER project, a successor to REBECCA, reviewed progress on the restoration of water bodies from eutrophication, pollution from organic sources and unregulated land-use, and developed methods for assessing and restoring aquatic ecosystems. However, the project highlighted that pressures from hydromorphological alterations on biota were largely unknown in the majority of the water bodies across the 16 countries engaged in the project (Hering et al., 2013). WISER developed methods for the assessment of the hydromorphology of lakes (Jurca et al., 2021; Miler et al., 2015, 2013) building on the 'Lake Habitat Assessment' of Rowan et al. (2006). More recent projects at the EU level have included a significant component of hydromorphology (Table 14), with research often employing a multidisciplinary approach.

The EU FP7-funded REFORM project undertook an evaluation of current practices using a process-based, hierarchical and flexible framework for hydromorphological assessment, and considering multiple factors and scales of region, catchment, landscape unit, segment, reach and geomorphic units (Gurnell et al., 2016; Rinaldi et al., 2015b). The range of hydromorphological attributes studied comprised: geology, topography, hydrology, land-use, vegetation cover, river morphology, lateral confinement, channel dimension, river energy, hydraulics, bed and bank sediments, flow regime, floodplain, groundwater-surface water interactions (based on valley confinement, substrate character, geology and climate), riparian and aquatic vegetation. This led to an exhaustive list of indicators (Rinaldi et al., 2015b). For example, for fish the project investigated effects of: 1) water abstractions; 2) flow regulation; 3) increased flow; 4) flow regime modification timing; 5) hydropeaking; 6) river fragmentation; 7) morphological alterations; 8) impoundments; 9) channelisation/cross-section alteration; 10) channelisation/meander realignment; 11) alteration of riparian vegetation and in-stream habitat; 12) embankments, levees or dikes; 13) sedimentation; 14) sand and gravel extraction; 15) loss of vertical connectivity; and 16) other pressures. Alteration of in-stream habitat and impoundment were the hydromorphological pressures found to have the most widespread effect on fish species (23 and 19, respectively). The results indicated that 49% of the studied European freshwater species showed a significant (>90% c.l.) response to hydromorphological pressures, but that leaves 52 fish species that did not.

Considerable information on assessment and implementation of river restoration measures are presented on the project website , including an easily accessible 'wiki' and links to scientific publications. All of the guides provide background information on processes, practical information on design, and advice on assessing multiple benefits and working with stakeholders (Grabowski et al., 2019). A key conclusion was that designing restoration projects that aim for an imagined past or static reference state is flawed thinking (Rinaldi et al., 2015b).

Similar conclusions were found from assessment of river restoration projects from the WISER project (Feld et al., 2011), a review of restoration projects in the US (Bernhardt et al., 2005; Palmer et al., 2007, 2010) and the more philosophical considerations of Hilderbrand et al (2005) when considering meeting expectations of river restoration.

The AMBER project (Table 14), a collaboration of 20 partners from 11 countries, including Ireland, established the first-ever comprehensive distribution maps of the European Rivers. It is estimated that only 44% of the rivers in Europe are in a good environmental and ecological state. The project estimated 1.2 million barriers threatening freshwater bodies in 36 European countries (Belletti et al., 2020). Pressure from agriculture, with highly dense crossing of river roads and elevation of surface water, were the main predictors of barrier density affecting the morphology of water bodies. The project found that while unfragmented rivers remain in the Balkan, Baltic and Scandinavian regions, these require conservation efforts on an urgent basis to protect them from anthropogenic moderations such as dams, and with a need to assess the effect of climate change (Belletti et al., 2020). The project in collaboration with hydroelectric companies, fisheries authorities (including the Inland Fisheries Ireland, IFI), water providers, NGOs, anglers and local authorities, promoted the EU Biodiversity Strategy's 2030 goal to restore 25,000 km of rivers to a free-flowing state (see Section 2.2.7 on Arterial drainage). The adaptive management strategy was evaluated based on its impact on fish habitat restoration through seven different scenarios. Scenarios 0 and 1 represent reference and natural conditions in which there are no dams on a river and potentially unaffected by hydromorphological pressures. Scenario 3 also reflects current hydromorphology, but with the introduction of habitat stressors having a threshold limit of two days. In scenario 3, the lowering of dams occurs such that the impounding will be 20 km long, and 10 km long in scenario 4. In the 5th and 6th scenarios, the combined impact of the 2nd, 3rd and 4th scenarios are observed that involve the lowering of dams and the introduction of augmentation. An evaluation was done based on the calculation of the fish number in the stressed habitats along with an analysis of altered fish habitats (Parasiewicz et al., 2013; Vezza et al., 2015). The project recommended a barrier management strategy to reduce river fragmentation and mitigate the impact of hydromorphological alterations on water bodies.

The RESTORE project with six partners from four countries built upon work started under two previous LIFE projects which had established the European Centre for River Restoration (ECRR). Its main outputs were the European river restoration website , which provides information on river restoration at European level and the RiverWiki, which contains information on 1,399 river restoration case studies from 31 countries, and provides details and explanations of policy opportunities and constraints, the effectiveness of different restoration methods, design issues, and project costs and benefits. Moreover, in the frame of the project, a good practice guide 'Rivers by Design' for planners, developers and architects was produced. This was to raise awareness of the potential to include river restoration in urban regeneration schemes. It produced a report 'River restoration - the art of the possible' (RESTORE, 2013) that described project actions; key findings and recommendations for practical river restoration, flood risk management, spatial planning, economics, hydropower and habitats, fisheries and agriculture. The project highlighted the need for river restoration and raised public awareness of relevant issues i.e. floodplains as opposed to engineering solutions for river management, and the utilisation of legislation for motivating hydropower companies to allow fish passages and restore river morphology.

3.2 Transposition and administration of WFD in Ireland

3.2.1 Legislation and overview of administrative structures for WFD implementation in Ireland

The roles and responsibilities of multiple agencies with a legal mandate for the implementation of the WFD were reviewed by Irvine et al. (2002) as Ireland started to implement the WFD. While there have been some re-orientation of roles and responsibilities with each River Basin Plan, and some moving around of sections in central government departments, the policy landscape has remained similar, albeit somewhat more consolidated than when the WFD was implemented in 2000. A proposed Water Act to consolidate overall water governance was not effected, although some key legislations clarified the roles and responsibilities of the Local Authorities and planning legislation taking into account the requirements of the WFD (Cocchiglia et al., 2012). Nevertheless, Ireland's record of compliance with EU legislation remains generally unsatisfactory, and see Chapter 6.

Article 3 of the WFD requires that Member States determine the "appropriate competent authorities." In Ireland, the EPA takes the leading role in developing the assessment and reporting tools for the WFD (see below). Particularly important is the Government Department with overall responsibility and accountability for reporting WFD progress to the European Commission. Currently, this is the Department of Housing, Local Government and Heritage (DHLGH). A number of other Departments and their agencies have statutory responsibility for activities and management roles that come under the requirements of the WFD. Some of these have statutory responsibilities for the implementation of policies and compliance with them. A number of the branches of government are involved in guiding the methods and processes that come under the overall ambitions of the WFD.

In Ireland, the WFD was transposed into law by the *European Communities (Water Policy) Regulations 2003* (S.I. No. 722 of 2003) as amended, *The European Communities Environmental Objectives (Surface Water) Regulations 2009* (S.I. 272, 2009) and the *European Communities Environmental Objectives (Groundwater) Regulations 2010* (S.I. 9, 2010) established the legal framework to implement the environmental objectives of the WFD in Ireland. The 2009 Regulations transposed the requirements of Articles 6 and 9 of the WFD into Irish legislation, to provide measures for the protection of surface waters whose status is deemed to be high or good (or good ecological potential for HMWBs or AWBs), and for restoration of waters deemed to be at less than good status. Schedule 1 of the Surface Water Regulations, 2009 listed 24 relevant public bodies.

The *Water Policy Regulations 2003* identify the Environment Protection Agency EPA) as the Competent Authority with responsibility for coordinating WFD implementation. The current DHLGH has primary responsibility for policy and legislation relating to water and is responsible for overseeing the implementation of the WFD and providing necessary financial support. Local Authorities, and other public bodies, are involved to different extents depending on their individual remits and competencies. In practice, this makes the implementation of the WFD in Ireland a process involving multiple public bodies with differing formal roles with respect to the implementation of the WFD. This was also identified at the inception of the WFD (Irvine et al., 2002). In the first phase of the WFD, it was envisioned that the Local Authorities would play a significant and shared responsibility with formally created implementation groups.

Lessons from the first administrative phase led to the emergence of the Local Authorities Waters Programme (LAWPRO) to coordinate and implement management activities, working with local communities and collaborating with other public bodies to meet WFD objectives. The current administrative structure (Figure 39) is set out in the Water Action Plan of the third cycle River Basin Management Plan (DHLGH, 2024a). Five local authority regional committees, supported by LAWPRO, coordinate WFD measures at a regional and local level. Each committee produces a 'Regional Integrated Catchment Management Programme', setting out the areas prioritised for action at the water body, sub-catchment or catchment level. The programmes outline the measures to be implemented and the bodies responsible for them.

The EPA provides technical advice, effectively directing the process in consultation with the Department. An 'operational committee' made up of public and implementing bodies supports the regional committees. LAWPRO working 'on the ground' with other stakeholders provides an interface of technical advice and communication.

The overall administrative structure (Figure 39) is overseen by the 'National Coordination and Management Committee' (NCMC) and reports to the 'Water Policy Advisory Committee' (WPAC). A 'National Technical Implementation Group' (NTIG) advises on national implementation and acts as "a forum to coordinate actions among relevant State actors and address any operational barriers to implementation." This group is chaired by the DHLGH. The administrative structure is set up so that the NCMC should report to the WPAC to monitor implementation and advise the Minister on progress. The minutes of the WPAC are publicly available.

From the July 2025 minutes, the membership of the WPAC was:

- Department of Housing, Local Government and Heritage (Chair) (DHLGH)
- Environmental Protection Agency (EPA)
- Office of Public Works (OPW)
- Geological Survey of Ireland (GSI)
- Commission for Regulation of Utilities (CRU)
- Department of Agriculture, Food and the Marine (DAFM)
- National Parks & Wildlife Service (NPWS)
- County and City Management Association (CCMA)
- Health Service Executive (HSE)
- Uisce Éireann
- Inland Fisheries Ireland (IFI)
- Local Authority Waters Programme (LAWPRO)
- Department of the Environment, Climate and Communications (DECC)
- An Fóram Uisce

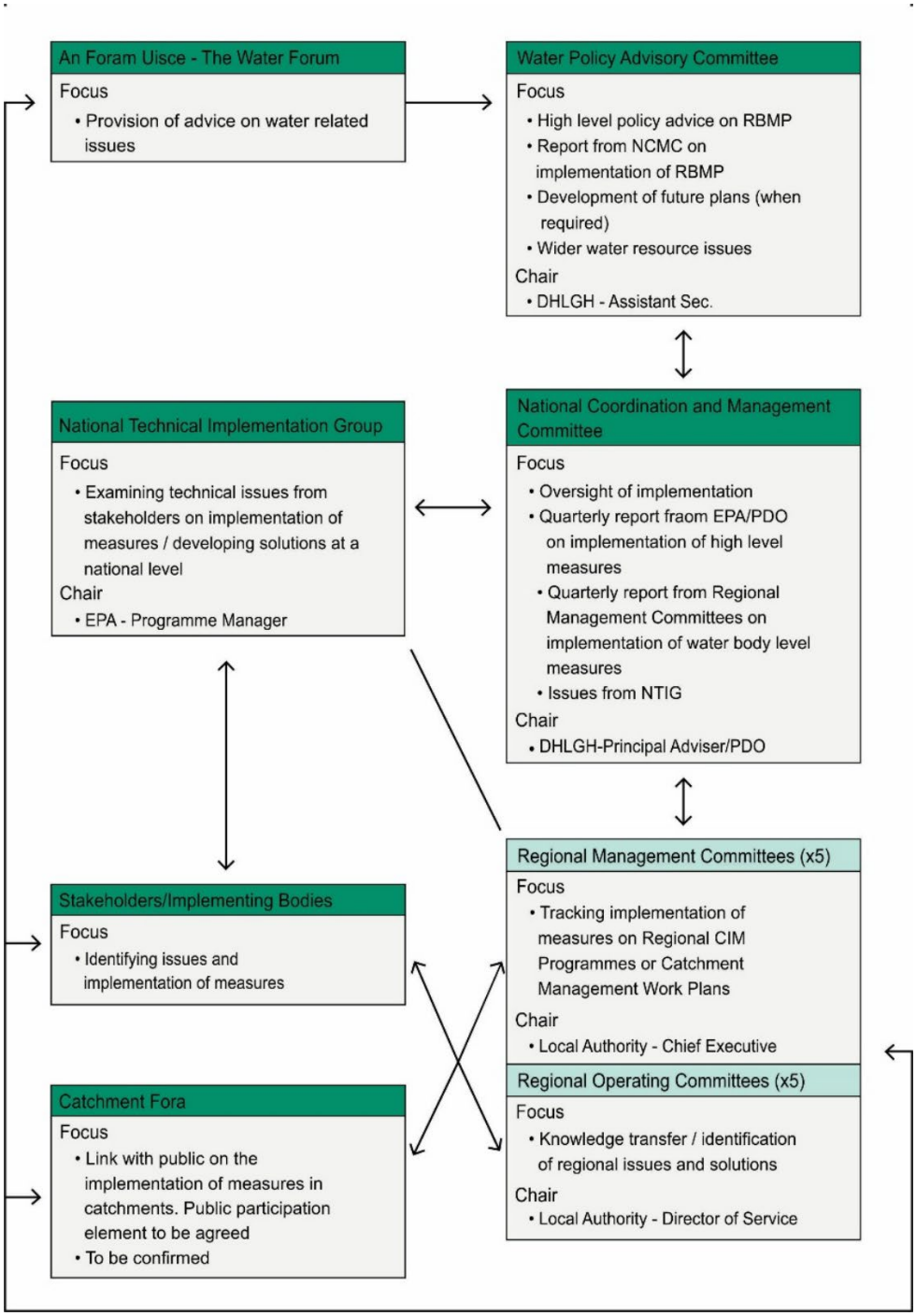


Figure 39. Overall coordination structure for the Water Framework Directive for the 2nd River Basin management cycle (DHLGH, 2024a).

Details of actions on individual water bodies, as laid out in the River Basin Management Plans (RBMPs) (see below) are disseminated through the catchment.ie website: a collaboration between the DHLGH, the EPA, and the LAWPRO.

3.2.2 Guidance and planning governing hydromorphological alterations

The structures described above and the actions outlined include the responsibility of the relevant bodies to address all pressures that can lead to a failure of WFD environmental objectives, including hydromorphology and, logically, the interaction between hydromorphological and other pressures. While Fehér et al. (2012) reported that about 40% of the rivers and 20% of lakes in Ireland were at risk of failing to meet their WFD environmental objectives because of hydromorphological alterations, this provided a very general overview, both because it was an early assessment but also, and importantly, it could not discern the extent of those pressures, and distinguish among the multiple factors at play for hydromorphological alteration, as outlined in the earlier sections of this report. The hydromorphological monitoring of water bodies is led by the EPA in collaboration with the OPW for rivers, the Marine Institute for transitional and coastal waters and Waterways Ireland for canals (although this water body type is not included in this report), and no public body seems to have formally assigned responsibility for the hydromorphological monitoring of groundwater of GDEs (EPA, 2021a). The frequency of monitoring of hydromorphology in Ireland's national surface waters monitoring programme is six years.

The next phase of hydromorphology monitoring is outlined by EPA (2021a): "In rivers and lakes, hydromorphological status of all surveillance and high status sites will continue to be assessed using the River Hydromorphological Assessment Technique (RHAT) and the lake Morphological Impact Assessment System (MImAS), respectively. RHAT will also continue to be used at sites where hydromorphological pressures are suspected of impacting ecology. In transitional and coastal waters, the new Hydromorphological Quality Index (HQI) (Keogh et al., 2020) will be used to assess the hydromorphological condition of all surveillance water bodies and operational water bodies identified as being at risk from hydromorphological pressures."

The EPA guidance is also clear in that: "Only sites that are at high status based on other ecological quality elements may be downgraded to good status based on the hydromorphological assessment failing to reach high status. As the rules of the Directive currently stand, this is the only scenario where hydromorphology can be used in classification. The role of hydromorphological assessment in water body classification is currently a topic of discussion at the European level." This does not prevent the assessment of hydromorphology across a 5-scale scheme and, as advised by Kampa et al. (2019), assessment of hydromorphology across what would effectively be a 2-scale scheme does not sufficiently support management and mitigation of hydromorphological alterations.

IFI (also a member of the WPAC) has a collaborative programme with OPW to assess the effects of hydromorphological alteration and work towards mitigation of impacts on fish habitat, spawning and migration (Brew and Gilligan, 2019; King et al., 2008; OPW, 2021a). A risk assessment in the Republic of Ireland carried out by the Freshwater Morphology Programmes of Measures and Standards (POMS) Study (Houston and Thompson, 2008; King et al., 2010) assessed the effects, primarily, of channelisation and intensive land-use, and what was needed for management and assessment for freshwater bodies. It was concluded from extrapolation of 60 studied water bodies, that 580 were under hydromorphological pressure. The project led to a range of suggested supplementary (not presumably Supplementary Measures as defined by the WFD) management recommendations (Table 15). An Environmental Drainage Maintenance (EDM) study conducted by the OPW and IFI identified actions during routine river maintenance of arterial drainage works to reduce the

environmental impact of river channelisation (King et al., 2000) (Table 16). See also Section 2.2.7.

3.2.3 Links of WFD with other EU legislation relevant to hydromorphology

The WFD is linked to a number of other EU Directives in several ways. The Birds Directive (2009/147/EC) and Habitats Directive (92/43/EEC) and Environmental Impact Assessment Directive 2014/52/EU have direct importance for the management and prevention of physical modifications on Irish water bodies. The Industrial Emissions Directive (2010/75/EU) (that repealed the Integrated Pollution Prevention and Control Directive (IPPC) Directive 2008/1/EC) provides a consolidated and integrated approach to the prevention of impact on water bodies from industrial activities, which could include hydromorphological alterations. Licensed discharges may affect chemical status (of surface or groundwaters) or directly affect biological status (e.g. via thermal discharges). Thus, an industrial installation might affect the achievement of good ecological status by affecting different elements that can affect surface or groundwaters.

An overview of relevant European and Irish legislation that relates to the hydromorphological alteration of Irish water bodies is provided in Table 17, and key statutory and non-statutory bodies involved shown in Table 18. Of key relevance in linking hydromorphological alteration with other EU Directives are Directives relating to habitat and species protection, as well as environmental impact assessment.

Table 15. Best Practice Measures Toolkit indicating measures that could be used to address Morphology Pressures and Sub Pressures. After Houston and Thompson (2008).

Pressure	Sub-pressure	Impact	No.	Measures	
Channelisation & Flood embankments	Channel alteration - straightening, deepening, widening of channel	Loss of morphological and ecological diversity	1	Re-meandering of straightened channels	
			2	Narrowing of channels	Assisted natural recovery
			3	Re-construction of pools	
			4	Substrate enhancement	
		Loss or impairment of riparian zone	5	Fencing programmes to exclude livestock	
	Flood walls and embankments	Reduced floodplain area/ loss of riparian zone and marginal habitats/ reduced connectivity with floodplain/ entrapment of sediments	6	Removal or relocation of flood banks	
	Drainage maintenance works (dredging and control of vegetation)	Loss of morphological and ecological diversity Disturbance of riverbed and banks/ mobilisation of sediments/ loss of in-stream and riparian vegetation	7	Application of OPW Environmental Drainage Maintenance guidelines	
			8	Incorporation of river restoration & fisheries enhancement projects (see Measures 2-4)	
			9	Measures to facilitate natural recovery	
	Hard protection - sheet piling, vertical walls	Loss of riparian zone and marginal habitats/loss of lateral connectivity/loss of sediment input	10	Removal of hard bank reinforcement/revetment, or replacement with a soft engineering solution	
	Culverts	Loss of morphological diversity and habitat	11	Re-opening of existing culverts	
Impoundments & Regulation	Dams & weirs	Loss of morphological and ecological diversity in impounded reach / Reduction in productivity / Accumulation of sediment upstream / Loss of sediment input downstream	12	Removal of structure and de-silting of impounded reach	
		Inadequate residual flow downstream	13	Adoption of operational protocols	
Intensive land-use	Over-grazing & bank trampling	Bank erosion/ over-widening of channel/ sediment deposition in water courses Loss of riparian zone	14	Stabilisation of riverbanks	
			15	Application of REPS special measures	
			16	Fencing programmes to exclude livestock	
	Forestry operations	Increased run-off rate through drainage systems/silt deposition in water courses / shading effects	17	Application of best practice guidelines	
	Peat extraction	Peat silt run-off and deposition in water courses	18	Operation and maintenance of silt traps	
			19	De-silting of affected reaches	
	Hard surface run-off - urban drainage, roads etc	Run-off of silt and deposition in water courses Increased peak flows Bank erosion	20	Incorporation of SuDS processes	
Barriers to migration	Dams, weirs, bridge aprons, & culverts	Lack of continuity Obstruction to migration of fish and invertebrates	21	Removal of structures	
			22	Structural modification - construction of fish passes etc	
			23	Adoption of operational protocols	

Table 16. Strategies to be implemented by Office of Public Work machine crews during routine maintenance in arterially drained Irish channels (after King et al., 2011).

1. Protect bank slopes	Retain vegetation on the nonworking bank
	Minimise scraping of bank slope on working bank
2. Restrict maintenance to channel	Remove in-stream material only
	No 'new' digging. Remove recent deposition
	Retain marginal vegetation
3. Deposit spoil on the bank full	Maximise spoil deposition on the bank full or spoil heaps
	Minimise spoil deposition on bank slopes
4. Selective vegetation removal	Retain Canary and other marginal grasses
	Remove Bulrush, Bur-reed and Water celery
5. Leave the section untouched	If channel capacity is not affected, then leave intact
	Only maintain if environmental works required
6. Management of trees	Leave intact if not reducing channel capacity
	Remove overhanging branches to flood level
	Use a saw or secateurs for removal, not an excavator
7. Manage the berm to form a two-stage channel	Remove the top of berms to low flow levels
	Remove vegetation and soil from gravel berms
	Replace sod to the berm where feasible
8. Replace stones and boulders	Reinstate material removed by maintenance operations
	Reinstate boulders into the channel from spoil heaps
	Boulders placed below low flow level and staggered
9. Loosen bed gravels	Loosen or toss bed gravels to wash out fines
	Only considered between 1 July and 30 September
10. Excavate Pools	Excavate pools staggered along channel centre and side
	Place excavated material to form riffles
	Completed only if channel bed of suitable material

The Birds Directive (79/409/EEC; codified as Directive 2009/147/EC), provides a framework for the conservation and management of wild birds, requiring the designation of Special Protection Areas (SPAs). The Habitats Directive (92/43/EEC) on Conservation of Natural Habitats and of Wild Fauna and Flora, required Member States to designate Special Areas of Conservation (SACs). Together with the SPAs, these form the Natura 2000 network of protected sites.

Together, the Birds and Habitats Directive are transposed into Irish law by S.I. No. 477/2011 *European Communities (Birds and Natural Habitats) Regulations 2011*, as amended). The 2011 Regulations consolidated the *European Communities (Natural Habitats) Regulations 1997 to 2005 and the European Communities (Birds and Natural Habitats) (Control of Recreational Activities) Regulations 2010*, as well as addressing transposition failures identified in rulings of the Court of Justice of the EU (CJEU). It is the "basic responsibility of all agencies of the state, including planning authorities, to act diligently to ensure that their decisions in the exercise of their functions, as well as their actions, comply fully with the obligations of the Habitats Directive" (DEHLG, 2009).

The protection of SACs previously relied on the prevention of potentially damaging activities through a list of "notifiable actions" needing consent from the NPWS. These are now replaced by 'Activities Requiring Consent' (ARCs), of which there are currently 38 covering a comprehensive range of activities potentially damaging to SACs.

Where activities from a plan or a project (in combination with other plans or projects) may have an impact on a SAC or SPA, there is a need for screening for an Appropriate Assessment (AA) (Articles 6(3) and 6 (4) of the Habitats Directive (92/43/EEC)) followed by an Appropriate Assessment if required. The EPA provides a publicly available spatial visualisation indicator tool for where AA might be needed. It contains a number of layers that have been used for the characterisation of Irish water bodies that may be at risk of failing to meet the WFD environmental objectives.

Hydromorphological pressures identified in the tool "include sediment/siltation pollution and alteration to the physical environment", with sub-categories of "channelisation, embankment, dams, barriers, weirs, locks, culverts, land drainage, overgrazing and bank erosion." Separate searchable layers are 'Abstraction', 'River Extractive Industry Pressures', and 'Groundwater Hydromorphology Pressures'. The tool includes a large mix of 'stories', which from a cursory exploration seem to relate mainly to small local interest information pieces relates to e.g. schools or tidy towns, rather than a portal to substantive reports.

The Irish National Parks and Wildlife Service (NPWS), charged with overseeing the implementation of the Habitats Directives, produced a 'Guidance document for Planning Authorities' (DEHLG, 2009), revised in 2010, with the replacement of 'Statement for Appropriate Assessment" by 'Natura Impact Statement' (NIS). This must be completed before project approval. The NIS and the AA must be completed prior to project approval and are not conditional on proposed assessment or surveys. This reflects a key aspect of AA to ensure that potential impacts on a Natura 2000 site are "at the forefront of every decision made in relation to plans and projects at all stages, including decisions to provide funding or other support."

Table 17. National and international legislation related to hydromorphological alterations.

Piece of legislation	Number	Related aspect
Water Framework Directive	Directive 2000/60/EC	Requires compliance with pre-existing Directives to achieve the objective of good water status in all European freshwater bodies. It is the core legal framework of direct importance in the assessment and mitigation of hydromorphological alterations' impact on fresh and coastal water bodies.
Floods Directive	Directive 2007/60/EC	Requires a preliminary assessment to identify the areas under flood risk in both coastal and river basins. Under this Directive flood risk management plans and maps are drawn.
Freshwater Fish Directive	Directive 78/659/EEC (repealed)	Repealed by Directive 2006/44/EC of the European Parliament and of the Council of 6 September 2006 on the quality of fresh waters needing protection or improvement in order to support fish life (Codified version), which was implicitly repealed w.e.f 21/12/2013, by the WFD
Integrated Pollution Prevention and Control Directive (Updated by Industrial Emissions Directive, see below)	Directive 96/61/EC	Requires effective monitoring of industrial and agricultural activities that may lead to the discharge of pollutants in water bodies above set legal standards. The link with hydromorphology is indirect, as this is not specified in the legislation.
Environmental Impact Assessment Directive	Directive 85/337/EEC Directive 2003/35/EC	Requires an assessment of the potential impacts of projects above a certain threshold of size or extent within defined sectors. Assessment should be related to hydromorphology or the interaction of hydromorphology with other factors that may lead to damage to the environment including human well-being.
Strategic Environmental Assessment Directive	Directive 2001/42/EC	Requires that the environmental consequences assessment of certain plans and programmes should be identified during their preparation and before their adoption. It also requires an in-depth assessment of land-use, agricultural, transport and other infrastructural plans to reduce impacts, including hydromorphological alterations of water bodies.
Birds Directive	Directive 2009/147/EC	Direct importance on how physical modifications can have an impact on bird species. Codified Directive 79/409/EEC on the Conservation of Wild Birds.
Habitat Directive	Directive 2009/147/EC	Promotes the conservation of natural habitats and provides specific protection of habitat types and species specified in the relevant annexes. This includes the requirement of an Appropriate Assessment of threats to habitats and species and of designated, or proposed, SACs.
Industrial Emissions and Environmental Impact Assessment Directives	Directive 2010/75/EU	Direct importance on how physical modifications and discharges through air or water affect the environment. This will include negative effects from hydromorphological alteration, or the interaction, of pollution and hydromorphology.

Table 17 (continued). National and international legislation related to hydromorphological alterations.

Piece of legislation	Number	Related aspect
Nitrates Directive	Directive 91/676/EEC	Requires the implementation of Nitrate Action Plans to limit the emission of nutrients into water, including measures to protect the risk of nutrient transport. Monitoring programme required to establish permitted derogation for a load exceeding 170 Kg N per ha.
European Marine Strategy	Directive 2008/56/EC	Requires the assessment of anthropogenic pressures on the marine ecosystem to protect marine biodiversity. An important strategy for analysing the modifications in the marine environment from natural and anthropogenic pressures.
Common Agriculture Policy (CAP)	EU Regulation 1305,1306,1307, 1308/2013	Ensure the maximum agricultural production in all EU countries without exerting any direct and indirect agricultural pressures, including on the hydromorphology, of surface- and groundwaters.
Regulation on the prevention and management of the introduction and spread of invasive alien species	EU Regulation 1143/2014	Requires measures to be taken to tackle the threat to biodiversity and related ecosystem services that invasive alien species pose which take different forms, including severe impacts on native species and the structure and functioning of ecosystems.
Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)		Requires the monitoring of human activities adversely impacting the marine environment of North-East Atlantic. Proper assessment of hazardous wastes, processes like eutrophication and environmental conditions is mandatory to identify morphological pressures.
European Green Deal		River Restoration projects to protect European rivers from pressures exerted by human activities i.e. construction, agricultural and industrial pollutants. A key initiative is the restoration of 25,000 km of river bodies across Europe by 2030 by removing barriers that hinder water flow.
Wildlife (Protection) Act, 1972	No 39 of 1976	Direct importance on how hydromorphological pressures and any kind of physical modifications impact the sustainability and resilience of wild aquatic animals.
European Communities Environmental Objectives (Surface Water) Regulations, 2009	S.I. No. 272 of 2009	Restoration of surface water bodies to achieve the good status of water as mentioned in the WFD. Restoration is primarily based on the reduction of pollutants, hazardous chemicals and morphological alterations in a surface water body.
European Communities Environmental Objectives (Groundwater) Regulations, 2010	S.I. No. 9 of 2010	Restoration of groundwater resources from the excessive discharge of harmful agricultural and industrial effluents. These regulations enhance the protection of groundwater dependant ecosystems (GDEs).
Water quality-Guidance standards on assessing the hydromorphological features of transitional and coastal waters	EN 16503	It describes a protocol for field survey and feature recording.
Water quality-Guidance on determining the degree of modification of the hydromorphological features of transitional and coastal waters	EN 17123	It guides on assessing the modification of hydromorphological features of transitional and coastal waters.

Table 17 (continued). National and international legislation related to hydromorphological alterations.

Piece of legislation	Number	Related aspect
European Communities (Water Policy) Regulations, 2003	S.I. No. 722 of 2003	Key regulations for controlling morphological pressures on water bodies by making Local Authorities and EPA responsible for conducting assessments to ensure compliance with morphological standards devised by the WFD.
European Communities (Birds and Natural Habitats) Regulations	S.I. No. 477 of 2011 S.I. No. 293 of 2021	Where a hydromorphological alteration affects a protected site, overarching considerations (presumably in the judgment of the Minister) can be evoked to permit damage to the SAC, but with even less protection for the candidate SAC.
Water Policy (Amendment) Regulations	S.I. No. 413 of 2005	Basic and supplementary measures to promote sustainable water use. New regulations to specifically address and control morphological pressures.
Arterial Drainage Acts	No. 3 of 1945 No 14 of 1995	Regulation of public and private drainage schemes.
Good Agricultural Practice for Protection of Waters Regulations	No. 588 of 2025	The Regulations give further effect to several European Directives including Directives in relation to protection of waters against pollution from agricultural sources (“the Nitrates Directive”), dangerous substances in water, waste management, protection of groundwater, public participation in policy development and water policy (the Water Framework Directive).
EPA Act, 1992	No. 7 of 1992	General overview of the preservation, protection and improvement of the environment, the rational use of natural resources, the control of pollution, and related matters. A broad range of guidelines on the type of pressures and related mitigatory measures. Requires treatment for all industrially discharged effluents.
Protection of the Environment Act, 2003	S.I. No. 27 of 2003	Protection of water bodies from harmful activities and natural processes that may result in morphological alteration. Requires that upon the completion of any activity, the restoration measures must be adopted
EPA Licensing Regulations, 1994	S.I. No. 85 of 1994	Regulation of activities that exhibit pressures on water bodies to be operated only through a proper licence.
EIA Regulations, 1988 to 2001	S.I. No. 221 of 1988 S.I. No. 538 of 2001	Regulations and procedures for the assessment of public and private projects in the context of pressures they put on the environment require pre-operational assessment.
Planning and Development Regulations, 2001, as amended	S.I. No. 600 of 2001 S.I. No. 70 of 2002	Requires environmental impact assessment of planning and developmental projects as development based on unsustainable planning impacts the characteristics of water bodies, resulting in non-compliance with WFD objectives. Regulations imply that the planning of developmental projects must consider the impacts and pressures on surface water bodies. Ensure that planning must control water impoundments and abstractions to reduce morphological pressures.
Planning and Development Acts, 2000, as amended	No. 30 of 2000	Provides the legal framework for planning system, including how land can be developed, the permitted types of development, the process for making of planning decisions and related appeals and enforcements of decisions, with implications for natural biota, water bodies and morphological pressures.

Table 18. An overview of the statutory bodies involved in the implementation of the Water Framework Directive in Ireland, and the main NGOs with a formal (mandated by Government) or informal role, and with a summary of relevant interest in hydromorphology.

Type	Organisation	Role/Responsibility
STATUTORY	Environmental Protection Agency (EPA)	Responsible for the development of strategies in collaboration with other agencies for the timely management of physical alterations in surface water bodies. Responsible for issuing licences and regulating urban wastewater discharges through proper aquatic management and regulations. EPA also reports to the Water Policy Advisory Committee (WPAC) about monitoring and implementation of WFD objectives in the river basin plan. This also includes the implementation of all the environmental objectives mentioned in the RBMPs.
STATUTORY	Water Policy Advisory Committee (WPAC)	WPAC provides policy advice and assistance to the Minister for Housing, Local Government and Heritage and policy directions for the implementation of environmental objectives mentioned in the river basin plan and WFD.
STATUTORY	Department of Housing and Local Government & Heritage (DHPLG)	DHPLG plays a central role in the Water Sector Policy, including the governance and funding of Irish Water. The department is also responsible for oversight of the Water Sector Group, including the implementation of the WFD and Marine Strategy Framework Directive. The department also makes laws that ensure the regulation of farming practices to reduce water pollution.
STATUTORY	Local Authority Waters Programme (LAWPRO)	LAWPRO is responsible for conducting localised assessments for the implementation of mitigatory measures were required to meet WFD objectives.
STATUTORY	Department of Agriculture, Food and Marine (DAFM)	DAFM funds and promotes schemes of good farming practices, and management and monitors subsidies under the Common Agricultural Programme (CAP). It is responsible for the provision of grant assistance for animal housing and waste storage facilities for better management of waste and good agricultural practices.
STATUTORY	Teagasc	Agricultural research and advisory service to support Irish farming, with a mandate also for environmental protection. This relates to potential hydromorphological alterations and mitigation measures.
STATUTORY	Department of the Environment Climate and Communications (DMNR)	Responsible for policy development across communications, climate action, land use and sectoral policy, energy, natural resources and postal services, ensuring that all the policies adhere to the EU and global obligations.
STATUTORY	Inland Fisheries Ireland (IFI)	IFI responsible for protecting, managing and conserving Ireland's inland fisheries and sea angling resources.
STATUTORY	National Parks & Wildlife Service (NPWS)	NPWS is responsible for the conservation of national parks and wildlife species inhabiting the national parks. NPSW works with the EPA regarding wildlife and national parks conservation, and the implementation of the European Nature Directives.

Table 18. (continued) An overview of the statutory bodies involved in the implementation of the Water Framework Directive in Ireland, and the main NGOs with a formal (mandated by Government) or informal role, and with a summary of relevant interest in hydromorphology.

Type	Organisation	Role/Responsibility
STATUTORY	Office of Public Works (OPW)	OPW delivers public services for flood protection. The OPW, as the leading agency for flood risk management in Ireland, minimises the impacts of flooding through sustainable planning. Moreover, OPW also ensures the protection of the vulnerable areas through measures, implementations and planning to reduce the impacts of flooding.
STATUTORY	Geological Survey of Ireland (GSI)	GSI is responsible for the acquisition of geological information relating to Ireland's earth resources and physical environment. GSI is also responsible for interpreting such information and then providing it to the relevant departments. Moreover, GSI also provides relevant information about bedrock, quarries, and soil types, important for identifying sources of sediment loads to water bodies
STATUTORY	Marine Institute	Responsible for coordinating, promoting and assisting marine research to enhance economic development. Marine Institute also regulates sea dumping and aquaculture industries in collaboration with the aquaculture licence advisory committee. Marine Institute is recognised by the EU Commission as the National Reference Lab in Ireland for marine biotoxins in shellfish (Directive 91/492/EEC), fish health (Directive 91/67/ECC), monitoring residues in farmed fish (Directive 96/23/EC).
STATUTORY	An Fóram Uisce/the Water Forum	Established under the Water Services Act, 2017, the purpose of the Water Forum is to advise the Minister in relation to water conservation, rural water services, and the interest of customers of Irish Water and to advise the Water Policy Advisory Committee in relation to any river basin management plan and on matters pertaining to the objectives of the WFD.
STATUTORY	Irish Water/Uisce Éireann	Incorporated in July 2013 as a company under the Water Services Act 2013, Irish Water is the national service provider for water and wastewater services. It is responsible for the management of national water and wastewater assets, maintenance of the water and wastewater system, investment and planning, managing capital projects, and customer care and billing.
STATUTORY	Waterways Ireland	Waterways Ireland is one of six North/South Implementation Bodies established under the British Irish Agreement of 1998. It is the cross-border navigational authority responsible for the management, maintenance, development and promotion of over 1,000 km of inland navigable waterways, principally for recreational purposes.
STATUTORY	Bord na Móna	Bord na Móna was formed as a statutory entity under the Turf Development Act, 1946 (taking over from a limited company established in 1933) to make better provision for the production, distribution and supply of turf for use as a fuel source. It has announced it is ceasing turf production and will focus instead on projects to restore bogs (given their carbon capture potential) and biodiversity.
STATUTORY	Coillte	*Coillte* is a statutory corporation established in 1989 which manages the State's commercial forests which cover approx. 7% of the land area of Ireland.

Table 18. (continued) An overview of the statutory bodies involved in the implementation of the Water Framework Directive in Ireland, and the main NGOs with a formal (mandated by Government) or informal role, and with a summary of relevant interest in hydromorphology.

Type	Organisation	Role/Responsibility
STATUTORY	An Taisce	An NGO with a formal role in advising on environmental planning and policy making. Provides advocacy services at national and European level regarding sustainable planning, management and policy implementation.
STATUTORY	Northern Ireland Environment Agency (NIEA)	NIEA collaborates with the Irish agencies on the transboundary water bodies.
NON-STATUTORY	Rivers Trust	Plays an advocacy and practical role in the restoration of rivers across Ireland and the UK. Involved in the removal of fish barriers that hinder the migration of fish in rivers and works on natural flood risk management schemes.
NON-STATUTORY	Irish Farmers Association (IFA)	Represents Irish farmers and provides consultation on an individual basis. Key stakeholder in the implementation of the Nitrates Directive (91/676/EEC) and environmental provisions under the EU Common Agriculture Policy (CAP).
NON-STATUTORY	Sustainable Water Network (SWAN)	Umbrella alliance of environmental organisations. Advisory and advocacy role in the implementation of WFD objectives by participating at local, catchment and national levels.
NON-STATUTORY	Irish Business and Employers Confederation (IBEC)	IBEC is Ireland's largest business representative group.

Even where potential impacts may be uncertain, or even unknown, obligations under the precautionary principle (ECJ case C-127/02 – Waddenzee, Netherlands) requires that if AA is required it is to be based on the best scientific evidence and methods. “Plans include all statutory and non-statutory land-use, framework and sectoral plans and strategies to the extent that they have the potential to have significant effects on a Natura 2000 site” (DEHLG, 2009).

The guidance is explicit: “If adverse effects are likely, or in cases of doubt, the derogation steps of Article 6(4) will apply, but only in a case in which there are Imperative Reasons of Overriding Public Interest (IROPI) requiring a project to proceed, there are no less damaging alternative solutions, and compensatory measures have been identified that can be put in place.” Where for IROPI, a plan that will have potentially negative effects on a SAC or SPA is approved, there is a legal obligation for Member States to inform the European Commission of the compensatory measures, so that they can be reviewed to ensure that the “coherence of the network is maintained.” Compensatory measures must be practical, implementable, likely to succeed, proportionate and enforceable, and they must be approved by the Minister, but the Commission may not need to be informed if the plan is deemed necessary for reasons of human health or public safety, or of primary importance to the environment (DEHLG, 2009), and see below.

In a judgement of the CJEU of 13 December 2007 (C-418/04), Ireland was found in breach of its obligations under the Habitats Directive by not, *inter alia*, requiring AA. As RBMPs progress, with the requirements of the WFD to also meet those of the Habitats Directive, it is important to review if Ireland’s compliance under European law has improved. It is worth noting that “Plans” include River Basin Management Plans (DEHLG, 2009) and that “from a planning and land-use perspective, the Competent Authorities are considered to be the regional authorities, the planning authorities and *An Bord Pleanála*. If a plan or project is being proposed by a competent authority, the competent authority will be responsible for the production of the NIS. All documentation needs to be retained so that if questions arise subsequently, evidence of the process followed will be to hand, i.e. an audit trail. Such material is crucial if litigation arises in the national courts or the CJEU, and for reporting to the Commission as required under the Directives.

Appropriate assessment is normally considered necessary only if the source of the potential impact is within a reasonable distance of the SAC or SPA, normally limited to 15 km. However “In the case of sites with water-dependent habitats or species, and a plan or project that could affect water quality or quantity, for example, it may be necessary to consider the full extent of the upstream and/or downstream catchment” (DEHLG, 2009). From the Guidance, examples of effects likely to be significant are:

- “Any impact on an Annex I habitat (for which there is a large list in Ireland of freshwater and coastal habitats, many of which are not designated or candidate Natura 2000 sites);
- causing a reduction in the area of the habitat or Natura 2000 site;
- causing direct or indirect damage to the physical quality of the environment (e.g. water quality and supply, soil compaction) in the Natura 2000 site;
- causing serious or ongoing disturbance to species or habitats for which the Natura 2000 site is selected (e.g. increased noise, illumination and human activity);
- causing direct or indirect damage to the size, characteristics or reproductive ability of populations on the Natura 2000 site; and

- interfering with mitigation measures put in place for other plans or projects."

In the assessment of alternatives when impact from a plan is likely, it is notable that "other assessment criteria, such as economic criteria, cannot be seen as overruling ecological criteria."

It is clear from the wording of Article 6(4) of the Habitats Directive that only public interests can be balanced against the conservation aims of the Habitats Directive. This, therefore, excludes consideration of interests from private or commercial concerns. "In every case in which a local authority envisages approving or proceeding with a plan or project on grounds of Imperative Reasons for Overriding Public Interest (IROPI), the Minister must be consulted. This should happen as early as possible in the AA process, and certainly before a decision is taken to proceed on the grounds of IROPI."

So, both in regard to the specific obligations for Natura 2000 sites and in terms of the obligations of the WFD, potential impacts from hydromorphological alterations would appear to frequently require Appropriate Assessment. Even where such sites are subject to plans that can have an impact on the public interest for health and safety, an AA, with a *full audit trail is* (italics added for effect) required. This is further elaborated in Ireland's transposition of the Birds and Natural Habitats Directives.

The interaction of the Birds and Habitats Directives with the WFD, and vice versa, is subject to a certain element of uncertainty, outlined in Irvine and Ní Chuanigh, (2012), and discussed further by a number of authors (Cowx et al., 2009; Hatton-Ellis, 2008; Irvine, 2009; Withrington, 2005). This lack of clarity in aligning quality among the Natura 2000 network with classifications under the WFD remains an issue of potential confusion for overall site designations, monitoring and management. There is a requirement for this alignment to take place and the necessary clarification to be given in light of the requirements of Article 4(1)(c) of the WFD which applies to 'Protected Areas', which are defined as including:

"…areas designated for the protection of habitats or species where the maintenance or improvement of the status of water is an important factor in their protection, including relevant Natura 2000 sites designated under Directive 92/43/EEC (1) and Directive 79/409/EEC"

Article 4(1)(c) states that in making operational the programme of measures specified in RBMPs for

"Member States shall achieve compliance with any standards and objectives at the latest 15 years after the date of entry into force of this Directive unless otherwise specified in the Community legislation under which the individual protected areas have been established."

Despite the publication of a brief FAQ on 'Links between the Water Framework Directive and Nature Directives' in 2011, there is a lack of practical guidance both at an EU level and at national level as to how Article 4(1)(c) of the WFD is to be applied in practice. Such clarification is now urgently required in Ireland.

The effects of climate change add an extra urgency to resolve this ambiguity.

Under Article 4.1(c) of the WFD, POMs are to "achieve compliance with any standards or objectives" in Community legislation under which the protected area was designated. This means that POMs need to be applied under the WFD in order to meet the objectives of Natura 2000 sites, irrespective of the identification of water bodies under the WFD. Withrington (2005)

provides relevant examples of restoration of river and coastal SACs as a consequence of this decision.

Under S.I. No. 272 of 2009, if a protected area does not attain favourable conservation status, because of a failure to meet water quality or hydromorphological standards then it cannot be classified as good status under the WFD. That fish protected under the Habitats Directive can be vulnerable to hydromorphological pressures (Alonso et al, 2013) is hardly a matter of debate.

Irvine and Ní Chuanigh (2012), reported that the implementation of the Habitats Directive in Ireland has been far short of providing the required protection for lakes and rivers, with a similar deficit of attention to the management of the GDEs of turloughs (Waldren, 2015), with a number of difficulties that have arisen for a variety of reasons (Irvine et al., 2007; Kilroy et al., 2013). Article 11 of the WFD refers to the Birds and Habitats Directives as key measures for WFD compliance. Curtis et al. (2009) provide an overview of the requirements of species and habitats that are covered by the Register of Protected Areas required by Article 6 of the WFD and the gaps in information required for their protection. They concluded an "urgent necessity" for a detailed survey of species and habitat distributions and their requirements. With the possible exception of well-studied fish such as trout and salmon, this would include hydromorphological needs.

3.2.4 Programmes of Measures for a Protected Species

Management requirements for protected species and habitats have been compiled (Curtis et al., 2009), but programmes of measures are largely lacking.

In response to ECJ case C-282/02 under the Dangerous Substance Directive, Ireland made the European Communities Environmental Objectives (Freshwater Pearl Mussel) Regulations (S.I. 296 of 2009). Other supplementary measures introduced related to the quality of salmonid waters and shellfish waters, and I subsequently replaced by the Environmental Objectives (Surface Water Regulations) S.I 272 of 2009. The latter are listed for updating in Appendix 2 of the current Water Action Plan RBMP – POM (DHLGH, 2024a). See below.

We have included under the Habitats Directives in this section information on management provisions for the freshwater pearl mussel (*Margaritifera margaritifera*) for which specific Supplementary Measures have been produced, under the *European Communities Environmental Objectives (Freshwater Pearl Mussel) Regulations 2009.* The pearl mussel is an endangered species on the International Union for Conservation of Nature (IUCN) Red List and is one of the most endangered species in the world (Nakamura et al., 2019). It is protected under the Wildlife Acts and Annex II and V of the EU Habitats Directive. In Europe, the pearl mussel populations have dropped by 90%, while in Ireland, 27 freshwater pearl mussel populations are protected within SACs, but many of the populations of this very long-living species are non-reproductive (Moorkens, 2010). Environmental Quality Objectives (EQO) for freshwater pearl mussel habitat require the production of sub-basin plans with measures to: a) set specific objectives and targets; b) investigate sources of pressures leading to the unfavourable conservation status of the pearl mussel; c) establish a programme, including a timeframe, for the reduction of pressures giving rise to unfavourable conservation status; and d) provide for monitoring to evaluate the effectiveness of measures and progress made towards restoring favourable conservation status.

According to the 'Pearl Mussel Project', eight 'priority action areas' contain 80% of the total Irish population of pearl mussels. These areas have a low rate of survival of juvenile mussels, which are extremely sensitive to slight changes in environmental conditions.

Juvenile survival is dependent on a clean, well-oxygenated riverbed, with little silt, sediment, or algal growth. Activities that result in changes in river flow, increased levels of silt, and increased concentrations of nutrients and sediment loads are potentially damaging to the mussels. In addition to drainage, and changes to river channel morphology, increased intensification of land-use provides a pressure that can reduce mussel survival.

Hydromorphological considerations of particular importance are the control of sediment load and free-flowing rivers because of the importance of salmonids as an intermediary stage in the life history of pearl mussels. Cooksley (2012) studied the impact of pressures including hydromorphological alterations on pearl mussel in the River Dee, Scotland. The impact of 31 variables was assessed, with major negative impacts associated with highly altered channels and bank protection, wastewater treatment, hindrance in fish passage, and areas of excessive sediment deposition.

Moreover, an increase in water temperature owing to climate change threatens the growth of mussels because of dry spring and summer seasons (Hastie et al., 2003). Similarly, saline intrusion from rising sea levels can cause the die-off of the mussels. Hydromorphology is, therefore, of major importance for viable pearl mussel populations.

Prior to the enactment of S.I. No. 296 of 2009, guidelines for the management of the pearl mussel were produced by the Forest Service (2008). More recently a consultation for a 'Plan for Forests & Freshwater Pearl Mussel' (DAFM, 2018) and a SEA and NIS of the draft plan were produced. Building on the Kerry LIFE (2014-2019) pilot project on conservation and agricultural partnerships, that tested various actions to reduce pressures and impacts, a six-year 'Pearl Mussel Project' (total budget €10 million) commenced in May 2018. This is funded under Ireland's 'Rural Development Programme'. Recommended management strategies for the pearl mussel in Ireland, along with protection of (other) high status water bodies under the WFD (Ní Chatháin et al., 2013; White (née Ní Chatháin) et al., 2014) led to the establishment of the Blue Dot catchments where management appropriate to these sites is promoted, although often not executed even by State bodies (e.g. clear felling licenses). In Northern Ireland the (ca. half million euro) Ballinderry River Trust Freshwater Pearl Mussel Rescue Project (2013-2015) established 20,000 m of new or repaired stock-proof fencing that reduced cattle access to the river, the closure of 60 open livestock watering bays, with alternative watering supplied; reduction of land erosion through (soft and hard) bank revetments; and extensive planting of willow and alder planning along vulnerable riverbanks.

Ireland's RBMP 2018–2021 outlined the principal forestry-related policy and measures to safeguard water during all forestry operations, and links with environmental objectives. As control of sediment loads is particularly important for developing pearl mussels in riverbeds, strategies to reduce sediment loss from forestry, prevalent in the pearl mussel catchments, are essential.

The EPA-funded project HYDROFOR: Assessment of the Impacts of Forest Operations on the Ecological Quality of Water (Kelly-Quinn et al., 2016) did not address pearl mussel conservation, but did specify among other conclusions: 1) the importance of reducing sediment loss to waters during felling and replanting by the installation of silt traps and greater application and oversight of the best practice guidelines; and 2) a recommendation to develop and evaluate mitigation measures and management approaches to reduce nutrient and sediment inputs to streams from forestry.

3.2.5 Hydromorphology and its importance for other key EU Directives

Hydromorphological alterations have a high potential to have a negative impact on fish populations and other aquatic life. A core objective of the Freshwater Fish Directive (78/659/EEC) was to improve the quality of freshwater which acts as a primary habitat for fish and aquatic invertebrates. This includes setting limits on in-stream sediment concentrations (see above, Section 2.2.4). The Directive was transposed into Irish law by the *European Communities (Quality of Salmonid Waters) regulations*, S.I. No. 293 of 1988, which has subsequently been superseded by the WFD. This means that the health of the fish in Irish water bodies is covered by the requirements (of at least good status) of the WFD.

An integrated approach for pollution control of emissions into freshwater bodies is covered by the Integrated Pollution Prevention and Control Directive (96/61/EC). This was transposed into national legislation by the EPA Act of 1992, the *Protection of the Environment Act of 2003, and the EPA Licensing Regulations of 1994*. Regulation (EC) No. 166/2006 subsequently amended the Directive, applying directly to the Member States. The EPA is the responsible authority for its implementation. Licenses are awarded to those industries and agricultural activities that exceed the designated thresholds of potential pollution. EPA can make specific requirements regarding the risk of a proposed agricultural and industrial activity on physical alterations of nearby water bodies and refuse to grant a license that poses threats to the physical characteristics of water bodies.

Environmental Impact Assessment (EIA) plays a central role in the environmental legislation of almost every country to ensure that development projects do not present a significant risk of environmental impact. The EIA Directive was codified in Directive 2011/92/EU, subsequently modified by Directive 2014/52/EU. The Directive includes the requirement for an assessment of the impacts of any proposed project on the hydromorphological characteristics of water bodies likely affected by the development, in the present or future. The Irish legislation to implement this directive includes a range of EIA Regulations, the Planning and Development Regulations 2001 (as amended), and the Planning and Development Act 2000 (as amended) Subsequent updates are implemented by Statutory Instruments (SIs). The numerous different legislative instruments governing activities with potential hydromorphological impacts are diffuse, lacking in coherence and not consistent with the integrated ecosystem approach underpinning the WFD.

The European Union (Planning and Development) (Environmental Impact Assessment) Regulations 2018 (SI 296 of 2018) inserted sections 176A to 176 C into the Planning and Development Act, 2000, section 176 A 2 (a) providing that:

“Subject to section 176B, where a proposed development is of a class standing specified in Part 2 of Schedule 5 to the Planning and Development Regulations 2001 and does not equal or exceed, as the case may be, the relevant quantity, area or other limit standing specified in that Part, an application for a screening for environmental impact assessment in respect of that development may be submitted to the planning authority in whose area the development would be situated.”

Regulation 3 (a) (iii) of the *European Union (Environmental Impact Assessment) (Environmental Protection Agency Act 1992) (Amendment) Regulations 2020*, amended the term “environmental impact statement” to . “environmental impact assessment report.”

It has increasingly been identified that the Article 4 Assessment process under the WFD may be met through an EIA or an EIA Screening process. There have been a number of significant decisions of the CJEU concerning the WFD in the past number of years, beginning with the seminal decision of the CJEU in C-461/13 *Bund für Umwelt und Naturschutz Deutschland* e.V.

Some of these decisions point to an increased synergy between the WFD and the EIA Directive, particularly as regards those projects which may be subject to categories of development with hydromorphological impacts contained in Annex I or Annex II of the EIA Directive.

In Case C-117/17 Comune di Castelbellino, the CJEU held as follows:

“It should be recalled that Article 2(1) of Directive 2011/92 requires that projects likely to have significant effects on the environment, for the purpose of Article 4 of that directive, read in conjunction with Annexes I or II thereto, must be subject to such an assessment before consent is granted (see, to that effect, judgments of 7 January 2004, Wells, C-201/02, EU:C:2004:12, paragraph 42, and of 26 July 2017, Comune di Corridonia and Others, C-196/16 and C-197/16, EU:C:2017:589, paragraph 32).”

The CJEU found that in the case of C-535/18 Land Nordrhein-Westfalen, there is a requirement that the information to be presented by a developer in an EIA process must be capable of assessing the effects of the proposed development having regard to the requirements of Article 4 of the WFD. The Court held:

“Therefore, in the light of Article 3(b) of Directive 2011/92 and in view of the mandatory nature of the check to be carried out pursuant to Directive 2000/60, recalled in paragraphs 74 to 76 of the present judgment, and in view of the importance which that directive attaches to the protection of waters, it must be held that the information referred to in Article 5(3)(b) and (c) of Directive 2011/92 must contain the data that are necessary in order to assess the effects of a project on the status of the bodies of water concerned in the light of the criteria and requirements laid down in, inter alia, Article 4(1) of Directive 2000/60.

Article 6 of Directive 2011/92 must be interpreted as meaning that the information to be made available to the public during the procedure for approving a project must include the data that are necessary in order to assess the effects of that project on water, in the light of the criteria and requirements laid down in, inter alia, Article 4(1) of Directive 2000/60."

Even without any specific mention of defined hydromorphological pressures and alterations, the EIA Directive is a useful instrument to protect habitats from any impact, including those that occur through hydromorphological alterations. However, there are limitations to the power of the EIA Directive, as the requirements of Article 4(7) of the WFD go beyond the activities covered by Annex I or II of the EIA Directive for example. The Planning and Development Regulations, 2001 ((SI 600 of 2001)(as amended) specify thresholds for activities for which an EIA is required. Hence, smaller hydromorphological alterations are not subject to obligatory Environmental Impact Assessment. The threshold for which an EIA is required is set out in Schedule 5 of the 2001 Regulations. Directive 2014/52/EU amends the 2011 codified Directive. Under Section 172(1) of the Planning and Development Act 2000 an EIA must be carried out by the planning authority or the Board, as the case may be, in respect of an application for consent for development. Guidelines for Planning Authorities and An Bord Pleanála for carrying out Environmental Impact Assessments were issued by DHPLG (2018a).

Article 9a of the codified Directive states:

"Member States shall ensure that the competent authority or authorities perform the duties objectively arising from this Directive and do not find themselves in a situation giving rise to a conflict of interest. Where the competent authority is also the developer, Member States shall at least implement, within their organisation of administrative competencies, an appropriate separation between conflicting functions when performing the duties arising from this Directive." The OPW plays a role in the design and screening for the need for an EIA for proposed flood defence schemes. From the 'Environmental Management' section of the Government website, under the section on the OPW, it is stated that:

"All individual flood risk management projects that qualify under an Environmental Impact Assessment (EIA) threshold, require anticipated environmental effects to be published in an EIAR. The primary application of an EIA is for large Flood Relief Schemes which typically are EIA scale projects." Where "cases occur where some flood risk management activity is proposed but no other form of environmental assessment is required [but] there are some potential environmental sensitivities that need further consideration, an Ecological Assessment (EcA) will be carried out. The typical application for EcAs is for small flood alleviation works and drainage maintenance activities that do not require an EIA or an AA."

A review of schemes (see also Section 5.3 below) indicates that EIA is done by consultants on the instructions of the Local Authority or OPW. Given the flood control mandate of either the Local Authorities or OPW, there is potential for conflicts of interest, or at the least, the appearance of the same, in respect of their juxtaposed roles of organising and evaluating an EIA.

Some activities such as hydropower development may be subject to an EIA as part of the planning process and further licensing by e.g. the Commission for Regulation of Utilities. However, guidance from the European Commission (2018b) states that "if the project does not compromise the objectives of the WFD but does adversely affect the integrity of a Natura 2000 site then it cannot be approved under the WFD unless an exemption under Article 6.4 of the Habitats Directive has also been accepted."

In the High Court case *Friends of the Irish Environment v Roscommon County Council* [2022] IEHC 44 concerning an application for interlocutory relief in respect of a flood relief scheme proposed by a local authority, it was observed:

"[47]…."There is a related argument to the effect that it is not appropriate for a local authority to self-authorise what is without doubt a highly controversial scheme of development. The chief executive of the local authority, by purporting to deem this an emergency situation, has by-passed crucial safeguards provided under domestic law to ensure the independence of decision-making in respect of local authority's own development. In particular, the facility which is provided otherwise under Article 120(3) of the Planning and Development Regulations 2001—whereby a concerned member of the public can refer local authority development to An Bord Pleanála for a screening determination—has been by-passed. It seems to me that, having regard to Article 9a of the EIA Directive, there is a strong argument that this is contrary to European law."

There is a corresponding argument that there is an analogous requirement for a very robust functional separation to exist between the authority promoting a project and the authority carrying out the environmental assessments under the Habitats Directive. Without this, there could be little or no effective functional separation in practice between authorities promoting projects with hydromorphological impacts and the same authorities carrying out the relevant environmental assessments.

The Nitrates Directive (91/676/EEC) forms an integral part of the WFD and is one of the key tools in the protection of waters against agricultural pressures. It has led to the development of schemes for farm advice and the Agri-Climate Rural Environment Scheme (ACRES) [1] supported by DAFM. Forestry, land and river drainage policies and practices have potential direct and negative impacts on water bodies. While many of these impacts are from nutrient pollution, land and riparian zone management can lead to hydromorphological alterations, including increasing transfer of soil and nutrients from land to water (Haygarth et al., 2005). Impacts from agriculture on water quality are regulated by the *European Communities (Good Agricultural Practice for Protection of Waters) Regulations, 2022* (S.I. No. 113 of 2022) (as amended) (following a series of other Regulations dating back to 2006). There has been criticism of the use of a derogation provided under the Nitrates Directive for increased application of fertilisers at the on-farm level, which has been blamed for an increase in nutrient inputs to water coinciding with a significant increase in the numbers of the dairy herd particularly in the south and south-east of the country. Ireland obtained a further Derogation from the provisions of the Nitrates Directive by a European Commission decision of 22 December, 2025 (C (2025) 9263 final), its predecessor having been widely criticised as failing to take due account of the scientific evidence of water quality deterioration as a result of increasing agricultural intensification. Following a judicial review taken by An Taisce the Irish High Court made a preliminary reference to the CJEU to resolve certain questions relating to the derogation, on which judgment is awaited .

The EPA Water Quality Indicators Report for 2019 showed that 47% of rivers were below the satisfactory concentration of nitrate (EPA, 2020), and there has been an overall decline in overall water quality from 2016-21 (EPA, 2022b). Under Article 15(3) of the WFD, "Member States shall, within three years of the publication of each river basin management plan or

[1] https://www.gov.ie/en/department-of-agriculture-food-and-the-marine/services/agri-climate-rural-environment-scheme-acres/

update under Article 13, submit an interim report describing progress in the implementation of the planned programme of measures." In Chapter 4, we review the progress of the RBMPs in so far as these have incorporated hydromorphology considerations.

3.3 Development of hydromorphological management planning in Ireland

While EU funding supported knowledge creation and dissemination useful for WFD implementation, national governments mobilised local research and management to support implementation of the Directive. Many of these projects worked in parallel, and sometimes in direct collaboration with EU projects. The EPA provided considerable WFD-related funding, often in formal or informal partnerships with agencies from other jurisdictions, particularly the UK. Irish researchers and managers, for example, sat on committees of UK Technical Advisory Groups (TAGs) and participated in joint research actions, such as that funded through the 'Scotland & Northern Ireland Forum For Environmental Research' (SNIFFER). This also led to notable contributions to hydromorphology research and monitoring development. The Lake Habitat Survey (LHS) (Rowan et al., 2006) was tested for application to biological communities by McGoff and Irvine (2009) and McGoff et al. (2013), and a modified more rapid assessment of lakes MImAS (Rowan et al., 2012) was adopted by the EPA. Often EU projects on lake hydromorphology enabled research in Ireland or worked closely with projects funded by national Irish initiatives (Evtimova and Donohue, 2016; Jurca et al., 2021; Miler et al., 2013).

The NS SHARE cross-border project funded by EU INTERREG, included the development of the River Hydromorphology Assessment Technique (RHAT) to evaluate physical habitat quality (DEARA, 2009), and was further developed using guidance from the European Committee for Standardisation (CEN, 2010; Toland and Murphy, 2013). RHAT classifies river hydromorphology based on a departure from naturalness and assigns a morphological classification using WFD pseudo-classes of high, good, moderate, poor and bad. The eight criteria used for the RHAT are channel morphology and flow types; channel vegetation; substrate diversity and condition; barriers to continuity; Bank structure and stability; Bank and bank top vegetation, Riparian land cover; and floodplain interaction. It is designed to be a rapid visual assessment based on information from desktop studies, using GIS data, aerial photography, historical data and data obtained from previous field surveys. The RHAT score provides a hydromorphological quality rating at a site-specific scale.

Complementary to the RHAT assessment, and likely to be rolled out more frequently in the future is the Morphological Quality Index (MQI), developed by the REFORM project (Rinaldi et al., 2015b). Gilligan and Quinlan (2020) highlighted these two methods to be used in assessing arterial drainage impacts on hydromorphology. The 'Small Stream Risk Assessment' (McGarrigle, 2014) is a further technique that has been developed particularly for streams in the upper parts of a catchment, which can provide important refugia for freshwater life and overall conservation value of a catchment (Riley et al., 2018)

A compilation of hydromorphological projects and activities that have either been commissioned or can help support, River Basin Management in Ireland is provided in Table 19.

Table 19. Projects done or ongoing in Ireland that can support hydromorphological assessment and River Basin Management Planning, with reports and project links where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
Environmental River Enhancement	EREP	2008-2013	OPW	EREP Website Link (https://www.fisheriesireland.ie/Projects/erep.html)	Report 2017 Report 2018	Scientific monitoring within a specific catchment using the River Hydromorphological Assessment Technique (RHAT). The objectives of environmental river enhancement programmes were to advance the environmental value of rivers by improving river habitat as rivers provide significant habitat to animal and plant species. River enhancement also helps in improving biodiversity and thus helps in promoting the rehabilitation and restoration of water bodies. This programme helped in raising awareness among the stakeholders for river care.
Catchment Flood Risk Assessment and Management Programme	CFRAM	2011-2015	OPW	CFRAM Website Link (https://www.catchments.ie/irelands-catchment-flood-risk-assessment-and-management-cfram-programme/)	PFRA Report AFA Report Flood Maps Flood Risk Management Plans	CFRAM was established to encounter the necessities of the EU Floods Directive, in the national flood policy. The main objectives were to lessen the risk of floods and introduce flood management plans to avoid impact on cultural heritage, economic activity, environment, and human health. The national Preliminary Flood Risk Assessment was used to provide input and the flood risks were mapped. Twenty-nine flood management plans were prepared. Through hydraulic modelling, the risks of upcoming floods were determined.
Measurement of sediment and silt flux in rivers, benefits of enhancement measures & policy implications	SILTFLUX	2013-2017	EPA 2010-W-LS-4	SILTFLUX Website Link (http://77.74.50.157/siltflux/Home.aspx)	Literature Review Report Final Report	SILTFLUX aimed at increasing the awareness of silt flux in Irish rivers and promote standards for suspended solids. The main objectives were to address the relationship among suspended silt concentration, deposited silt as well as environmental impacts on different rivers affected by land-use. It also aimed at guiding policymakers regarding effective sediment management and validate current methods used for the measurement of sediment flux

Table 19. (continued). Projects done or ongoing in Ireland that can support hydromorphological assessment and River Basin Management Planning, with reports and project links where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
Cattle Exclusion from Water courses: Environmental and Socio-economic Implications	COSAINT	2014-2019	EPA	Defunct EPA COSAINT Tab Link	Final Report Kilgarriff et al. (2020)	COSAINT addressed the impact of excessive cattle grazing on the morphological characteristics of lakes. It aimed at spreading awareness among Irish farmers regarding the role cattle play in altering the hydromorphology of lakes. The project aimed at exclusion of cattle from water courses in Ireland, with 80% of participating farmers committed to exclude their livestock from water courses in the future.
Disentangling the Effects of multiple Stressors on the Ecology of Water Bodies	DETECT	2014-2020	EPA	Defunct AFBINI DETECT Tab Link (https://www.afbini.gov.uk/articles/detect-project)	Bucior et al. (2021) Rippey et al. (2021)	The main objective of DETECT was to establish an assessment framework for the determination of factors/pressures that counter the restoration of Irish water bodies. The project helped in examining the effect of those stressors by finding out their antagonistic and synergistic effects. Through a valuation outline, DETECT helped in disintegrating the effects of stressors on the biological and morphological condition of the Irish water bodies.
RECONNECT Programme	RE-CONNECT	2016-2019	EPA	RECONNECT Website Link (https://www.ucd.ie/reconnect/)	Atkinson et al. (2018a) Atkinson et al. (2018b) Poster River Obstacles App	The main objectives of this programme were to provide information on the barrier types, their distribution and their effects on Irish rivers. To progress connectivity and hydromorphology in rivers, a validated methodology was developed for the identification of barriers so that they can be modified or removed. The project helped in improving the uprightness of Irish rivers both physically and ecologically by addressing policy gaps. An interlinked study found 372 obstacles in the Irish rivers mainly dams, weirs and rail crossings. RECONNECT successfully located 85% of potential obstacles in the study area and action plans were devised for their removal and modification (Atkinson et al., 2020).

Table 19. (continued) Projects done or ongoing in Ireland that can support hydromorphological assessment and River Basin Management Planning with reports and project links where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
River Flow and Ecology - Biological Tools to measure impacts of flows and Ecology in Irish Rivers	FLOWECOLOGY	2014-2020	EPA 2019-W-MS-45	FLOWECOLOGY Website Link (https://flowecology.com/)	Poster	The main objective of FLOWECOLOGY was to: a) inspect the relationship among river flow and aquatic organisms mainly fish, macrophytes and macroinvertebrates; and b) investigate the relationship between macrophytes and river flows by using a macrophyte-based flow index. Various indices and modelling approaches were devised for the identification of hydromorphological impacts on macroinvertebrates, fish and macrophytes. In this way, optimum conditions for survival of fish, macrophytes and benthic invertebrates were analysed.
MACRO-MAN Programme	MACRO-MAN	2014-2020	EPA 2018-W-MS-32	MACROMAN Website Link (https://macromanproject.com/research)	Report Karki et al. (2021)	The objectives of MACROMAN were to: a) develop and implement faster and inexpensive methods for the identification of the main pressures acting in Irish estuaries affected by large macroalgal blooms; b) generate useful information on green seaweed development; c) predict the response of these blooms to different management actions in a context of global change; and d) identify solutions aimed at preventing eutrophication ecosystem recovery.
Catchment Models and Management Tools for diffuse Contaminants (Sediment, Phosphorus and Pesticides)	DIFFUSE	2014-2020	EPA 2016-W-MS-24	DIFFUSE Website Link (https://cwrr.ucd.ie/diffusetools-project/)	Presentation Mockler et al. (EGU 2017)	The objectives of DIFFUSE include the recognition of methods that help in the management of diffuse contaminants that are easily applicable in Ireland. DIFFUSE presented new and revised management tools (catchment management) for the removal of diffuse contaminants like sediments, pesticides and phosphorous. It also includes catchment models that can be used by stakeholders to review catchment management policies in Ireland. As a key output, diffuse pollution models were developed in this project to provide guidelines for effective catchment management in the country. The outputs are combined in a previously existing modelling outline which is used by the catchment managers as it contains official documents.

Table 19. (continued) Projects done or ongoing in Ireland that can support hydromorphological assessment and River Basin Management Planning with reports and project links where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
Specific Management And Robust Targeting of Riparian Buffer Zones	SMARTER_BufferZ	2014-2020	EPA	SMARTERBUFFERZ Website Link (http://smarterbufferz.ie/)	Stutter et al. (2021) Database	Objectives include the identification of tools and factors for the analysis of risk on the designated buffers. To improve the spatial resolution in the EPA's designated areas with the help of screening-level tools. Another objective was to develop effective tools for national buffer screening that are effective at the scale of local farm catchment. SMARTER BUFFERZ project helped in improving the management of surface water landscapes and agriculture in Ireland. Moreover, this project evaluated the effectiveness of targeted riparian management measures for maintaining and enhancing the water quality in Irish rivers. Identified those networks that showed best practices for landscape improvements and acknowledged their efforts towards the improvement of buffer efficiency. Provided strategic recommendations for landscape conservation depending on site location, and its physical, biological and habitat aspects.
Strategies to improve Water quality from Managed Peatlands	SWAMP	2014-2020	EPA	SWAMP Website Link (https://www.ucd.ie/swamp/)	Poster (EPA Event 2021)	The objectives of SWAMP were to: a) appraise the significance and extent of contaminants in affected catchments; b) evaluate or develop methods and treatment technologies to prevent and reduce pollution at site levels and develop best practice guidelines to apply in this sector; and c) propose predictive tools for effective watershed management involving drained and extracted peatlands that would include land-use management and sustainable restoration and after-use of cutaway or cutover bogs in order to protect water quality with potential for synergy with biodiversity-climate change measures and policies.

Table 19. (continued) Projects done or ongoing in Ireland that can support hydromorphological assessment and River Basin Management Planning with reports and project links where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
Knowledge, Assessment and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies	AQUACROSS	2015-2018	EU Horizon 2020 H2020-EU.3.5.2. Contract No: 64231	AQUACROSS Website Link (https://aquacross.eu/index.html)	Full List of Deliverables Final Report Deliverable 3.2 Deliverable D9.2: Case Study 4 Case Study 4: Local Stakeholder Summary Rouillard et al. (2017) Seliger et al. (2016)	The main objectives of the AQUACROSS project were to support EU efforts towards biodiversity and also to guarantee the running of aquatic ecosystems mainly through achieving the timely goals of EU Biodiversity Strategy 2020. An assessment framework was devised for understanding the anthropogenic impacts on aquatic ecosystems considering resilience and adaptations. AQUACROSS helped in reducing biodiversity loss towards coastal, freshwater and marine ecosystems.
Managing the Small Streams Network project	SSNet	2018-2022	EPA	SSNET Website Link (https://www.ucd.ie/ssnet/about/)	Short synthesis Kelly-Quinn et al. (2019)	The key objective of the SSNet project is to provide research-based information regarding the importance of small streams and their influence on biodiversity. This project also focuses on the achievement of WFD and other related objectives by describing the importance of small streams on certain components of an ecosystem. Moreover, policy gaps, management measures, and knowledge gaps about small-stream benefits shall be addressed for their effective conservation.
Pearl Mussel Programme	-	2018-2023	Department of Agriculture, Food and the Marine as part of Ireland's Rural Development Programme 2014-2020	PEARL MUSSEL PROGRAMME Website Link (https://pearlmusselproject.ie/farm-programme/)	Information Booklet	The main objectives of the Pearl Mussel Programme are: a) To protect freshwater pearl mussel population in eight Irish catchments by enhancing their natural habitats; b) To restore the catchment and reducing morphological pressures that inhibit their movement and growth; c) To reward farmers with extra income for using sustainable agriculture and land-use practices with little impact on catchments; and d) To use peatland and woodlands as effective indicators for determining the habitat improvement alongside the catchments. Expected outcomes are the improvements in the quality of water and biological habitat of the catchment.

Table 19. (continued) Projects done or ongoing in Ireland that can support hydromorphological assessment and River Basin Management Planning with reports and project links where available.

Programme	Acronym	Duration	Funder	Website	Reports/papers	Key objectives/key outputs
SLOWWATERS project: A Strategic Look at Natural Water Retention Measures	SLOWWATERS	2019-2023	EPA & OPW	SLOWATERS Website Link (https://nwrmireland.wordpress.com/slowaters/)	-	The key objective of the SLOWWATERS project is to enhance, flood risk, sediment and nutrient attenuation by using GIS mapping and hydrological modelling methods. Within spatial scales, Irish catchment will be investigated as per NWRM (natural water retention management) to improve their agricultural outputs. The project will identify measures that can be adopted for flood risk reduction and targeting flood flows.
Coastal Lagoons: Ecology and Restoration	CLEAR	2019-2022	EPA& NPWS	CLEAR Website Link (https://www.projectclear.ie/)	Roden et al. (n.d.) Roden et al. (2020)	The key objectives of the CLEAR project are: a) To identify nutrient amounts that cause benthic domination in the lagoons of Lady's Island instead of phytoplankton domination. b) To study the role of excessive nutrient input on the salinity of Irish lagoons. c) To access conditions suitable for high phytoplankton population in Irish lagoons and devise measures on how to achieve those conditions. d)To implement successful techniques that are used abroad for controlling eutrophication in the lagoons of Lady's Island.
Blue Dot Catchments Programme/ High Status waters	Blue Dot	2019-2024	EPA	BLUE DOT Website Link (https://www.catchments.ie/the-blue-dot-catchments-programme/)	Report White et al. (2014)	The key objective of the Blue Dot catchment programme is to improve Ireland's water quality. 319 rivers, 37 lakes, 12 transitional water bodies, and 16 coastal water bodies are included in the study area where water quality is rapidly declining. The main priorities of the Blue Dot programme are to collaborate with communities and promote catchment-led initiatives along the targeted areas. Moreover, efforts are on their way for effective control, planning and assessment of the impacts that degrade water quality in those water bodies. According to the Irish water strategic financing plan (2019-2024), the "sustainability support and advice programme" was launched in the second management cycle to protect significant water bodies.

Disentangling multiple pressures is inherent in applied ecology, but has practical problems in developing effective methods to achieve that. Hydromorphological alterations are only one facet in that and involve a number of components, described earlier (Section 1.2). The Irish projects listed in Table 19, have focussed on the assessment of hydromorphology, driven mainly by the needs of the WFD. The work has application to other policy goals, such as the EU Habitats Directive, agricultural management and land and urban planning. Examples are the Environmental River Enhancement (EREP) project (2008 and 2013), a collaboration between OPW and IFI that tested the RHAT in a pilot catchment; and the Catchment Flood Risk Assessment and Management Programme (CFRAM, 2011-2015) evaluating past and current actions that affected hydromorphology, with recommendations about the management of flood vulnerable areas (Harney, 2018). It provided input to the national 'Preliminary Flood Risk Assessment' (PFRA) by preparing 29 Flood Risk Management Plans (FRMPs). The information on hydromorphological characteristics and alteration from surveys of river longitudinal and cross-sections, channel and bank structures, and the geometry of bridges and weirs are used to provide better understanding and predictions of how hydromorphological alterations affect flood risk (EPA, 2019). Historic flood events, rainfall records and a detailed survey of the channel structure are included in the data to assess flood risk assessment.

The SILFLUX project reviewed the impacts of sediment on river ecosystems and analysed biological responses to elevated sediment and the identification of sediment-specific bioassessment metrics (Conroy et al., 2016; Lawler et al., 2017). It confirmed that small concentrations of suspended sediments in fluvial environments have adverse impacts on freshwater organisms, including the protected freshwater pearl mussel (*Margaritifera margaritifera*) (Moorkens, 2010; Rymszewicz et al., 2015). SILTFLUX developed a modelling approach to estimate sediment flux and proposed a list of mitigations to reduce the sediment loads in small catchments vulnerable to pressures from fairly minor hydrological pressures and land-use changes (Ní Chatháin et al., 2013). Similar pressures can also lead to varied impacts because of catchment and land-use character. This has major implications for the need to be attentive to the requirement of the WFD for no deterioration of water quality status, but also to how the lack of specific protection for high status water bodies has contributed to their rapid loss over the last three decades. Recognition of the need for improved protection of the high status sites led to the 'Blue Dot Catchments Programme' (Table 19), with the first phase of funding from 2019-2024. Local impacts often affect small streams, an important but often overlooked conservation resource.

Local impacts were the topic of the 'Cattle Exclusion from Water courses: Environmental and Socio-economic Implications' (COSAINT) project (2014-2019), working with farmers to manage impacts of cattle access on water hydromorphology. Around 80% of the participating farmers committed to excluding their livestock from water courses in the future in headwaters in five catchments (Blackwater, Douglas, Milltown Lake, Bracken and Commons Rivers). The 'Small Streams Network' (SSNet) project worked with stakeholders on the importance of the small streams network (Kelly-Quinn et al., 2019), and connects with work done by McGarrigle (2014) on the Small Stream Risk Assessment.

The interaction of multiple pressures and stressors on habitat quality is often clearly visible in small streams in upper catchment sites, but less obvious in the larger catchment areas, where the resulting impact in the water body can be a consequence of activities across the catchment and often at distance from riparian zone. The project 'Disentangling the Effects of multiple Stressors on the Ecology of Water Bodies' (DETECT, 2014-2010) investigated the effects of these, including suspended solids and siltation, on macrophytes in rivers; with the conclusion that high amounts of variation in the data hindered the identification of clear relationships governing macrophyte growth in rivers (Bucior et al., 2021). This supported a broader European assessment of the difficulty of making clear links between pressures and impact, measured by Biological Quality Elements (BQEs) (Poikane et al., 2020a). The DETECT project also developed a number of techniques to assist the identification of stress at a stream or river site and the constraints to the recovery of lakes in Ireland by: 1) the response of macroinvertebrates in rivers to siltation; 2) a Combined Fine Sediment Index and the 'Shuffle' method for rapid assessment of siltation in streams; 3) a model for total phosphorus concentration in lake water that allows the phosphorus loading that supports good status to be established; and 4) a model to estimate time for internal phosphorus load from sediment to decrease to an insignificant amount (Rippey et al., 2021). Only the latter appears to have been adopted by the relevant agencies.

While alteration of flows may not have been the major focus heretofore on river regimes in Ireland, there is increasing recognition of its relevance (Webster et al., 2017). This includes the striking reality of the controlled flows of the Lower River Shannon and River Lee, and the extensive modifications of floodplains going back decades (Purseglove, 1989). It also, necessarily, includes the effects of barriers on rivers. The RECONNECT project (2016-2019) identified the distribution and types of barriers on Irish rivers, intending to advise on the modification or removal to improve hydromorphology and connectivity in Irish rivers (Kelly-Quinn et al., 2022). The project involved citizen science by linking with the UK River Obstacles project (https://river-obstacles-theriverstrust.hub.arcgis.com), using a mobile phone app to record the location and type of man-made and natural obstacles. This resulted in the identification of 372 obstacles, mainly dams, weirs and rail crossings on 10 river catchments in Ireland (Atkinson et al., 2020). Such obstacles directly impact fish migration, delay the movement of river material/sediments and reduce the ability of freshwater organisms to access suitable habitats.

The RECONNECT project used a desk study and made use of GIS to map barriers in Irish Rivers. The data collected allowed an estimate of fragmentation, derived by the obstacles' density, and the calculation of the Dendritic Connectivity Index (DCI) for each catchment studied. DCI is a metric for assessing longitudinal connectivity in a river that takes account of the number of obstacles, the passability of each obstacle by fish, the effect of habitat structure between obstacles in the river channel (e.g. length or wetted area), nature of the obstacle (natural or man-made), the location of obstacles in the channel and the cumulative impact of a number of obstacles in the same channel (Cote et al., 2009). The resulting DCI is a value between 0 and 100, where a fully connected river with no obstacles would receive a value of 100. For context, within the Irish river network of an estimated 74,000 km, first and second-order streams comprise 77%, most of which lack any form of monitoring. The methodology of the project was tested using the Nore and Dodder catchments (Atkinson et al., 2018).

Related to the connectivity and altered flow regimes is the EPA and Marine Institute-supported 'River Flow and Ecology-Biological Tools to measure impacts of flows and Ecology in Irish Rivers' project (FLOWECOLOGY, 2014-2020) which aimed to develop biological tools to measure the impact of flow on ecology in Irish rivers (https://flowecology.com/). This examined the relationship between river flow and macroinvertebrates, fish and macrophytes.

Quantifying alteration of land-use to water pollution has been a long-standing research activity in Ireland, ranging from acidification from conifers (Kelly-Quinn et al., 2016) to diffuse nutrient run-off from agriculture (Deakin et al., 2016). The hydrological pathways along which diffuse pollution runs from land to water are generally well known (Bilotta et al., 2007; Haygarth et al., 2005). Alteration of those pathways through land-use has consequences for flow rates and potential flooding (EEA, 2020). Recent research on the hydrological pathways from land to water in Ireland includes the projects 'Catchment Models and Management Tools for diffuse Contaminants (Sediment, Phosphorus and Pesticides)' (DIFFUSE) that investigated the use of best models for the estimation of connectivity, and sediment, phosphorus and pesticide transport (Mockler et al., 2017; Mockler and Bruen, 2018). The SLOWWATERS project: 'A Strategic Look at Natural Water Retention Measures' (2019-2023) aimed to provide guidance on the benefits of Natural Water Retention Measures (NWRM) for agricultural catchments in Ireland, and approaches to reduce flood risk.

Coastal alterations and the relationship with the WFD have been largely neglected in Ireland, although monitoring for conservation status has increased in recent years (Brophy et al., 2019). Conservation status for the EU Habitats Directive Annex I saltmarsh habitats: *Salicornia* and other annuals colonising mud and sand (Natura code 1310), Atlantic salt meadows (*Glauco-Puccinellietalia maritimae)* (1330), Mediterranean salt meadows (*Juncetalia maritimi*) (1410) and Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*) (1420) were generally considered as unfavourable-bad. Perrin et al (2020) reporting on the EPA-funded project 'Saltmarsh Function and Human Impacts in Relation to Ecological Status' (SAMFHIRES) identified as a key need for a more standardised approach to monitoring saltmarshes. Similar needs will be likely recognised for the 90 or thereabouts Irish lagoons. A project on 'Coastal Lagoons: Ecology and Restoration' (CLEAR, 2019-2022) worked towards producing a manual for a suite of techniques to restore environmentally degraded lagoons, which can also learn from recent French experiences on lagoon restoration (de Wit et al., 2020).

While many of the projects described above have been commissioned to support environmental management of Irish water bodies, and presumably compliance with the WFD, it is generally unclear how project outcomes are used in River Basin Management Planning. This appears to demonstrate a disconnect between State-funded research and its application for water management. It is unlikely to be a uniquely Irish experience. For example, in Ireland, there are no specific methods for assessment of planform of rivers, or sediment dynamics and its management. It is unclear how the assessment of river barriers will lead to clear and verifiable management objectives. In this respect, there are parallels to the need for environmental flow assessment as a missing element of monitoring. The extent to which various ecological assessment tools commissioned by State funding are applied is highly variable and largely underutilised in management.

There are a number of reasons for that. They include inertia in established and especially large organisations which makes it difficult to change practice, especially when tools for assessment have been agreed previously, the lack of a 'champion' within an agency for adaptation, including the transfer of such a person to a new role, or through staff turnover, leading to the loss of experience and expertise, or where an assessment technique is considered too complex to be used. It may also be considered that application of new methods may be too costly to put into operation. Hydromorphological assessment can involve added complexity compared with the more straightforward (at least in theory) response of biological elements to familiar pressures such as nutrients, organic matter, and acidity. Further, thinking is needed for how hydromorphology will be incorporated into ecological assessment in a meaningful way. While this remains a debate within the EU ECOSTAT, clarity on what actually comprises good ecological potential, and clear guidance on hydromorphological assessment (Rinaldi et al., 2015b) is not yet fully adopted.

Furthermore, the effects of climate change (including the associated spread of invasive species) have not been considered sufficiently in the research or planning for River Basin Management in Ireland. This was recognised by the EPA (EPA, 2021a) in outlining future monitoring needs, and including assessment of invertebrates in low-impacted (presumably high-status) rivers to detect climate change. Climate change has potentially important implications for the determination of reference state and overall ecological assessment (Moss et al., 2009), linking to the view that the WFD, in general, is based on a static view of ecosystems, neglecting important ecological processes (Moss, 2008a).

Climate change effects that alter flow regimes in Irish rivers are already evident (Kennedy and Crozier, 2010). In the Eriff River, which is used as Ireland's **'**National Salmonid Index' Catchment, effects attributed to climate were apparent during the 2020 smolt migration downstream (Kelly et al., 2022). Changes, particularly reduced flow conditions during the annual migratory phase, can decrease migration success, highlighting the heightened sensitivity of diadromous fish to a changing climate (Bunn and Arthington, 2002). The number of warm spell days has increased slightly over the last 60 years, with very little change in cold spell duration (Walther et al., 2021). An overall increase in precipitation across northern hemisphere mid-latitude land areas during the last 70 years, is also apparent in Ireland. Annual precipitation was 6% higher in the period 1989-2018, compared with the period 1961-1990, and the decade 2006-2015 has been the wettest on record. While overall river flows in Ireland are generally increasing, they may be decreasing in the south and east of the country.

In lakes, with lower residence times, increased temperatures leading to de-oxygenation of temperate lakes (Jane et al., 2021) are exacerbated by nutrient enrichment. When lakes stratify even for a short period, this can lead to compression of fish in the uppermost waters, or fish kills if this compression is close or near the surface. Small increases in temperatures can also increase breeding success of introduced species, with potential to alter fish communities. Ireland has a depauperate species richness of fish and is vulnerable to these effects.

Chapter 4

4 River basin planning and hydromorphology

4.1 River Basin Management Plans

The requirements for WFD implementation are outlined in Section 1.2. The River Basin Management Plans (RBMPs) are central to achieving the environmental objectives of the WFD, with EU Member States obliged to prepare RBMPs for each 6-year cycle of planning and assess risks of failing to meet environmental objectives through reporting under Article 5. Progress on achieving the objectives of the Directive, such that EU Member States were to achieve good status in all bodies of surface water and groundwater by 2015 unless there were grounds for derogation, was disappointing. Subsequent targets were extended to 2021 or by 2027 at the latest. The overall failure to sufficiently meet the target by 2015, resulted in this being rolled out for assessment following the second cycle of implementation, up to 2021. The verification of the success of the RBMPs is done by water body type-specific monitoring.

Both for the design of monitoring for hydromorphology and the measures of response, River Basin Management Planning is crucial. This applies especially to the planning for restoration measures. While restoration of rivers has been widespread in Europe and globally (Kuemmerlen et al., 2019; Nakamura et al., 2006; Ormerod, 2004), the sharing of what works and what does not, and integration within a catchment context remains an important need (Angelopoulos et al., 2017; Feld et al., 2011). Excellent guidance exists for river management (Beechie et al., 2008; Gurnell et al., 2016), but restoration projects often lack clear goals, reporting and monitoring, or consideration of sound ecological principles and integration with the wider catchment (Bernhardt et al., 2005; Feld et al., 2011; Jansson et al., 2007; Palmer et al., 2010). The same risks apply to River Basin Management Planning and the cost-effective investments needed for success.

Ensuring consistent policy integration between the River Basin Management Planning process and other national and local plans was identified as a priority years ago (European Commission, 2006). Forging consistent and robust linkages among different policy areas is a significant challenge, including how these are connected with Climate Adaptation Plans, Marine Spatial Planning, Flood Risk Management Plans, and Biodiversity Action Plans.

In Ireland, an environmental water-monitoring programme, run by the EPA has been implemented to support the planning and reporting of the RBMPs. In the reporting of the first cycle (2009-2015), Irish Local Authorities took the lead ensuring basic measures for WFD compliance. In the early stages of the WFD, the Article 5 Characterisation reports were prepared by the Local Authorities and the EPA (Government of Ireland, 2005). The original River Basin Advisory Councils lacked resources, expertise and possible motivation, given the lack of input stakeholders had to WFD implementation decisions. The Local Authority River Basin Management led groups ceased to operate in 2009, with their role progressively transferred to the Local Authority Waters Programme (LAWPRO) (see https://lawaters.ie/) as an advisory body to the Local Authorities on water quality. Kilkenny and Tipperary County Council jointly manage LAWPRO across 13 local authority centres within five regions (Border, Midlands and East, South East, South West, and West).

LAWPRO interacts with state agencies and public bodies, with overall scientific guidance provided by the EPA. Ultimate responsibility for the implementation of the WFD lies with the Government of Ireland, and currently managed by the Department of Housing, Local Government and Heritage (DHLGH). An overview of the history of RBMP in Ireland is provided by Antwi et al. (2021).

The following are key elements of the WFD that relates to River Basin Management and hydromorphology, and associated monitoring requirements:

- under Article 11(3) of the WFD 'Basic measures' are the minimum requirements to be complied with to meet the environmental objectives (i.e. at least good status or good ecological potential (GEP) for artificial water bodies (AWBs) and heavily modified water bodies (HMWBs), and no decline of high status water bodies. Article 11(3) (e) includes the hydromorphology relevant "controls over the abstraction of fresh surface water and groundwater, and impoundment of fresh surface water, including a register or registers of water abstractions and a requirement of prior authorisation for abstraction and impoundment. These controls shall be periodically reviewed and, where necessary, updated. Member States can exempt from these controls, abstractions or impoundments which have no significant impact on water status";
- for groundwater bodies, Article 11(3) (f) specifies the need for: "controls, including a requirement for prior authorisation of artificial recharge or augmentation of groundwater bodies. This also occurs in Ireland (https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/Appendix_A.pdf).
- The water used may be derived from any surface water or groundwater, provided that the use of the source does not compromise the achievement of the environmental objectives established for the source or the recharged or augmented body of groundwater. These controls shall be periodically reviewed and, where necessary, updated";
- Article 11(3) (i) states that: "for any other significant adverse impacts on the status of water identified under Article 5 and Annex II, in particular measures to ensure that the hydromorphological conditions of the bodies of water are consistent with the achievement of the required ecological status or good ecological potential for bodies of water designated as artificial or heavily modified. Controls for this purpose may take the form of a requirement for prior authorisation or registration based on general binding rules where such a requirement is not otherwise provided for under Community legislation. Such controls shall be periodically reviewed and, where necessary, updated";
- under Article 13(5) "River basin management plans may be supplemented by the production of more detailed programmes and management plans for sub-basin, sector, issue, or water type, to deal with particular aspects of water management. Implementation of these measures shall not exempt Member States from any of their obligations under the rest of this Directive"; and
- under Article 11(4) 'Supplementary measures' that are "designed and implemented in addition to the basic measures can be implemented, with the aim of achieving the objectives established pursuant to Article 4. Part B of Annex VI contains a non-exclusive list of such measures. Member States that may also adopt further supplementary measures in order to provide for additional protection or improvement

of the waters covered by this Directive, including in implementation of the relevant international agreements referred to in Article 1."

The programme of measures requires cross-compliance with other relevant Directives, specifically but (under Article 11) not exclusively, the Environmental Impact Assessment Directive (85/337/EEC and 2003/35/EC), the Birds Directive (2009/147/EC), and the Habitats Directive (92/43/EEC). The European Commission (2007) hydromorphological policy paper identified the need for better policy integration, and the importance of public participation such that "balancing the interests of various groups will be particularly relevant for the design of river basin management plans."

In the early planning for the RBMPs, the hydromorphological pressures on the European surface water bodies were classified by the Member States into the following main groups (Fehér et al., 2012):

- "water abstraction: modifying significantly the flow regime of the water body;
- water flow regulations and morphological alterations (includes water storage in reservoirs, changes in hydrological regime and impacts by weirs and locks);
- river management (includes water bodies with physical alteration of the river channel including the effects of dredging, land drainage and barriers due to bridges, culverts and more);
- transitional and coastal water management (includes alteration of water flow and water level as well as modification of coastal beds, banks and shores);
- other morphological alterations; and
- other pressures (including land drainage)."

In Ireland, shortcomings related mainly to the effectiveness of the management structure were identified in the initial phase prior to the first cycle of the RBMPs. This led to a number of changes in how the process was organised and responsibility for its delivery, with further revisions between the first and second cycles (Antwi et al., 2021). The first cycle of the RBMPs ran from 2009-2015. Eight River Basin Districts (RBDs) were identified in Ireland as a whole, including two international ones (Figure 40). In the first cycle, many Member States provided little details on pressures or reported on the same pressure groups. Large variations among the RBMP reporting of Member States and methodologies were evident. In Ireland, shortcomings in implementation (European Commission, 2015a) were considered in the preparation of the second cycle of RBMPs. For hydromorphology, this reflected inconsistencies and insufficient detail on what comprised hydromorphological pressures for specified water body types (Poikane et al., 2020a, 2020b).

In the second cycle of RBMPs, new national-to-regional governance structures were put in place. Ireland revised its River Basin areas, by identifying a single national River Basin District, covering 70,273 km^2. The two cross-border (Neagh Bann and North Western) RBDs remained, as did the three wholly within Northern Ireland (Neagh Bann NI, North East NI and North Western NI). The RBD comprised 46 catchment management units, broadly aligned with the traditional hydrometric areas used by the Local Authorities. The 46 catchment management units were further divided into 583 sub-catchments, made up of water bodies classified as 513 groundwater bodies, 3,192 rivers, 818 lakes, 195 transitional waters, and 111 coastal waters (DHPLG, 2018b).

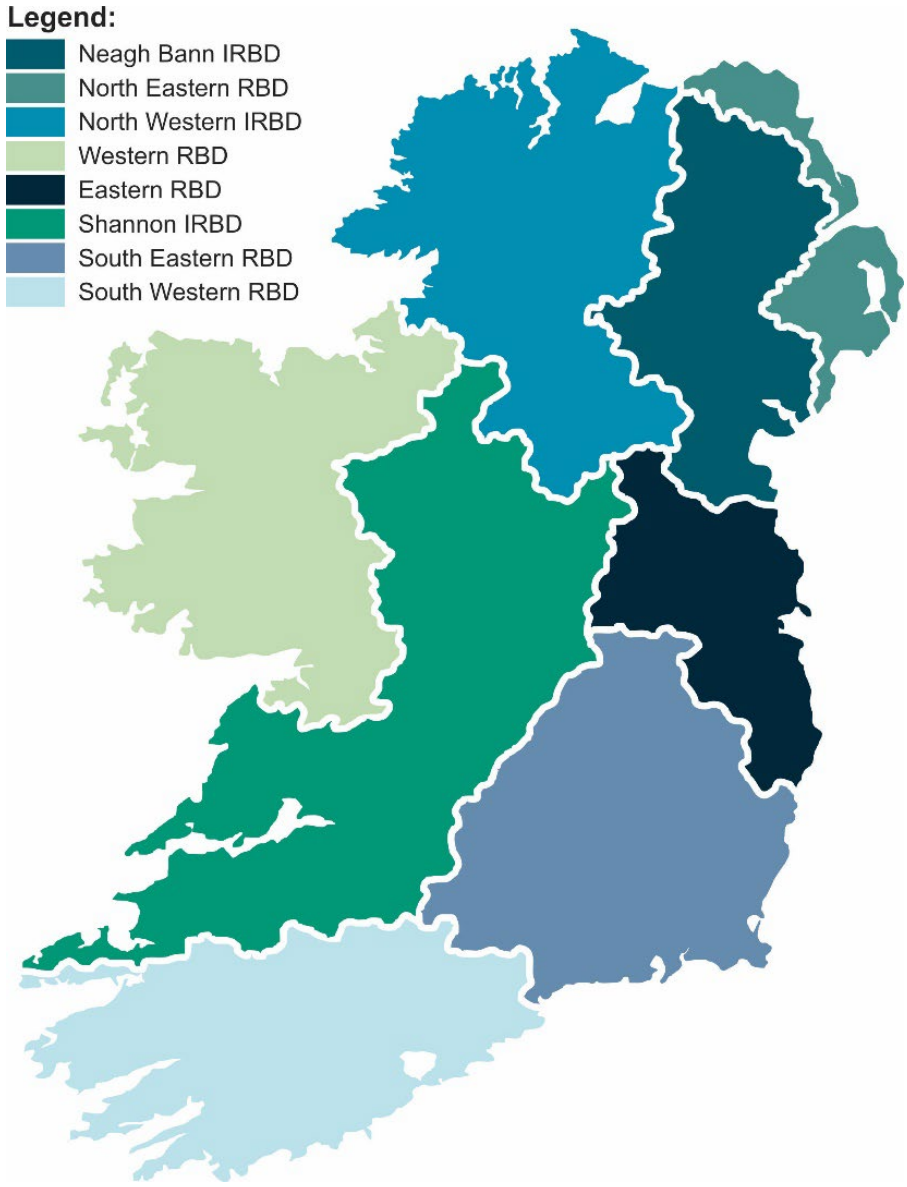


Figure 40. The eight RBDs established in Ireland in the first cycle of River Basin Planning, including three international districts (IRBDs). Modified from McNally (2009).

The second cycle of the RBMPs ran from 2015-2021 (https://environment.ec.europa.eu/topics/water/water-framework-directive_en). Across Europe, 40% of reported surface water bodies were considered to be under significant hydromorphological pressures (EEA, 2018). As apparent from previous sections of this report, a broad approach to considerations of hydromorphological alterations is inherently crude, as it belies the differing nature of impact under a myriad of circumstances. Not least, the issue of scale is important.

Assessments done at water body scale can occlude many small-scale impacts, which local management can address, as evident from the experience of the Blue Dot catchment approach in Ireland (Ní Chatháin et al., 2013). This is further hindered by the designation process itself, where water bodies can only fail on one status class (high status) because of hydromorphology; otherwise, the assessment is based on Biological Quality Elements (BQEs), for which the link with hydromorphological alteration is often tenuous. This is not surprising as the metrics for assessment of ecological status in relation to hydromorphology are under-developed. The key underlying assumption is that water body assessment is predicated on departure from reference consideration, and that hydromorphological alteration is just another pressure that will be 'picked up' by the biota. This raises the fundamental discussion of the reliability of type-specific reference conditions (Carvalho et al., 2009). For the traditional use of biota, there is either a rich history in understanding the mechanisms of community response to pressures such as nutrients, acidity, oxygen depletion and heavy metals, or considerable recent research effort motivated by the WFD itself to identify causality of impact. Without a sufficient understanding of ecological mechanisms and ecosystem functions related to hydromorphological alteration, defining management options to address putative hydromorphology-driven impact is highly uncertain. This is likely to be more difficult for modest interventions, that are nested within larger ecosystem structures and processes, rather than large-scale restoration efforts.

In the second cycle of the RBMPs, 1460 Irish water bodies were identified as at risk of failing to meet WFD environmental objectives, with impact from a range of significant pressures (DHPLG, 2018b). The main significant pressures with an impact on water quality in Ireland were agriculture, sewage, industrial emissions, peat extraction, wastewater discharges, impacts on the physical habitat conditions, and forestry.

In the second river basin cycle, for 832 of the water bodies identified as being at risk from failing to meet their environmental objectives, no actions were identified as to how that would be achieved. It was proposed that a detailed assessment of these water bodies be carried out in the third cycle of the RBMP. Hydromorphological alteration was considered a significant pressure relevant for 329 rivers, 10 lakes and 6 transitional water bodies.

The RBMP (2018-2021) also identified 190 Priority Areas of Action, covering 726 water bodies. This was promoted as a more collaborative approach with, in particular, local stakeholders. It connects strongly with LAWPRO and its outreach programme.

The planning of the second cycle of RBMPs identified a number of actions to mitigate hydromorphological alterations:

- existing regulations, providing for Environmental Impact Assessment (EIA) to mitigate the impact of planned land-use changes on waters, reducing the exemption-development threshold for drainage of wetlands from 20 ha to 0.1 ha;
- the EPA was to improve assessment methods and knowledge of the physical condition of surface waters through a number of actions, including the development of, or adoption of, the Morphological Quality Index (Rinaldi et al., 2015b), for Irish rivers and enhanced use of GIS for assessing lakes, transitional waters and coastal waters;

- the EPA, with the support of other agencies, would configure a national hydromorphology technical work programme to develop the necessary evidence for establishing the link between the physical integrity of water bodies and ecological status for management of hydromorphological pressures on Irish water bodies. The EPA would also define appropriate environmental supporting conditions for hydromorphology;
- The DHPLG was to prepare high-level guidance for Planning Authorities on the relationship between physical planning and river basin management planning, which was to provide a methodology for Planning Authorities to ensure that relevant plans and planning decisions were consistent with the requirements of the WFD. (Still awaited).
- Inland Fisheries Ireland (IFI) was to lead a multi-stakeholder programme to collect and collate data to support the development of an inventory of barriers to fish migration nationally. This also relates well to the Blue Dot catchment programme for the protection of the highest quality water bodies and associated habitats. IFI has been working with the Office of Public Works (OPW) to identify barriers to fish movements, and assessing the potential move to remove those barriers that interfere with channel connectivity (https://www.fisheriesireland.ie/what-we-do/barrier-mitigation);
- mitigation measures should be incorporated during the OPW drainage maintenance programmes (see above, Sections 2.2.7 and 3.1); and
- The DHPLG was to establish a Steering Group to review and make recommendations on improving fish passage throughout the Shannon catchment.

In the second cycle RBMP, a main measure relevant to hydromorphology was that new legislation for sustainable management of water abstractions was to be introduced to the Oireachtas through the Water Environment (Abstractions) Bill providing for a licencing system compliant with the WFD (DHLGH, 2021) In addition, *Abstractions Registration Regulations* (S.I. No. 261 of 2018) were introduced requiring that all abstractions both from surface and groundwater bodies over 25 m^3 within a 24 hour period are registered via an online portal operated by the EPA (https://www.epa.ie/licensing/watwaste/watabs/). These regulations were subsequently revoked by the Water Environment (Abstractions and Associated Impoundments) Act 2022 and the Water Environment (Abstractions and Associated Impoundments) Regulations 2024. Only registered abstractions are considered by the Irish EPA for the purposes of environmental assessment. At present, only abstractions of 25 m^3.or more in a 24 hour period are required to be registered.

Explicit references to abstraction are limited within the text of the Directive itself. Unlike pollution, references to abstraction and related subjects is notably modest. It plays a significant role in only three of the Directive's Articles (4, 7 and 11)[2].

- Article 4(b)(ii): (ii) Member States shall protect, enhance and restore all bodies of groundwater, ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good groundwater status at the latest 15 years after the date of entry into force of this Directive, in accordance with the provisions laid down in Annex V, subject to the application of extensions determined in accordance with

[2] SWAN on abstraction

paragraph 4 and to the application of paragraphs 5, 6 and 7 without prejudice to paragraph 8 of this Article and subject to the application of Article 11(3)(j);

- Article 7(1): . Member States shall identify, within each river basin district:

  - all bodies of water used for the abstraction of water intended for human consumption providing more than 10 m3 a day as an average or serving more than 50 persons, and

  - those bodies of water intended for such future use.

  Member States shall monitor, in accordance with Annex V, those bodies of water which according to Annex V, provide more than 100 m3 a day as an average.

- Article 11(3)(3): (e) controls over the abstraction of fresh surface water and groundwater, and impoundment of fresh surface water, including a register or registers of water abstractions and a requirement of prior authorisation for abstraction and impoundment. These controls shall be periodically reviewed and, where necessary, updated. Member States can exempt from these controls, abstractions or impoundments which have no significant impact on water status;

Nonetheless, the European Commission made it clear that the control of abstraction and impoundments is a critical part of the WFD, and brought infringement proceedings against Ireland for insufficient transposition of the Directive. The Commission sent a letter of formal notice[3] to Ireland in October 2007, followed by a reasoned opinion[4] in November 2011. The Commission re-assessed the case and sent an additional formal notice to Ireland in January 2019, followed by an additional reasoned opinion[5] in October 2020. The key areas the EU highlighted as deficient were providing for appropriate controls of: water abstraction, impoundment and activities causing hydromorphological changes such as dams, weirs and other interferences in natural water flow.

In 2018, Irish Water (now known as Uisce Éireann following the Water Services (Amendment) Act 2022), estimated an average per capita water use of 133 litre per day (https://www.water.ie/conservation/conserve/). A threshold of 25 m^3 equates to 188 people's use per 24 hours. By comparison, in Northern Ireland, England and Wales abstractions over 20 m^3 require a licence, with Northern Ireland and Scotland having 10 m^3 as the threshold for registration. The cumulative impact of unlicensed and unregistered abstractions below 25 m^3 in a drought situation could have serious consequences on water quality, wildlife and the availability of drinking water. If abstractions are unknown, they cannot be regulated

Subsequently, a recent ruling (22nd November 2025) of the Court of Justice of the European Union European Court (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:62024CJ0204) found that the Government of Ireland had failed to provide adequate controls on water abstraction and that volumes of abstraction allowed without licence or registrations were too high.

[3] January infringements package: key decisions (europa.eu)

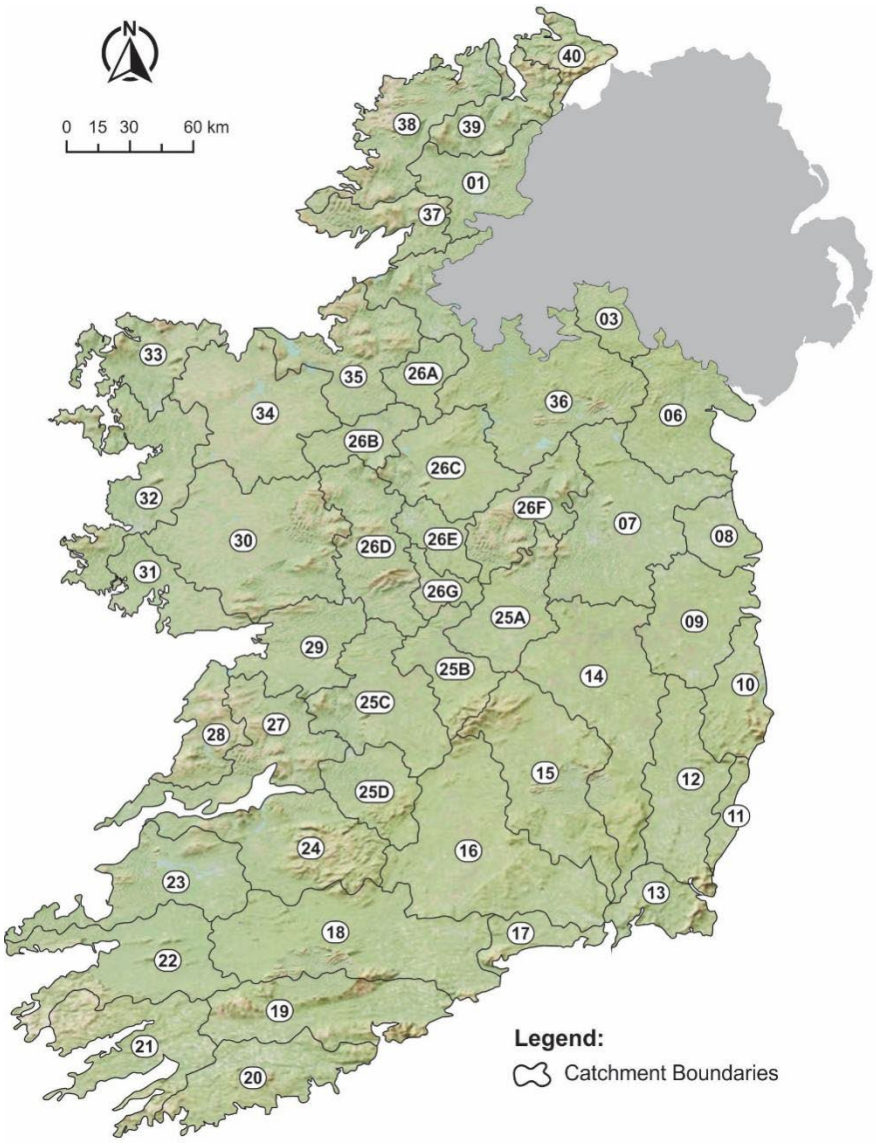
[4] October infringements package: key decisions (europa.eu)

[5] October infringements package: key decisions (europa.eu)

Given the Court's findings, further measures will now have to be taken to ensure that the Irish controls over abstractions and impoundments are effective and comply with the requirements of the WFD.

4.1.1 RBMP Water Action Plan (WAP) (2022-2027)

After some delay, the third cycle RBMP 2022-2027, now called the Water Action Plan (WAP), was published in September 2024 (DHLGH, 2024a), as a main report with 12 appendices (www.gov.ie/en/department-of-housing-local-government-and-heritage/policy-information/river-basin-management-plan-2022-2027/). The plan was put out for consultation from September 2021 to March 2022. The governance structure for implementation is the same as that of the second cycle (Figure 39), comprising a single national River Basin District (RBD), comprising 46 catchment management units, broken down further into 583 sub-catchments (Figure 41). Agreement between the two jurisdictions on transboundary cooperation for the two cross-border RBDs, the Neagh Bann International RBD with 35 shared water bodies, and the North Western International RBD with 85 shared water bodies (and the catchment areas that relate to these) are proposed to continue (DHLGH, 2024a).



Catchment No.	Catcment Name
01	Foyle
03	Lough Neagh & Low
06	Newry, Fane, Glyde
07	Boyne
08	Nanny-Delvin
09	Liffey and Dublin Ba
10	Ovoca-Vartry
11	Owenavorragh
12	Slaney & Wexford H
13	Ballyteigue-Bannow
14	Barrow
15	Nore
16	Suir
17	Colligan-Mahon
18	Blackwater (munster
19	Lee, Cork Harbour a
20	Bandon-Ilen
21	Dunmanus-Bantry-K
22	Laune-Maine-Dingle
23	Shannon Estuary So
24	Lower Shannon
25A	Lower Shannon
25B	Lower Shannon
25C	Lower Shannon
25D	Upper Shannon
26A	Upper Shannon
26B	Upper Shannon
26C	Upper Shannon
26D	Upper Shannon
26E	Upper Shannon
26F	Upper Shannon
26G	Upper Shannon
27	Shannon Estuary No
28	Mal Bay
29	Galway Bay South E
30	Corrib
31	Galway Bay North
32	Erriff-Clew Bay
33	Blacksod-Broadhave
34	Moy & Killala Bay
35	Sligo Bay & Drowse
36	Erne
37	Donegal Bay North
38	Gweebarra-Sheepha
39	Lough Swilly
40	Donagh-Moville

Data Source: EPA /Osi
Date: 20/05/2021

Figure 41. Catchments identified in the third cycle RBMP (identified in DHLGH, 2021).

The WAP goals to meet the environmental objectives of the WFD will be effected through inter-agency monitoring of 2,899 surface and groundwater bodies representing 60% of the total number of registered national water bodies, covering 2,429 river water bodies, 224 lakes, 80 transitional water bodies, 45 coastal waters, 16 canals and 121 groundwater bodies (DHLGH, 2024a).

Hydromorphological alteration affects all land-use categories. Just over 58% of land-use in the Republic of Ireland is grassland, just under 11% is forest (of which 8% is conifers), and just over 17% is designated as peatlands and other wetlands (Haughey, 2021). The majority of the population live in coastal cities. But, there too, hydromorphology can be a key issue for sustainable water use. With respect to hydromorphology, two overriding principles of the WAP laid out in its Chapter 1 with reference to UN Sustainable Development Goal SDG 6, that has targets to:

- “Implement integrated water resources management at all levels, including through transboundary cooperation as appropriate;

- Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes";

The first of these is a basic principle of catchment management and the philosophy of Integrated Water Resources Management (IWRM) (Warner et al., 2008). The second provides for a clear recognition of the links within a catchment across different habitats and associated water (and pollutant) transport. This is essential for integrated thinking and brings greater emphasis to the, already inherent link between the WFD and the Habitats Directives, as well as the implicit link with the need for the RBMP to connect with the climate and biodiversity emergencies recognised by the Irish Government (https://www.oireachtas.ie/en/debates/question/2019-05-21/75/).

In addition is the key consideration included in the WAP (DHLGH, 2024a) of "the call from Ireland's Citizen's Assembly on Biodiversity Loss for "prompt, decisive and urgent action by the State to address biodiversity loss and restoration and to provide leadership in protecting Ireland's biodiversity for future generations" from https://citizensassembly.ie/report-of-the-citizens-assembly-on-biodiversity-loss-report-launches/.

The need for a greater pace for improvements to river basin management and water body restoration is acknowledged on page 34 of the WAP, in that "it is clear that new targeted and effective measures are also necessary. Many of these measures will deliver co-benefits for climate mitigation and will help to enhance biodiversity. Implementing these policies will require ongoing and adequate financing, resources and must be fully integrated across sectoral areas especially into land use management and in agriculture. This work will be reinforced by collaborative participation of stakeholders at national, regional and sectoral levels." (DHLGH, 2024a).

Based on EPA assessment, the WAP reports that slightly more than half (54%) of Ireland's surface water bodies are in good or high ecological status, while the remaining 46% are in unsatisfactory ecological status. The WAP identifies "physical impacts to habitat conditions in water bodies (for example, the interruption of river continuity due to river barriers, and drainage of lands and channelisation of rivers)" as a major pressure that needs to be addressed. In its assessment of the risk of failing to meet WFD environmental objectives, the WAP identifies agriculture as the most common significant pressure, affecting 1,023 water bodies, followed by physical alterations to habitats, affecting 448 water bodies, and then forestry affecting 216 water bodies.

The WAP also identifies (page 25) that "Of the 1,649 water bodies that are 'At Risk', 46% are impacted by a single significant pressure, while the remaining 54% are impacted by more than one significant pressure." Assessing hydromorphological alteration and its consequences has many more facets than impacts from e.g. diffuse nutrient loads, or sediment loss from forestry, this will be subject to the reliability of opinions of "single pressure." As emphasised elsewhere in this report, the impact of agriculture and forestry can be driven by, or involve, hydromorphological alterations. Overall, the details of how hydromorphological assessment is made are of key relevance to a review of the WFD and hydromorphology. The number of water bodies identified in the WAP (DHLGH, 2024a) affected by hydromorphological alterations has risen since the last river basin cycle, from 345 to 448.

During the second RBMP monitoring cycle, the assessment of significant pressures of 1,603 water bodies at risk revealed that for 164 water bodies the pressures could not be fully identified, with possibility of multiple pressures. In the third cycle WAP, the ambitions of the second cycle will continue such that, as stated on page 69, "Each local authority supported by

LAWPRO will conduct assessments of other water bodies where the pressures are unknown (which are not within priority areas for action) to identify the specific issues and actions that are required to protect or restore water quality as necessary." A further indication of integration among agencies to meet specific environmental objectives and improvements in public dissemination of information into the public domain, which is recognised as clear need, is the commitment (page 34 of the WAP), as that "Further information on specific environmental objectives for water bodies will be made available at the website www.catchments.ie. This is a collaboration between the DHLGH, the EPA and LAWPRO. The website provides substantial background information and data is available on each of the 46 catchments, 583 sub-catchments and 4,842 water bodies. Regular updates and information will be made available in support of the implementation of this plan, including up-to-date information on the status of each water body and the environmental pressures they are subject to, alongside specific catchment and sub-catchment assessments" (DHLGH, 2024a).

The overall messaging is that lessons learnt from the earlier RBMP cycles inform a programmes of measures that will be more integrated both in governance and application, as outlined in Appendix 1 of the WAP (DHLGH, 2024a). The WAP (page 52) states that there is now "a clearer view of what mitigation measures are required and where those measures need to be implemented locally to improve the status of natural waters", so that there is an evidence based approach of "putting the right measures in the right place" (DHLGH, 2024a). That is clearly important for the cost-effectiveness of measures. Strongly connected with this ambition is the stated objectives that it is "considered necessary to deliver the objectives of the WFD in full and to contribute co-benefits to other environmental priorities including biodiversity and climate mitigation and adaptation." These measures are listed in Appendix 2 of the WAP. The WAP for the third cycle RBMP presents a higher level of ambition than heretofore, although the scale of the task should not be under-estimated. Improved integration and governance of Ireland's water management was highlighted by Irvine et al. (2002) with respect to the preparedness of Ireland for the WFD. A key recommendation then was the need for a new consolidated Water Act. It will be seen if the new structures proposed in DHLGH (2024) "(such as LAWPRO and ASSAP), additional water protection measures under CAP, additional investment in public wastewater infrastructure and the remediation of domestic wastewater treatment systems" will provide a more coherent legislative framework that can support the WFD. See Chapter 6 of this report for a more comprehensive overview of the legislative landscape in supporting implementation of the WFD in Ireland, and especially how that relates to hydromorphology.

Third cycle RBMP (WAP) and hydromophology

Chapter 3, Setting Environmental Objectives of the WAP (DHLGH, 2024a) has a dedicated section (page 40-43) on *Environmental Objectives for water bodies designated as Artificial or Heavily Modified water bodies.* The introduction to this section outlines that:

1) "There are 16 artificial water bodies at present, all of which are canals. 15 canal water bodies are at 'Good' ecological potential based on the latest water quality assessment to 2021. The Shannon-Erne canal is at 'Moderate' status which has improved from 'Poor' status at the previous assessment; and
2) In the first and second-cycle river basin management plans, there were 33 water bodies designated as heavily modified based on the limited available information at the time (see Table 9). These included 4 river water bodies used for water storage and flood protection; 16 lakes used for water supply and power generation; and 12

transitional and coastal waters modified for urban development and ports or harbours. Of these, 7 have achieved 'Good Ecological Potential', 14 required additional measures, and there are insufficient monitoring data available to determine the condition of the remaining 12 water bodies."

The assessment of ecological potential is a major challenge for the designation of Artificial (AWBs) or Heavily Modified Water Bodies (HMWBs), as outlined in section 2.2.8, and elsewhere, of this report

The designation, but not the classification, of an AWB is relatively straightforward, and no changes were proposed in the third compared with the second RBMP. The approach to HMWBs designation is quite different compared with the previous RBMP, with the intended expansion of the number of HMWBs to 466 across water body type and specified use, of which 325, all river water bodies, have a specified use of Arterial drainage (DHLGH, 2025).

Under Article 4(3) of the WFD), a water body can be designated as an HMWB if:

"a) the changes to the hydromorphological characteristics of that body which would be necessary for achieving good ecological status would have significant adverse effects on:

(i) the wider environment;

(ii) navigation, including port facilities, or recreation;

(iii) activities for the purposes of which water is stored, such as drinking water supply, power generation or irrigation;

(iv) water regulation, flood protection, land drainage; or

(v) other equally important sustainable human development activities; and

b) the beneficial objectives served by the artificial or modified characteristics of the water body cannot, for reasons of technical feasibility or disproportionate costs, reasonably be achieved by other means, which are a significantly better environmental option."

In this regard, the EPA (2022a) review states "The designation means that a realistic objective is set that acknowledges that the water body has been physically altered for a specified use that society needs to be continued." It is worth reflecting on this sentence before addressing some of the ecological implications of the new designations and the management of these water bodies. The opinion of the EPA may not be taking full account of the meaning of Article 4(3)b and interests of the wider environment and net societal benefits, as implied by the need for a review and possible repeal of the Arterial Drainage Act 1945. The new designations follow the development of a number of hydromorphological assessment techniques developed over the recent RBMP cycles, and notably the more recent Morphological Quality Index (MQI) for rivers adapted to Ireland, Lake-MimAS for lakes, and TraC-MimAS for transitional and coastal waters. These are described elsewhere in this report, and with further details as an annex in EPA (2022a)

Indicated in the WAP and elaborated in DHLGH (2025), of 466 proposed designations of HMWBS (Table 1, DHLGH (2025) and following a test of the steps needed to be done for HMWB designation (European Commission, 2003f), the listed specified use of 297 modified rivers is arterial drainage. The remaining designated HMWBs comprise beneficial use for (other) flood protection, navigation, water storage and regulation, and urban protection. In the

WAP, it is stated (page 41) that “The EPA would recommend that DHLGH carry out a wider national policy review of whether the specified uses are appropriate during the 3rd river basin management planning cycle.” In DHLGH (2025) it is recommended that:

> “all 466 water bodies be designated as HMWBs for the third RBMP cycle (2022-2027), and based on the available data for all 466 water bodies it was determined that in each case,
>
> - “The restoration measures necessary to achieve GES would have an adverse effect on the wider environment and on the specified use.
> - There is no alternative means to supply the benefits of the specified use that, based on current knowledge, would be a:
>
> significantly better environmental option,
> technically feasible,
> and not disproportionately costly”

At least for arterial drainage, the process that is now summarised in the third cycle RBMP WAP appears to have originated from a joint presentation by OPW and EPA by Gilligan and Quilan (2020), and that following a review of HMWB designations by the National Hydromorphology Working Group, 135 river water bodies were identified for designation as HMWBs, mainly with respect to arterial drainage and flood relief. A subsequent review (EPA, 2022a) identified that 466 water bodies met the criteria for designation as HMWBs, following a 9-step designation and management process outlined in the European WFD Common Implementation Strategy Guidance document number 4 (European Commission, 2003f). The EPA process is summarised in DHLHG (2025). Of note is the EPA recommendation to the Minster of DHLGH that “waterbody specific designation tests, that are informed by the policy review, should be carried out in due course. Such assessments may be best carried out when there is more detailed water body specific information available, noting that designations can be reviewed with each RBMP cycle.” No time frame for this process is indicated, other than an indication in the WAP (Page 43) that:

1) “Those water bodies that require further site-specific studies during the third-cycle to assess whether there is a significantly better environmental option that is not technically infeasible or disproportionately expensive before deciding whether to designate or not. These water bodies should be designated for Cycle 3 so that there is certainty regarding objectives. However, they should be reviewed for Cycle 4 based on the further site-specific studies.”; and
2) A final public consultation was undertaken in early 2025 and as of the time of writing, a final decision is due to be made by the Minister. Once decisions are made on the designations these shall apply for the third RBMP cycle.

The description of the new designations of HMWBs provided by DHLGH (2025) is that a “designation of Good Ecological Potential is not a less stringent objective.” However, while methodology is still under development establishing an equivalent of reference state for a HMWB is contestable. Ireland will not apply a reference state approach to HMWBs, but rather will apply the co-called *Mitigation Measures (Prague) Approach* that identifies appropriate measures first, followed by monitoring of how the ecology responds (DHLGH, 2025). This is an “expert judgement” approach that at the very least requires effective monitoring protocols and collation of results *before* mitigations (POMS) are applied. DHLGH (2025) also states that “The water body will still need to meet all of the other water quality standards that are not

deemed to be affected by the hydromorphological modification as well as achieving the best possible standard for parameters that are affected by the modification." In the WFD (2000), it is clearly stated that "Heavily modified water bodies that are not meeting their objectives must still […] be included in the programme of measures and should not be mistaken for, or confused with an exemption."

Hydromorphological alterations can also have indirect effects on e.g. nutrient loads, so care is needed not to assume direct causality between management for hydromorphology and ecological status. Table 1 in DHLGH (2025) does not specifically refer to hydromophological management options. It is, however, of note that "when setting an objective of GEP for a HMWB there remains the requirement to ensure that those elements which are not sensitive to hydromorphological impacts but sensitive to other pressures such as nutrient or organic enrichment are considered" , and that "the HMWB review process is an iterative process and will be reviewed with each cycle of the River Basin Management Plan" (DHLGH, 2025). A re-designation resulting in a large number of new HMWBs does, however, raise a number of issues. Primarily, and not withstanding the assurances of the WAP outlined in the previous paragraph, it can reduce the quality targets of designated water bodies designated as heavily modified.

Of significance in the WAP is the intention (Action 3.11) that "A review of arterial drainage requirements and the underpinning Arterial Drainage Act will be undertaken in order to inform future land use policy decisions arising out of the Land Use Review and to support the preparations for the implementation of the new Nature Restoration Law and the Heavily Modified Water Body review process." This is of major potential importance for Ireland's approach to WFD compliance and hydromophology. The WAP (page 42) provides information of the process and timeframe in that:

1) "The Government will "undertake a national land-use review, including farmland, forests and peatlands, so that optimal land-use options inform all relevant government decisions;
2) The review will balance environmental, social and economic considerations and involve a process of evaluation of the ecological characteristics of the land. It will include consideration of emissions to air and water, carbon sequestration and climate adaptation challenges; and
3) Following the completion of Phase 1 of the Land Use Review (O'Rourke et al., 2023), Phase 2 sought to use the evidence gathered in Phase 1 to optimise land use to support key Government objectives including socioeconomics, climate, biodiversity, water, and air quality. Phase 2 recommendations went to government early in 2025."

A legitimate question is why the review of arterial drainage would not precede the expansion of the designated number of arterial drained HMWBs. Further discussion on arterial drainage is provided below in Section 4.1.2.

For water storage and regulation, the WAP includes the designation of 46 HMWBs. In the WAP (Page 41), a key consideration of the EPA is stated as "there may be implications for abstraction licensing if water bodies with abstractions and associated significant impoundments are not designated as heavily modified and listed in the river basin management plan. This may make it difficult to license these abstractions where Good Ecological Status cannot be achieved. This concern was also raised by Irish Water (now Uisce

Éireann). This point supports early designation of these candidate heavily modified water bodies."

Programme of Measures for Hydromorphological Alterations

Appendix 1 of the WAP provides a description of proposed Programme of Measures (POM) to 2027. Physical modifications are covered from page 14-22. On page 14 of Appendix 1 it is stated that "Hydromorphology has been identified as a significant pressure impacting 448 water bodies 'At Risk' of failing to achieve their WFD objectives. The breakdown of activities altering the physical habitat include: channelisation (296); land drainage (78); dams, barriers, locks and weirs (66); riverbank erosion (31); embankments (31); overgrazing (18); and culverts (4). Morphological impacts (i.e. altering physical habitat such as the bed, bank, riparian zone or natural sediment conditions) have been identified within the majority of these 448 'At Risk' water bodies (~99%), whereas hydrological impacts (i.e. changes to flow conditions) have been identified in 30% of these water bodies."

Chapter 3 of this report outlines a large number of projects investigating the impacts from hydromorphological alterations at a European level and in Ireland. The knowledge generated in recent years is recognised (page 15, Appendix 1 of the WAP) in that "recent technical advances mean that a comprehensive, robust and streamlined management regime can now be developed and implemented", but also that "There is a significant body of work ahead in delivering a new comprehensive and robust management framework for pressures on hydromorphology on water." Greater attention to the assessment and management of hydromorphologically altered water bodies is needed. It also raises an expectation for realising stated aims within the WAP for better integration across State actors, engagement with stakeholders, and compliance with the WFD environmental objectives relating to hydromorphology.

The WAP commits to "the development of a new enhanced and consolidated legislative regime to address pressures on the physical condition of waters." (DHLGH, 2024). In several sections of the WAP there is reference to Nature-Based solutions as a means to mitigate pressures on water bodies. If the ambition is to deliver multiple benefits for water, nature and biodiversity, and climate mitigation and adaptation (as implied in Action 6.15 on page 84 of the WAP (DHLGH, 2024a)), there is extensive information available on the interaction between hydromorphology and ecological quality, as reviewed in Chapter 3, and a theme running through this whole report.

To support addressing hydromorphological assessment and management, the WAP (Appendix 1, page 15-16) outlines the creation of "National Hydromomorphology Programme" and Expert Group to report directly to the Water Policy Advisory Committee (WPAC). Management of the new administrative system will involve a new inter-government department regulatory regime. As also outlined in the legal section (Chapter 6) of this report, the WAP Appendix 1, page 16 recognises that "The existing body of legislation is dispersed across several regulatory and legislative areas, it is complicated and has already been heavily amended. As such, it requires considerable cross-referencing and skill to navigate. Therefore, it will be necessary to develop new consolidated legislation, including the development of a Bill and associated secondary legislation aimed at better regulating pressures on hydromorphology. This will also require a number of repeals or amendments to existing pieces of legislation across a number of policy areas." Furthermore (WAP, Appendix 1, page 17) "The

regime will also require the design of a new administrative system. The operation of the new regime may be assigned to one or more competent authorities, depending on the nature and scale of the new laws. Codes of Practice and/or General Binding Rules (GBRs) will also need to be developed to support the new regime. This will build on the most up-to-date technical knowledge and expertise available, from work progressed under the WFD and Nature Directives, and it will require input and engagement with a wide range of stakeholders"

In addition to the establishment of the expert group, development of legislation, review of HMWBS and the review of the Arterial Drainage Act (along with arterial drainage requirements), seven other Actions are proposed in the WAP (Appendix 1, page 21) to address hydromophology pressures. Four of these (Hymo 5, 6, 7 and 8) will be pilot projects on the removal or mitigation of barriers to improve fish passage in rivers (respectively on the River Dodder, Annacotty Wier, at the Ardnacrusha hydroelectric scheme, and Clohmon Weir on the River Slaney). The WAP of the third-cycle RBMP aims to "initially mitigate approximately 5% (270) of the 2,000-7,000 problem barriers" (page 17, Appendix 1), with further information needed to determine the exact number. The focus on barriers, while a welcome start is quite a modest programme, although there is an opportunity to combine with catchment management mitigations of pressures. IFI have identified approximately 73,000 barriers nationally.

The remaining three Actions involve, respectively, "Hymo 3, a restoration programme to mitigate the negative impact of past construction in or near waterbodies; Hymo 4, a Sectoral Action Work Plan for Hydromorphology [to] include measures and plans to address the 448 water bodies at risk from pressures on hydromorphology"; and "Hymo 9, other restoration and mitigation work from 2026 (near the end of the third cycle RBMP) that will be "partly guided by the framework for prioritising measures for both river restoration and Nature-based Catchment Management." The latter seemingly relates to text in Appendix 1, page 17 that "Restoration targets for water-dependent habitats and species listed in the Nature Directives, which have been adversely affected by pressures on hydromorphology, will also need to be considered as part of any restoration programme."

An EPA gap analysis (EPA, 2024a) assessing the need for targets for mitigation of hydromorphological alteration indicates:

> "Although there are many local actions, including barrier removal work, there are no clear and direct relationships that can be drawn between these actions and the achievement of the environmental objectives in those specific waterbodies with hydromorphological pressures by 2027. As part of the preparation of the Local Catchment Management Plans by LAWPRO and the Barriers Mitigation Sectoral Plan by Inland Fisheries Ireland (IFI), the impact of the planned barrier mitigation programme on Ecological Status nationally will be assessed. Overall, for the forecast of achieving objectives, there are currently no specific, targeted, waterbody-specific, implementation measures planned for Hydromorphology pressures before 2027."
>
> Furthermore, EPA (2024) state that while "Nearly 450 waterbodies have significant hydromorphology pressures, …more than 80 have a High-Status Objective. The majority of these also have other significant pressures identified. The key activities causing these declines are channelisation, dredging, land drainage associated with agriculture, forestry and peat extraction, and changes to the physical habitat conditions to facilitate urban development."

The EPA are clear in that there are no specific measures to address hydromorphological pressures and that such pressures "will not be fully mitigated by 2027" and that "All with hydromorphology as a significant pressure will have a target environmental objective date set to beyond 2027." While the new WAP and the associated Sectoral Action Work Plan for POMs are welcomed developments, it is clear that the next phase of WFD implementation requires a sincere and concerted cross-sectoral engagement to both raise the awareness of the effects of hydromorphological alteration on Irish water bodies and the measures required to mitigate them. As referred to in the WAP (and in the review of knowledge in Chapters 2 and 3 of this report), the knowledge to progress measures is largely available, and the more obvious challenges are a combination of available finance, political motivation and effective governance. A thorough review of the Sectoral Action Work Plan is essential to see the extent to which this absence of targeted measures is addressed.

Differing views will certainly be raised for how best to mitigate key hydromorphological pressures arising from e.g. land drainage, sedimentation, river channelisation, flood risk, hydropower operations and river barriers. The RBMP emphasises stakeholder engagement. It will be a measure of the Government's commitment as to which stakeholders' voices are most listened to in striving to meet the new ambitions for WFD compliance.

Many key issues in progressing management for hydromorphology have been covered in Chapter 3 and elsewhere, including the above text of this chapter. Key issues that connect with the WAP (DHLGH, 2024a) are discussed further below.

4.1.2 HMWBs, Land drainage and Land-use (see also Section 2.2.7)

Heavily Modified Water Bodies

The RBMP POM specifies that "land and river channel alterations arising from agricultural activities are also a significant pressure on the physical condition of river channels. Additional and/or enhanced measures are now urgently required." There are a number of interconnected issues, in relation to agricultural impact on hydromorphology. The most significant is likely arterial drainage. Important in this context is the approach to HMWBs.

The shift in approach to HMWB designation affects mainly the arterial drainage network This *de facto* relates to the Arterial Drainage Act 1945 as a state-sponsored activity that has a demonstrable impact on freshwater life, including protected species (King et al., 2008). It raises important questions as to the societal need to maintain the arterial drainage network in its current form rooted in 75 year old legislation, and that these alterations are intended as permanent for the river channel. The permanency of change is only fulfilled by ongoing legally mandated maintenance. It is now timely to review the extent and commitment to arterial drainage in light of the need to both reduce legally binding greenhouse gas emissions under the Paris Accord and to meet water quality objectives under the WFD in a cost-effective way, with added value for biodiversity and to bring the legislation in line with the requirements of the WFD. This is an important opportunity. While the additional HMWB designations are subject to review with each river basin management cycle, once a site is designated it could be difficult politically to de-designate.

The review of HMWB designation associated with flood defence schemes involved river water bodies with flood relief schemes and/or embankment schemes. After the 9-step process, 64 river water bodies were identified as potential HMWBs for the designated use of flood

protection (EPA, 2022a). These appear to have been brought forward into the DHLGH (2025) consultation document.

For river water bodies downstream of water storage and regulation activities, the EPA (2022a) review identified 29 potential HMWBs, which are also reflected in the 2025 designation proposal. Included in the specified use are impoundments used for water abstraction, with data provided by Irish Water. It is noted that the difficulty accessing information on water abstraction hinders meaningful public consultation. For river water bodies specified urban and navigation use are proposed, respectively, for 23 and 30 river water bodies. As would be expected in Ireland, there were relatively few lake water bodies identified as pHMWBs. Of the 20 water bodies proposed (DHLGH, 2025), all but one are dammed. The number of transitional and coastal water bodies proposed as HMWBs is also low at 13 (DHLGH, 2025).

The above text summarises the endpoint of the 9-step process for the proposed designation of HMWBs, where a decision was made that good ecological status could not be achieved by restoration measures without significant adverse effects on the wider environment (Step 7) and that beneficial use of the water body could not be achieved by other means (Step 8).

Inevitably the process of arriving at the proposed HMWBs is open to further scrutiny and discussion, not least because the linkages between hydromorphological pressures and ecological outcomes (within Step 5 of EPA (2022a)) are often difficult to measure or quantify. The final step in the EPA 11-step process is the identification of maximum ecological potential (MEP) and from that of good ecological potential (GEP). This is only possible if there is a sufficient understanding of how hydromorphological alterations affect ecological community structure and associated ecological processes. The EPA, recommended Prague approach (see above) for estimating GEP relies to a large extent on expert judgment on the biological values expected following the implementation of mitigation measures. This is less ecologically robust than the reference approach requiring well-developed ecology-hydromorphology links (European Commission, 2019a), and is emphasised as important throughout the earlier sections of this report.

The issue is a difficult one, as there is a shortage of harmonised methods to assess hydromorphological alteration from drainage and other hydromorphological pressures, and there is a need for further development of these (Kampa and Bussettini, 2018; Poikane et al., 2020b; Vartia et al., 2018). For the EPA to advocate for the less stringent approach as an interim measure is likely expedient given that the Commission has put pressure on Ireland to improve hydromorphological assessment. However, it also risks that the necessary further research and/or incorporation of extensive research already done into assessment techniques, linking both hydromorphological pressures to ecology and designations of ecological status and potential, will be insufficiently considered. As stated in EPA (2022a), “The true biological values for GEP can only be derived […] when links between hydromorphology and biology are known.” Furthermore (italics added for emphasis) “In time it is *hoped* that increased understanding will allow us to use the Reference based approach which will allow a more targeted selection of mitigation measures and a more direct and precise determination of GEP” does not appear very definite.

Furthermore, the EPA (2022a) follows with ”The assumption is that most of the HWMBs designated for the third cycle do not have mitigation measures in place that would help to achieve GEP. There is insufficient knowledge to support the use of the Reference-based approach, so this makes the Mitigation Measures approach a practical alternative until this knowledge gap improves. If Ireland was to apply this classification method to the current

HWMBs they would likely come out as Moderate Ecological Potential or lower. Over time as the measures are implemented this situation would improve but initially, there would be a larger number of HMWBs failing to meet their ecological objectives" (EPA, 2024a).

The publication of EPA (2022a) is relevant for the ambitions of the third cycle RBMP in the assessment of the impact of land-use on water quality "Ensur[ing] that new development and changes in existing land-use or in the activities that take place on land are appropriately assessed and appropriate mitigation measures are put in place, so that they do not adversely impact on water quality." EPA (2022a) concludes with "There is a need now to invest time and resources to improve our understanding of how hydromorphological changes affect ecology, this will allow us to use the Reference-based approach and better protect the ecology of our HWMBs into the future."

Land use

A "consolidated legislative regime to address pressures on the physical condition of waters.." and the review of the Arterial Drainage Acts outlined on page 64-65 of the WAP (DHLGH, 2024a) and conjunction with Nature-based Catchment Management could have important consequences for land management if the scale of ambition is high enough. It opens up the possibilities for greater use of the landscape as part of the management for flood protection (see Chapter 5.3 below), and furthering to use of Nature Based Solutions (NBS) to mitigate the effect of land use and flood defence schemes on hydromorphology (see Chapter 2.6 above on European case studies and opportunities arising from the EPA commissioned report as part of the national Land Use Evidence Review (O'Rourke et al., 2023)). This is also an effective means to align the objectives of the WFD and Floods Directive (EEA, 2017). On page 4 of Appendix 1 on Programme of Measures (DHLGH, 2024a) it is stated: "Sustainable farms will continue to provide sustainable incomes while also benefiting nature. Farmland can also be managed to provide key eco-systems services, such as nature-based water management and flood protection, protection of ecosystems, restoration of biodiversity and carbon storage." Agricultural measures in the Sectoral Action Work Plan for Agriculture (WAP, Appendix 1, page 64) "will include targeted measures to address the 1,000 water bodies at risk from agriculture during the third-cycle, along with protection measures needed to prevent further deterioration. The aim of the plan will be a rapid graduated reduction of nitrogen, phosphorous and sediment losses to water bodies with a target to reach sustainable use and discharges in all catchments of concern by 2027." This provides another clear opportunity to connect the measures for hydromoprphology with those of nutrient management and biodiversity. Achieving these ambitions will require appropriate incentives for farming and strengthening agricultural and nature support mechanisms. Hydromorphological interventions such as sediment traps and the use of well-placed constructed wetlands can greatly reduce the risk of sediment loss to water bodies, while at the same time providing nature conservation benefits (Mander et al., 2017; WWDR, 2018).

The Programme of Measures (page 6, of Appendix 1 of the WAP) indicates that: "regulation of land drainage and river channel works will be enhanced and improved", and includes as a 'sector target' for agriculture (page 7), "To reduce the mass loading of phosphate and sediment by establishing a minimum of 2,500 linear kilometres water interception measures (woodlands for water) representing 3% of all river channels." While, if pursued, this is an important step it still represents a fairly limited approach given the scale of the nutrient management

challenges. There are substantial opportunities for combined nutrient loss and hydromorphological benefits effected through the 'Green Architecture' of the EU.

The text in the draft of the third cycle RBMP (DHLGH, 2021) on "The development of a new authorisation system for instream engineering works ..[which] will strengthen controls of land drainage practices and their enforcement" is not contained in the WAP (DHLGH, 2024a). These measures can of course be re-introduced through proposed new legislation.

For peatlands and bogs, the WAP outlines a series of proposed measures that will protect the bogs, and reduce the impact of their degradation on water bodies. The Programme of Measures (WAP, Appendix 1, page 37) makes specific mention of the link between the drainage of peatlands and changes to the hydromorphological condition of rivers, and how maintaining and restoring bogs decreases the loss of ammonium and fine-grained suspended sediments. The National Raised Bog Special Areas of Conservation Management Plan 2017-2021 (DCHG, 2022) set out measures promoting linkages to RBMPs. *Bord na Mona* announced in 2021 that they will cease peat extraction from its lands, although planned alternative uses include wind farms, so that some areas continue to be drained. This has led to concerns from conservation groups on impact to natural habitats (https://www.thejournal.ie/wasted-wetland-peatland-drainage-6345093-Apr2024/). It seems that these measures are not contained in the WAP.

4.1.3 Mitigation of the negative impact of constructions in or near water bodies

In the second management cycle, a roadmap supporting EU Biodiversity Strategy objectives for restoring rivers to a free-flowing state was prepared. The outcomes of a multi-agency steering group to propose recommendations for improvements to fish passage are now contained in Actions summarised above in the third cycle RBMP WAP (DHLGH, 2024a). This includes a 'key objective 'to improve fish migration at Parteen and Ardnacrusha in the Lower River Shannon, a much-anticipated action (see also below, Section 5.1.1). The potential effects of barriers in Irish rivers are, however, far more extensive than just in the Lower Shannon and the other pilot projects outlined in the WAP. The WAP includes a commitment to establish a long-term restoration programme to mitigate the negative impact of existing constructions in or near water bodies. IFI has identified 73,000 barriers and river modifications (DHLGH, 2021) of which 2,000-7,000 will likely need mitigation. The third cycle WAP (Appendix 1, page 17) intends to remove or modify 270 (5%) of these barriers. Small barriers such as weirs can have negative impacts on river continuity and fish passage. One of the pilot projects to inform options for mitigation is the Annacotty Weir, in the Mulkear Catchment, County Limerick, described further in Section 5.1.1).

The pilot projects provide a means to develop assessment techniques to provide the management needed to achieve good ecological potential (GEP), in which: "there are slight changes in the values of the relevant biological quality elements as compared to the values found at maximum ecological potential" (WFD Annex V 1.2.5). This necessitates monitoring that verifies only "slight changes from Maximum Ecological Potential (MEP)." Kampa et al. (2018) state that "a functioning ecosystem is a prerequisite for a water body to be at GEP. Slight change cannot be equivalent to an absence or severe change of the biological quality elements compared with the closest comparable water category and type and needs to be supported by corresponding conditions in the supporting quality elements (e.g. flow, habitats, continuity). For example, GEP requires that best approximation to ecological continuum is

ensured. As discussed above, making such a judgement is often not straightforward, because a new state following restoration can still have equivalent ecosystem function as another similar site, but maybe not exactly the same composition of BQEs. One of the recognised difficulties with the WFD ecological assessment protocols is the greater reliance on ecosystem structure (i.e. presence of some indicator taxa) rather than assessing more difficult functional aspects (e.g. productivity, food webs) (Moss, 2008a).

The third cycle WAP provides the means for new guidance for physical planning and the WFD, previously proposed to be developed as part of the second RBMP (DHLGH, 2021), now brought forward to the third cycle. It is important that this does not apply only to urban areas. Land Use Action 1 commits to finalising "guidelines for the incorporation of the Water Framework Directive into the planning system and roll out of training on the new water and planning guidelines to practitioners" and Action 2 that legislative provision to give effective to the Water and Planning Guideline "be progressed" (pg. 49 POM) There will be a reliance on Local Authorities, LAWPRO and other Competent Authorities to manage WFD assessments as part of the statutory planning process. The capacity of the competent Authorities to resource and manage these assessments depends on the quality of the guidelines and associated training and remains to be clarified.

In relation to urban areas, the WAP POMs (Appendix 1, page 31) states that "Sustainable Urban Drainage objectives are evident in the majority of the City and County Development plans." However, the resultant outcomes currently seem to be focused upon engineering solutions rather than nature-based solutions which will have multiple benefits to the environment." To address this, a National Strategy for 'Nature Based Management of Urban Rainwater and Urban Surface Water Discharges' has been developed (DHLGH, 2024b). These moves support NBS in urban areas but should not be confined to them. The principles outlined that "nature-based solutions (NBS) are designed primarily to take in rainwater runoff, store the rainwater or "slow the flow" and, in doing so, remove many of the pollutants before allowing the treated runoff back into the drainage system" does not only apply to use of NBS in the urban landscape, but is an important means for managing nutrient loads and high volume hydrological loads in rural areas as well. See examples in Chapter 3 and 5 and international review in UN WWAP (2018).

4.1.4 Invasive species

In the third cycle of the RBMP, the implementation of EU Regulation (1143/2014) on '*The prevention and management of the introduction and spread of invasive alien species'* was planned. This will be accompanied by introducing clear governance arrangements for managing aquatic invasive alien species, including the assignment of responsibilities and development of agreed co-ordination mechanisms, including cross-border cooperation.

The Regulation specifies the need for measures to prevent the intentional or unintentional introduction of invasive alien species of EU concern, the need for early detection, surveillance system, rapid eradication, and management to prevent spreading. The plan refers specifically to the likely need to control and manage Japanese knotweed (*Fallopia japonica*), Himalayan balsam (*Impatiens glandulifera*), zebra mussels (*Dreissena polymorpha*), and crayfish plague (*Aphanomyces astaci* infecting the white-clawed crayfish, *Austropotamobius pallipes*).

Although this is far from a definitive list of invasive species that can alter the structure of aquatic and riparian habitats, these are species that have been identified to cause particular concern.

The development of a national management plan for invasive alien species is an Action in the WAP (Appendix 1, page 43) POM. The need for enhanced freshwater biosecurity in Ireland has been noted for at least two decades, with guidance provided in the EPA report on 'Prevention, Control and Eradication of Invasive Alien Species' (Lucy et al., 2021). The risks of invasive species establishment apply to both water quality and quantity (Bunn and Arthington, 2002), and therefore to hydromorphology. Invasive species such as the zebra mussel change the nature of the benthos, with consequences for the ecological integrity of extensive areas of a water body. The need for a strong management plan for control of Invasive Alien Species (IAS) is a long-standing issue that must be addressed.

4.1.5 Links to climate change in the third cycle Water Action Plan

The WAP (DHLGH, 2024a) recognises that "Climate Change should be considered one of the drivers of environmental factors that impact on water quality and quantity as opposed to a significant management issue itself." The WAP however, provides little in the way of guidance on what needs to be done, likely reflecting a more widespread uncertainty in proposed measures that will have cross-sectoral support. Across the EU there remains a strong element of political inertia regarding the likely consequences, despite increasing evidence of dramatic effects. The WFD itself, has insufficient regard for climate adaptation and how climate-related changes reshuffle the deck of ecological function (Moss et al., 2009). The WAP does refer to the investment through the National Development Plan of €12 billion in public water and wastewater infrastructure, but is notably silent with regard to climate and flood protection, other than a reference to its inclusion in the Sectoral Action Work Plan, a few references to the opportunities for NBS to mitigate flooding, and that five rivers are used for water storage and flood protection. Flood Protection Projects that derive from or assist with the implementation of the Flood Risk Management Plans (FRMPs) require checking for compatibility with WFD Objectives (DHLGH, 2018).This will identify the potential impacts of the proposed measures on water body hydromorphology and status and build on the work done during the preparation of the FRMPs. Improved assessment methods for river morphology have the potential to assist in: a) the assessment of the potential impact of flood management measures on WFD objectives; b) the identification of the most appropriate mitigation measures; and c) the support of decisions on the application of derogations under WFD Article 4(7).

The EU Floods Directive 2007/60/EC (transposed into Irish law as S.I. No. 122 of 2010) required Member States to produce Preliminary Flood Risk Assessments (PFRA) with flood maps, and FRMPs. The OPW has the leading role in implementing the Directive, with a national Catchment Flood Risk Assessment and Management (CFRAM) programme initiated in 2011.The focus of these plans is the protection of human life and property, although inevitably these link also with the OPW's remit for arterial drainage. In the Strategic Environmental Assessment (SEA) of the latest proposed arterial drainage programme (OPW, 2021a), there is a requirement for the conservation of protected species and habitats, and opportunities for a re-focus on how arterial drainage is managed (see Chapter 3). This could involve an emphasis on multifunctional floodplain management, which has not been a strong feature of catchment management in Ireland, where the emphasis on flood protection is in more traditional ways, involving hard engineering solutions (Schindler et al., 2016). It is a very important opportunity for incorporation in the review of the Arterial Drainage Acts outlined in

Action 3.1.1, page 21 of Appendix 1 of the WAP (DHLGH, 2024a). There are many potential synergies in achieving the objectives of the WFD and Floods Directive, but these are often not capitalised upon by the respective WFD and Floods Directive practitioners (Dworak and Kampa, 2018).

The application of 'Natural Water Retention Measures' to store or attenuate water in the environment was a feature of proposals in the second RBMP consultations but have less prominence in the third cycle RBMP, although captured without much related detail in ActionHymo 9 (WAP, Appendix 1, page 21) advocating river restoration and Nature-based Catchment Management. Reducing run-off can alleviate flooding downstream. Managing land-use to provide greater capacity for water storage and controlled release can also benefit from the restoration or creation of wetlands. The SLOWWATERS project funded by the EPA in collaboration with the OPW has been ongoing since 2019 (See Table 19). This project is an example of closely working together with the OPW, EPA, and other agencies with potential benefits for both WFD and flood risk management objectives.

4.1.6 Water Dependent Habitats and Species, and Appropriate Assessment

The WAP (DHLGH, 2024a) connects with water-dependent habitats and protected species stating that: "approximately 88% or 385 of the 439 Special Areas of Conservation (SACs) have water-dependent habitats or species, with 90% or 149 of the 165 Special Protection Areas (SPAs) having water dependent bird species." There remains a lack of effective alignment and implementation between the Habitats Directive and WFD (Irvine, 2009). Of 44 groundwater dependent ecosystems (GDEs) that were delineated and assessed, three associated groundwater bodies were at poor status and 41 (93.1%) were at good status for the assessment period 2013-2018. As protected areas, it should be that the ambitions for the majority of these sites are managed to achieve the highest quality status. A Natura Impact Statement was published by DHLGH (RPS Group, 2021) after public consultation to outline the links with the third cycle RBMP and in compliance with European and national legislation, including SEA and Appropriate Assessment (AA) of the draft RBMP, carried out in parallel with the drafting of the plan.

It is notable in the WAP that actions to the integration of activities across water, climate and nature seems to lie with the promotion under Action 6.15 (page 84) that the Local Authority Waters Programme (LAWPRO) will "facilitate public participation in the development of the Catchment Management Work Plans through workshops for …5 pilot catchments, [to] inform the development and implementation of a national approach to public participation to deliver outcomes for water, climate and nature. As part of this initiative LAWPRO will work with public bodies with responsibility for water related environmental enforcement to improve public awareness of public body responsibilities and reporting procedures for pollution incidents." This appears to somehow by-pass actual POMs for the integration of these aspects, whereas the water, climate, food and nature 'nexus' is increasingly, and internationally, seen as a crucial need for sustainability (Kleemann et al., 2025).

4.1.7 Conclusion, third cycle RBMP and hydromorphology

The Water Action Plan of the third cycle RBMP (DHLGH, 2024a) provides the opportunity to significantly advance the protection of the waterscape in Ireland and address current and potential hydromorphological alterations. This is needed for compliance with the

environmental objectives of the WFD, but especially for embedding a greater application of hydromorphological thinking for land and water management. Attending to hydromorphological issues and overcoming the inherent challenges between land-use and water management is all the more needed for adapting to climate change and the consequences of that across multiple sectors. The Sectoral Action Plan committed in the WAP (Appendix 1, Hymo 4) provides a roadmap for these challenges, the success of which will depend on enhanced cross government departmental commitment, and availability of the necessary resources. The forward of the WAP is optimistic in that "We will achieve this by ensuring that the necessary resources are available."

The development of the "new enhanced and consolidated legislative regime to address pressures on the physical condition of waters" outlined in the WAP is a critical and priority objective. The success of that will depend on how well the different legislative elements are integrated (see Chapter 6 below for our independent assessment). Water management and the goals of the WFD connects land to water. Hydromophology is the manifestation of that, as illustrated through large sections of this report that identify the connection between hydromorphological pressures and ecological assessment. Issues relating to how to determine good ecological potential in HMWBs is of critical consideration and is the measure of the success of mitigation. For the WAP, the review of the 1945 Arterial Drainage Act, and notably arterial drainage requirements, is of major importance, but the potential political challenges cannot be underestimated. It needs to take account of not only hydromorphological alterations *per se*, but the effects of that on nutrient and sediment transport and management. Other legislative issues such as water abstraction are currently under review following the CJEU ruling in Case 2024/24.

Management Actions and pilot projects for fish passage and river ecological continuity are welcomed initiatives, but require adequate pre- and post-monitoring to both judge success and to learn and document lessons for the ecological assessment and decision making for WFD compliance. Process and results need to be in the public domain and subject to critical review. Of wider, and necessary, scope is the restoration plans mentioned throughout the WAP, but the timeframe for these appear disappointing as the target for actions commence towards the end of the third cycle. The ambitions for the "wider countryside approach" could be accelerated, a process that will depend on concerted actions also by the EPA and NPWS and their respective remits.

In summary, the Sectoral Action Plans signify good potential for incorporating hydromorphology into river basin management in Ireland. Their success lies in the details of the actions taken. The Mission Statement of the WAP is (page 7) is "To take action to protect and improve all of Ireland's water bodies by implementing the right measure in the right place, at the right time, with the objective of reaching as close to full compliance with the Water Framework Directive by 2027 as possible, and closing any remaining gaps as quickly as possible, thereafter, subject to the rules of the directive." The juxtaposition is the statement from the EPA that "All waterbodies with hydromorphology as a significant pressure will have a target environmental objective date set to Beyond 2027." Ambitions and realities may need further consideration.

Finally, a number of sections of the WAP call out for new or amended legislation to improve or put into effect procedures for better WFD compliance. A major challenge in water management in Ireland has been the piecemeal and disjointed legislative approach for water.

Consolidation of legislation into an overarching Water Act is a key recommendation of this report (see Chapter 6).

4.2 Hydromorphology Stakeholders Consultation Meeting

Stakeholder engagement is considered by the Government of Ireland, the EPA and the LAWPRO to be important for the implementation of the WFD. The LAWPRO programme has dedicated stakeholder actions at local scales. A national water forum as a statutory body exists, but its influence on water management, including hydromorphology, appears so far limited. Access to information can be particularly troublesome, despite Ireland being a signatory to the *Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters*, and the creation of *An Foram Uisce* in 2018 as a statutory body to facilitate "stakeholder engagement on all water issues at a national, strategic policy level with the common goal of improving water quality" (https://thewaterforum.ie/what-we-do/).

Government Ministers, including those at the highest level, have publicly criticised NGOs for exercising their legal rights in challenging planning decisions, and even citizens being permitted to make formal observations on planning applications if in areas that they themselves do not reside. Hydrometric data is generally available in 'real-time', and searchable for individual stations, also over extended periods. Much, and historic, WFD monitoring data is available from EPA at https://www.catchments.ie/, but requires level of expertise to extract and use. Other environmental data, including that assembled by the EPA, are not readily available on the web but require specific requests. For water bodies, a policy of accessing only summaries of ecological status quality categories appears to have been recently changed reflecting a more open approach to water quality data than was previously provided in the EPA Water Quality reports in the 1990s and 2000s. Access to other spatial data held by public bodies is often excluded from formal requests or involves costly and/or time-consuming procedures. Information is often redacted to make it meaningless. This could be in breach of Directive (EU) 2019/1024 on open data and the re-use of public sector information, transposed into Irish law by S.I. No. 376/2021 - *European Union (Open Data and Re-use of Public Sector Information) Regulations 2021*. See also recent High Court Judicial Review [2022] IEHC 6 [2021 No. 846 JR] [2021 No. 770 JRT for an opinion that appears to limit the requirement of applicants to pay prohibitively expensive costs in the process of exercising rights under national and international law.

RBMPs require a public consultation process under Article 14 of the WFD. Despite the 'accepted wisdom' of stakeholder engagement (Norgaard et al., 2009; Warner et al., 2008), the processes to engage the public across the EU in the implementation of the WFD have been very varied, but generally are at the lower end of the participatory scale (Jager et al., 2016).

A number of Non-Governmental Organisations (NGOs) have interests in the implementation of the WFD and hydromorphological aspects of it. The expectations of NGO stakeholders can be very different from the technical experts charged with the implementation of the WFD. Engagement with all relevant stakeholders is encouraged under Article 14 of the WFD on Public Participation. In the early stages of the WFD in Ireland, the process for public engagement was limited compared with international best practices (Irvine and O'Brien, 2009). More recently Rolston et al. (2017) provided an extremely informative overview of public engagement in Irish environmental policy related to catchment ecosystem services, and the

mechanisms available for citizen involvement. This has direct relevance for stakeholder engagement in addressing hydromorphology in support of the environmental objectives of the WFD. The development of LAWPRO provides a platform for stakeholders to get involved in water management issues (see: https://lawaters.ie). As part of this current project, key statutory and non-statutory stakeholders affected by hydromorphological alterations in Ireland were identified (Table 18). This indicates quite a range, and even fragmentation, of roles and responsibilities. A self-assessment by 30 stakeholders' using power analysis (Annex I) provided input to a putative matrix of stakeholder power compared with Influence and Interest (Figure 42) regarding hydromorphological alterations and stakeholder influence.

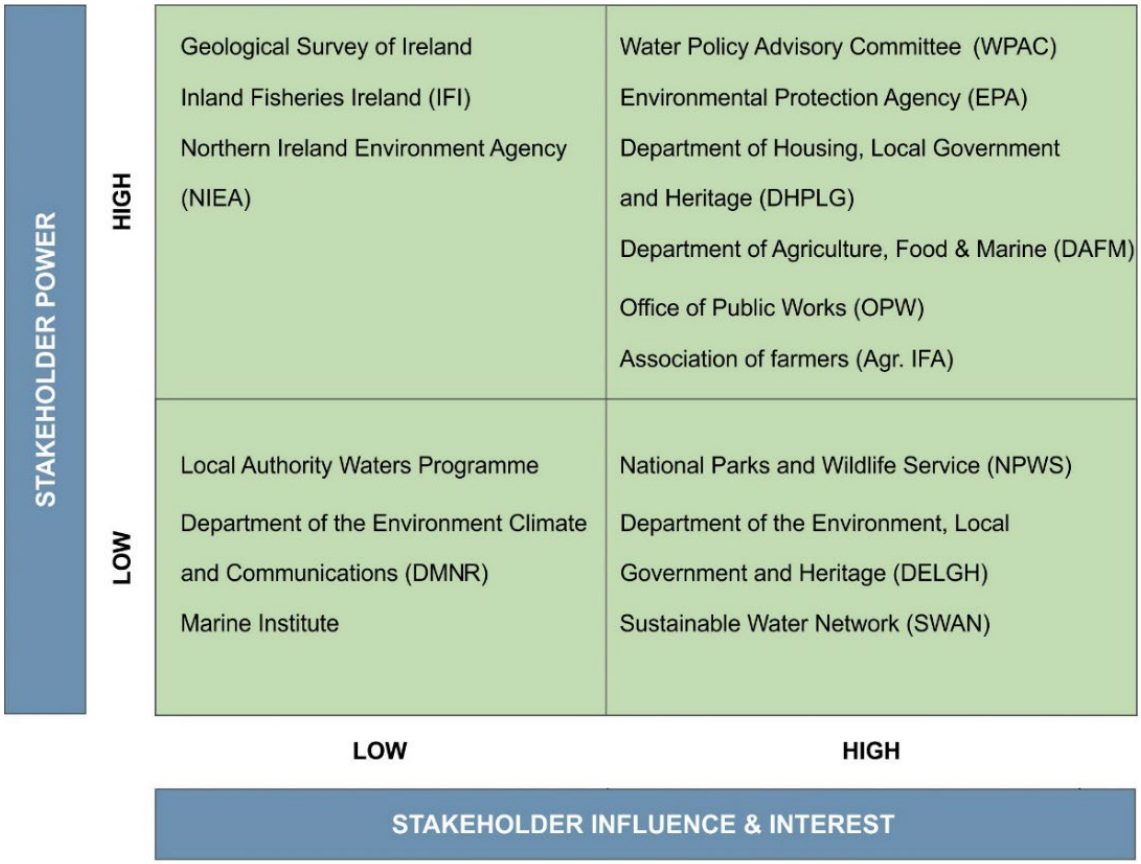


Figure 42. Stakeholder Analysis Matrix. Process adapted from Mendelow (1981).

Of the 30 stakeholders who were sent a questionnaire, a ranking of responses (from high to low) was that the most important criteria of success for effective engagement of their organisation was the willingness of the other stakeholders to contribute (sense of community), followed by transparency of the process and human resources to ensure effective engagement (Figure 43).

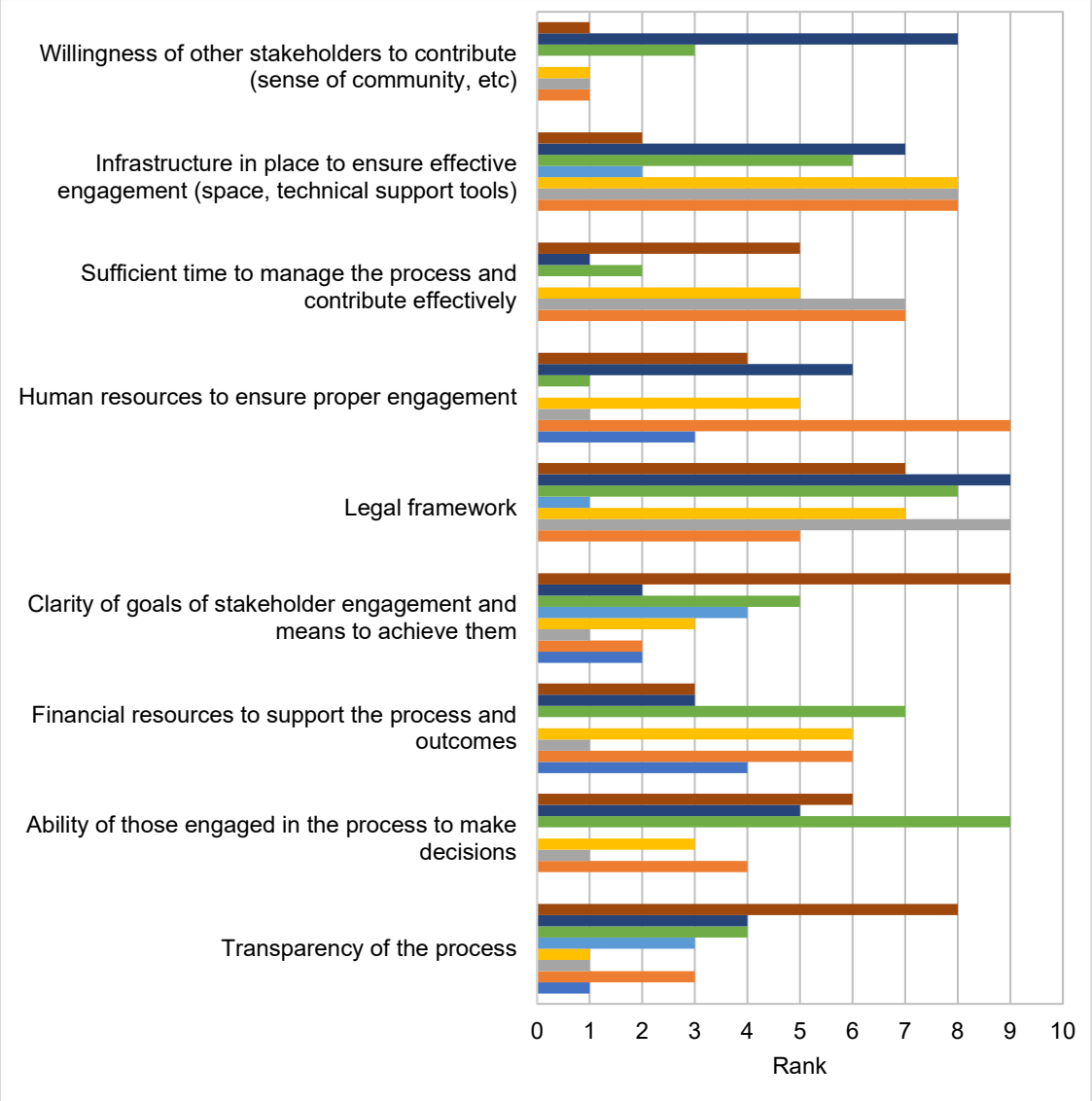


Figure 43. The most important success criteria for effective engagement of the organisation as a stakeholder.

The key points arising from the questionnaire were:

- data on the operation scale of the stakeholder's organisation was retrieved upon which it was revealed that 80% of the stakeholders operate at the international scale and 90% of all the stakeholder organisations conduct operations and are involved in national projects and policy development. The national levels of operation majorly include the state level, community and the municipal level. However, financial resources are also crucial for the management of an organisation as they support the expected outcomes without any financial barriers. Only one stakeholder ranked it important for effective organisational management;
- stakeholders were also asked about the important hydromorphological aspect upon which the majority agreed on the conservation of water resources, water quality and groundwater from pressures and pollution. Flood prevention, land loss due to sedimentation and habitat protection are also considered important hydromorphological aspects. Other important aspects of the stakeholder involvement

include 100% interactions with local and regional authorities, with NGOs involved in water management and river restoration, with forestry, river management and drainage institutions;

- as far as WFD objectives are concerned, only 20% of the stakeholder organisations have made it mandatory to incorporate and achieve the WFD objectives in any part of their organisational decisions, planning and policy development. However, 70% of the stakeholders indicated awareness of the WFD objectives especially related to water conservation, management and hydromorphology;
- the questionnaire also reflects the response of stakeholders in the context of the involvement of their organisation in the mitigation of hydromorphological pressures. The majority of the respondents to the survey ranked WFD regulations and Habitat Directives as important for hydromorphological policy-making at the European level. The arterial drainage scheme, Floods Directive and planning and development legislations are considered important national regulations for the reduction of hydromorphological pressures on Irish water bodies. The majority of the respondents identified regulations by the IFI, Wildlife Act and national and EU guidance on Appropriate Assessment as easy to comply with. When asked about ongoing activities related to hydromorphological alterations, 60% of stakeholders indicated that their organisation have been directly involved in such activities that influence hydromorphological alterations and are committed to supporting effective implementation of policies, reforms or projects;
- the analysis of the questionnaire reveals that stakeholder participation with the active regulatory authorities, Directives, and national and international laws is important for assessing the role of their organisation could play in mitigating pressures on the hydromorphology of water bodies. Moreover, the key elements discussed above show that consultation in regulatory processes with stakeholders is by far the most active mechanism for stakeholder engagement. Finally, many stakeholders agreed to share project reports, internal reports and relevant sources they have that could assist this project; and
- the questionnaire was followed by a stakeholder workshop, identifying key issues on the approach to hydromorphological alteration in Ireland (Republic and N. Ireland). Although overall low in number (n=10), the range of stakeholders who attended the workshop, brought different perspectives on the key issues and their solutions. Using the questionnaire, document searches, including the RBMPs of the first and second cycle, and internal discussions with the project team, a scoping of key hydromorphological pressures for Irish water bodies was compiled. Potential pressures and impacts were circulated in an introductory leaflet shared with the stakeholders prior to the workshop, and provided a stimulus for the workshop. The identified pressures and impacts arising from the scoping and workshop (Figure 44) indicated areas where stakeholders considered beneficial hydromorphological measures could be applied to assist with meeting WFD environmental objectives. A report of the workshop sent to the participants is included in Annex II.

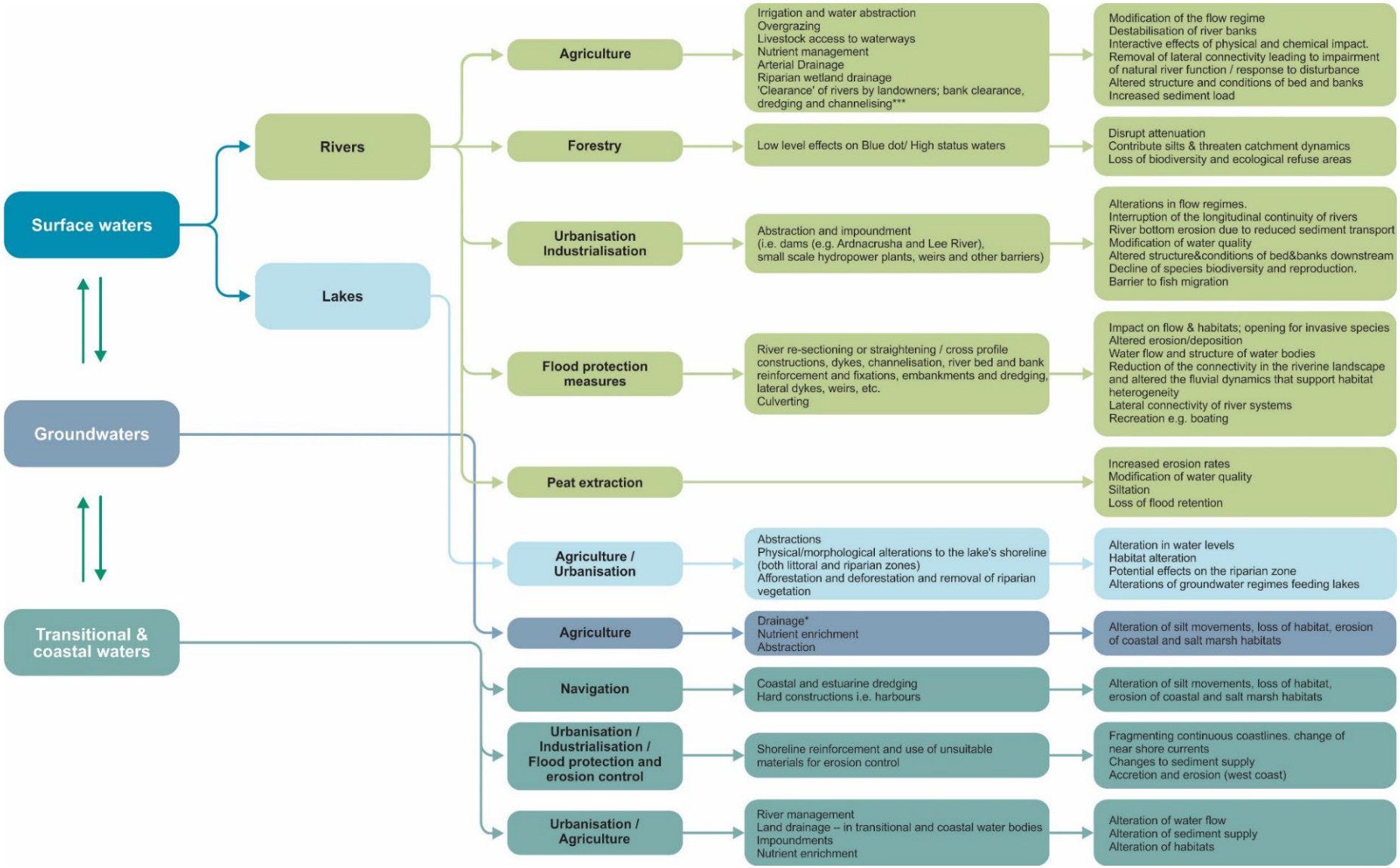


Figure 44. Scoping of hydromorphological pressures and impacts of importance for Irish waters.

Chapter 5

5 Application: Irish case studies

5.1 Irish Rivers

5.1.1 Shannon River

The Shannon is the longest river in Ireland (Figure 45), draining about 30% of the land mass. Its upper catchment is just inside the border of N. Ireland, which technically makes it an international River Basin. It includes 113 lakes in total, 53 of which are over 50 ha. The Shannon River has diverse morphological characteristics, representing a major waterway from source to sea (Cooper, 2011). As would be expected for such a major river, hydromorphological alterations have affected the main stem and many tributaries. Most notable has been the Shannon hydroelectric scheme at Ardnacrusha, and the arterial drainage and management issues the mid-river and Shannon Callows.



Figure 45. Overview of the River Shannon, with insert of the area downstream of Parteen Basin (see below). Figure supplied courtesy of ESB

The hydrological alterations that could have possible impacts or changes in ecological state cover the general themes of hydrological regime, river continuity and morphology. Specific potential impacts that can influence ecological classification from the four examples below include alteration of flow regime, sediment regime, water levels, impediment to fish migration

and hydrological connectivity between the main channel and floodplain. Very local potential impacts relating to riparian alterations for ports, harbours and jetties may be widespread but overall of low extent. Impacts from pressures of nutrient loadings and invasive species, while prevalent in the Shannon system, are not considered as a main focus here.

Ardnacrusha Dam and Parteen Basin

Construction of Ardnacrusha Dam was completed in 1929, as the major electricity generating scheme in Ireland. It is about 19 km downstream of the town of Killaloe, Co. Clare. Parteen Weir is approx. 6 km downstream of Killaloe where the regulating weir diverts the water into the headrace canal (Figure 46). While once supplying almost 90% of national demand, Ardnacrusha now accounts for < 3% of the country's electricity (Cullen, 2002). At the time of its construction, the Shannon was one of the largest salmon runs in Europe. The potential loss to the salmon fishery from the dam raised controversy during its planning and construction (McCarthy et al., 2008). Among other impacts, the scheme restricted access to migration of fish to the upper Shannon and led to reduction of spawning sites in the Lower Shannon (Reale, 2011). Species affected include salmon (*Salmo salar*), the European eel (*Anguilla anguilla*), sea trout (*Salmo trutta trutta*), twaite shad (*Alosa fallax*), allis shad (*Alosa alosa*) and sea lamprey (*Petromyzon marinus*). A portion of the Lower Shannon is a Special Area of Conservation (SAC) under the Habitats Directive. Despite its impact on the fisheries the hydroelectric scheme was accepted as a reasonable decision. As an impressive feat of engineering it remains an important part of Irish heritage. In the quest for energy security and national development by the newly independent Irish Government, the priorities were, however, clear. The history of the hydroelectric scheme is documented by Reale (2011): "In Dáil debates it was stated, the protection of fisheries rights had to take second place. McGilligan stated emphatically that in carrying out this scheme, 'although all reasonable precaution will be taken to prevent injury, we do not preclude the possibility of injury being done to the fisheries, and if in a case of conflict between fishery and electricity interests, then electricity is going to have superiority'."



Figure 46. A representation of Parteen Basin (Irish Water, 2016). Note that the western embankment is better known as Ardclooney Embankment .

The dam regulates water retention upstream in Lough Derg, where the Electricity Supply Board (ESB) maintains water fluctuations to a normal operating band of 36 cm. An additional 10 cm is retained for emergency black start services to the Transmission System Operator in the event of a national electricity system blackout (ESB, pers comm), or as indicated by Irish Water (2016), as a contingency in flood periods. Lough Derg's hydrodynamics have the character of a lake, and was designated as such in the second RBMP, although subject to "extensive" hydromorphological modifications and major pressures including nutrients and the infestation of the zebra mussel (*Dreissena polymorpha*) (EPA, 2021b). The populations of zebra mussel are sufficiently dense to represent a hydromorphological alteration itself, but not grounds for considering designation as good ecological potential in any revised approach to HMWBs under the third cycle RBMP (see section 4.1.1).

The ESB classifies Ardnacrusha, along with the headrace canal formed by Embankment Dams, and the Fort Henry and Ardclooney Embankment Dams upstream of Parteen Weir are Category A dams (ESP, per com.). A breach of a Category A dam could endanger lives downstream. Parteen Basin was created with the power plant after flooding a former village downstream of Killaloe. The water supply to the powerplant is estimated to regularly comprise about 95% of the flow (T. O'Connor, pers comm). The ESB diverts water at Parteen into a headrace canal to the power station, with a statutory compensation flow of 10 m^3/s, equal to the low summer flow before the Shannon scheme. This flows down the Old Shannon River channel, and affects flow rates through 15 km of the Lower Shannon SAC. The low flows also leads to sections of the old Shannon channel to be overgrown with water weeds, and in places trees have established in the bed of the natural channel (OPW, 2018). Cullen and McCarthy (2006) reported that the "mean annual flow of the River Shannon at Killaloe, located 3 km upstream of the regulating weir, is 186 m^3/s. The mean summer discharge is 99 m^3/s and the mean winter discharge is 274 m^3/s. However, flows may be as low as 10-15 m^3/s in dry summers or over 700 m^3/s in major floods." The statutory flow of 10 m^3/s is maintained until approximately 350 m^3/s is reached, that approaches the capacity (max 400 m^3/s) of Ardnacrusha. At which point additional flow through Parteen Basin is diverted over Parteen Weir and down the 'Old River Shannon' (OPW, 2018).

During very high flows, water can be discharged down the old river channel through spill gates at the Parteen Regulating Weir. In these situations, Ardnacrusha Station is also considered as providing a flood relief by diverting 350-400 m^3/s of water away from flood prone areas of the Lower Shannon (ESB, pers comm). The riparian zones pf the Old River Shannon are mainly agricultural, but the town of Castleconnell is prone to risk from flooding (OPW, 2018). On the River Shannon Group website, it is stated that in a flood with 800 m^3/s (such as happened in December 2015), ESB can divert nearly half of the water through Ardnacrusha and away from the "old" river channel. However, if the operating capacity of Ardnacrusha is 350 m^3/s as described in OPW (2018), then only at flows greater than this will water in excess of the compensation flow of 10 m^3/s move down the old channel. Because of the electricity generating capacity at Ardnacrusha this *de facto* provides flood alleviation during high flood periods.

While there was a fish pass installed when the hydroelectric plant was built, its effectiveness has been subject to quite intense debate. Reale (2011) reported that the high water discharge in the Ardnacrusha Dam led to a drop in salmon population in the Limerick fishery from 414,000 to 42,000 pounds, or about 188,000 kg to 19,000 kg, respectively. In 1962, a new fish pass was installed (see below, and Figure 46), but this also was considered to be insufficiently

effective, with claims by O'Connor (pers comm) in 2020 the Shannon River was meeting <5% of its annual conservation escapement target Assessment of the salmon population in the Parteen reservoir dropped from 23,322 in 1963 to 1,904 fish in 2003 (OPW, 2019). Concerns for the effectiveness of the fish pass are shared by the Government, who set up a multiagency review panel (including IFI, the Marine Institute, Waterways Ireland, OPW, NPWS, ESB and Irish Water), which was featured as an action in the second RBMP (see above, Section 4.1). The likely pressures on the salmon migration were recognised when Ardnacrusha was constructed (see above). A fish hatchery to support salmon survival was constructed in 1958. Salmon migrating upstream are collected for broodstock. The Ardnacrusha fish pass is subject to review and upgrade for better functioning under the third cycle RBMP (see Section 4.1.1).

There are also indications of high mortality of the European eel (*Anguilla anguilla*) moving through the turbines on their seaward migration. However, the ESB operates a "trap and transport programme" that captures eels coming in from the Atlantic and then releases them to upstream habitats. A previous commercial eel fishery has now been replaced with a conversation management objective (Cullen and Mccarthy, 2006). The European eel has undergone declines in recent decades including in the Shannon, with international restoration programmes now common, and governed by European Council Regulation 1100/2007 "*Establishing measures for the recovery of the stock of European eel*" (Degerman et al., 2019; Meulenbroek et al., 2020; O'Connor, 2003).

As part of their statutory duty to manage the fisheries on the River Shannon, ESB operate the 'trap and transport' programme as part of the mitigation measures under EU Regulation 1100/2007. A history of the Shannon eel fishery and discussion of eel management and conservation is provided by McCarthy et al. (2008). At the time, commenting on the dramatic decline of eels, and considering the perilous state of the European eel at large, the authors observe that "it would be possible to capture virtually the entire silver eel run, as is now done mostly for commercial sale, if required for conservation measures." This is what indeed occurred, with eels moving downstream on their outward migration now captured at Killaloe Bridge for release downstream of the power plant. Such techniques appear to be successfully applied elsewhere (McCarthy et al., 2008), although in the Lower Shannon the maintenance of this operation is also claimed by some stakeholders as ineffective.

The ESB has a statutory obligation to manage and preserve the fisheries of the Shannon (along with the Rivers Erne, Lee and Liffey). The programme includes a commitment in the Shannon to "protect eel and salmon stocks" and "the construction of weirs and fish passes to bypass man-made in-river structures." The ESB produces a Fisheries Conservation annual report. Below are extracts from the 2020 report (ESB, 2020):

- While acknowledging that the Ardnacrusha power station accounts for <3% of national electricity needs, the key rationale for its continued use is that "the ability to generate electricity at short notice when electricity demand suddenly increases makes it very important generation asset";
- "ESB controls the fishing rights of the entire River Shannon, and the role of the maintenance and preservation of the entire fishery resources is undertaken by ESB Fisheries Conservation";
- "The lakes of the catchment are naturally productive and can be generally classified as either semi-enriched (mesotrophic) or enriched (eutrophic)";

- “Although the Shannon scheme caused major changes for salmon in the river, the impact of extensive drainage schemes, water regulation and canalisation, intensive farming, afforestation and water pollution have also impacted negatively”;
- key seasonal targets are: 1) Silver eel trap and transport occurs between October and February; 2) Juvenile eel trap and transport occurs between March and September; 3) adult broodstock trapping for salmon occurs between October and December; 4) restocking of juvenile salmon is between April and September; smolt release for salmon returning the salt water is between March and May; and 5) fish counters at Ardnacrusha and Parteen operate all year;
- “Smolt passage through a Kaplan turbine located at Ardnacrusha was independently assessed based upon the results of a Heisey Tag test in 2004. The survival rate of smolt migrating during the annual Ardnacrusha salmon smolt generation protocol has been calculated at 89.4%”; and
- the number of salmons moving up through Ardnacrusha and Parteen Weir (Figure 47) has declined markedly since the mid-1970s. The graph also highlights the increase of fish passing through Ardnacrusha in the early 1960s, presumably as a result of the construction of the fish pass at that time.

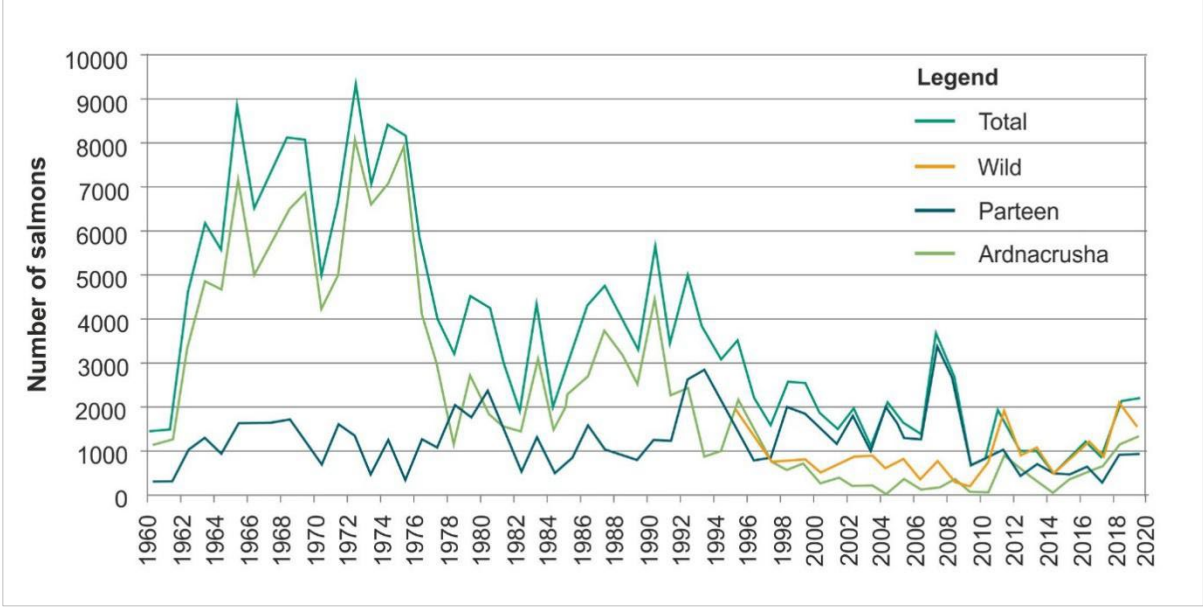


Figure 47. Adult salmon through Ardnacrusha and Parteen Regulating Weir on the Lower Shannon catchment from 1960-2020. Modified from: ESB (2020). Used with permission.

The 2020 ESB report, although brief, suggests active management and monitoring of salmon and eel populations. It is also notable that the third bullet point on the nutrient status of the Shannon uses very old terminology stemming from the OECD (1982) rather than the current WFD approach. For clarification, the lakes within the Shannon basin would not be considered as naturally eutrophic. The fourth bullet point highlights the need for integrated catchment management, but also that the management under the ESB remit is occluded by other catchment pressures.

The Government Working Group on ‘Improved fish passage on Shannon’ was launched in 2018. The consultancy company CDM Smith was commissioned by DHPLG to provide expert advisory services to the Steering Group, although expertise on this would presumably reside in IFI and other State agencies. Nevertheless, the findings of that study appear to have found

that: “Neither fishway at Ardnacrusha and Parteen meets modern best practice and do not facilitate multi-fish species passage as required by the Water Framework Directive.” On the CDM Smith website (https://www.cdmsmith.com/en-EU/Client-Solutions/Projects/Improving-Fish-Migration-in-the-Lower-River-Shannon-Catchment)” (page now moved, 1st September 2025), the project manager quotes that “Improvement of fish passage on the River Shannon will be a significant challenge but can have a transformative impact on the river ecosystem.” A recent EU project FIThydro ‘Fish friendly Innovative Technologies for Hydropower’ considered mitigation measures and strategies to avoid individual fish damage. The project developed a risk-based Decision Support System to support best practices and compliance with European legislation (Table 14). More details on the CDM Smith proposals were presented at the 2022 EPA conference . The key findings was that a new flow regime down the Old River Shannon with a modified “baseline” of 17 m^3/s would allow fish migration up the old channel for at least 10 months of the year. This would result in an estimated loss of ESB revenue of about 650,00 euros per year. These proposals were submitted to be incorporated into the third cycle RBMP, leading to an Action for a proposed pilot project that “will use state-of-the-art technical solutions to improve fish passage through the largest hydroelectric scheme in Ireland” (see also section 4.1.1 of this report). Alongside any technical solutions is the clear need for an environmental flow regime accounting for seasonal fish movements. This was proposed by the CDC Smith EPA Conference presentation, applying the ‘Building Block Methodology’ for environmental flows (Tharme and King, 1988).

A search for “Ardnacrusha” on the IFI website on 24th February 2024 returned three results: 1) a ‘Public Notice’ in April 2922 of report from a member of the public and subsequent investigation of an eel fish kill, that did not confirm the instance but did include the IFI statement “There is no doubt that the turbines at Ardnacrusha are causing mortalities of eels at an estimated rate of 21% of the total run of down-migrating eels. IFI does not have a role in regulating the operations of the ESB at Ardnacrusha as the ESB are the fishery owner. However, IFI would welcome a review of the flow and turbine operations around the time of peak silver eels migration to reduce the mortality levels and improve fish passage via the old Shannon channel”; 2) a press release in May 2023 on conviction from illegal salmon netting; and 3) announcement in August 2022 of a public consultation for the Long Term Management Plan for the Great Western Lakes, apparently reflecting a comment in that process requesting that mitigation plans for barriers should be on the IFI website. A follow up search of “Barriers fish migration” turned up several pages of results, including information contained in this report. These include “IFI is rarely, if ever the owner or responsible party for the management of these barriers but understand the impact of barriers to riverine ecosystems and the benefit which can be gained by improving fish passage.” In the meanwhile, the expected report on ‘Improved fish passage on Shannon’ is anticipated. As of February 2024 was also not on the IFI website, although the announcement of May 2021 that IFI was to lead on the Annacotty weir fish passage improvement project was there). However, recent useful documents and web-links are now available in the public domain on barriers and effects on fish. Examples are the *National Barriers Programme Annual Report 2023* (Coghlan et al., 2024), an information on barrier to fish movement, *River Boyne Barrier Assessment* (Donovan et al., 2023). See also proposed pilot projects under the Actions of the third cycle RBMP in section 4.1.1 and 4.1.3, and as outlined in Appendix 1 of DHLGH (DHLGH, 2024a)

The operating procedures at the Ardnacrusha power station are designed primarily (and originally) for power generation. The maintenance of a minimum statutory compensation flow’ of 10 m^3/s into the Lower Shannon SAC is due for a timely review. A new environmental flow

regime could also benefit fish movements, channel structure and habitats. See also section 2.1.1 *Interconnectivity and flow regimes* above. A reduction in natural flows to the statutory minimum is unlikely to represent a hydromorphological classification commensurate with WFD good ecological status. A less than good status would be a breach of the required WFD status or equivalent under the Habitats Directive (see above, Section 3.2). It is noteworthy that the ECOSTAT interpretation of compliance with environmental flows states that: "To be consistent with the environmental objectives in (WFD) article 4(1), the definition of eFlows should be the result of a technical/scientific process with no consideration of the associated socio-economic impacts. These latter impacts should only be considered when deriving the flow regime to be implemented in HMWBs or water bodies subject to an exemption, consistent with the conditions set by the WFD" (European Commission, 2015b).

Ardnacrusha, hydromorphology and the WFD raise many important issues in the modern context. Without doubt the power station was a major accomplishment and a vision for Ireland's development and electrification. In the intervening years since its construction there has been much greater emphasis, and legislation, on protection of habitats. The Old River Shannon channel is currently not designated as a HMWB. While hydromorphology can only of itself reduce a status from high status, in terms of assessment of a water body the 5-scale classification of hydromorphological alteration is recommended (Kampa et al., 2019; Kampa and Bussettini, 2018). A review of the hydrological regime applying to the Old River Shannon is recommended, using current thinking on environmental flows (Arthington et al., 2018). Contributions of Ardnacrusha and climate neutrality are part of the discussion. The third cycle RBMP provides the opportunity for that discussion to integrate strategic planning for hydropower development with WFD objectives (Kampa et al., 2011).

Shannon Callows

The hydrology of the River Shannon between Lough Rea and Lough Derg, and the low gradient of the area leads to seasonal flooding of the Shannon Callows, an area exceptionally rich in birds and plants (Mills, 2001). The diverse soil types in the Shannon Callows are the grey-brown podzols, peats, brown earths and gleys on which annual fluctuations in the water levels play an essential role in maintaining plant species.

Under the EU Habitats Directive, 5700 ha of the floodplain, the Shannon Callows, are designed as an SAC that includes habitats of ecological importance i.e. Molinia meadows (EU code: 6410); lowland hay meadows (6510); floating river vegetation (3260); limestone pavement* (8240); alluvial forests (91E0); and hydrophilous tall herbs (6432) (Maher, 2013; NPWS, 2013). The Callows are also a designated Natural Heritage Area (NHA).

The Callows have retained a high conservation value by virtue of their topography and seasonal flooding, although changing agricultural practices have had an impact on the wet meadows and seasonally flooded habitats. National agri-environmental schemes have also not managed to sufficiently protect the natural landscape (Tockner et al., 2009), and changes in flooding can also have negative effects on breeding birds (NPWS, 2002). The Callows have many of the features and controversies of seasonally flooded wetlands, seen the world over. Conservation and economic interests can at times seem incompatible, but it is also an area where compromise and new approaches can be trialled. Although the total area of the Callows has limited habitat for breeding waders, those areas that do exist are extremely valuable. A 'Results-based' Agri-Environment Pilot Scheme (RBAPS)' funded through the EU with co-

funding provided by The Heritage Council, Teagasc and the Department of Agriculture, Food and the Marine was trialled in the Shannon Callows between 2005-2018. Its objectives included testing if a results-based scheme can conserve and enhance populations of breeding waders and their habitats, and the extent that advice to farmers in the Callows can support conservation.

As a 'payment for ecosystem services', response to conservation objectives would determine payments farmers will receive. The project reported that farmers found the results-based approach fair and meaningful for farming for conservation (McLoughlin, 2018). The project provides an example of a result-based model for farming High Nature Value (HNV) farmland (Moran et al., 2021). Farming for hydromorphology can be incorporated into this, but as the Shannon Callows demonstrate, striking an appropriate balance can be a challenge.

Water management in the Callows has stimulated much debate with respect to the flooding of fields and homes, with frequent calls for further drainage works to prevent both winter and summer flooding. A sense of local concerns is as reported in the Athlone Observer 10th September 2020: "Formally known as the Mid Shannon Flood Relief Group, the 'Save Our Shannon' organisation is seeking prompt redress pertaining to the situation and is imploring upon local and national politicians to implement plans to alleviate the consistent concerns of residents within the Callows region of the river who have been subjected to rising flood waters during the summer season.

The Save Our Shannon organisation stated that their cause will be "pursued relentlessly" in the coming times as residents of the Callows fear further inevitable flooding in winter, and "For the second occasion in two consecutive years flooding has come to the Shannon Callows during the summer season. The flood waters have spread over the fields used by farmers for hay and silage and for grazing their animals. The rising flood has destroyed people's livelihoods and is causing damage to the habitats of wildlife, particularly to various varieties of wading birds that nest in the Callows. Summer flooding has already driven the corncrake from our area and now the curlew is under threat."

The effects of drainage in Shannon Callows also has potential impact on a number of turloughs. According to Heery (1993), the Shannon Callows in Ireland are exceptional as they have remained largely undisturbed during past drainage attempts. Yet there is evidence that large-scale floodplain damage alongside the Shannon Callows has occurred from arterial drainage (Brennan, 2006). The response of Shannon Callows towards individual rainfall events is considerably slow as they are located at a low altitude. Further drainage could have a huge impact on their conservation status. It is also not assured to have the desired effect of alleviating flooding for farming or residences.

The position of the Office of Public Works (OPW) in terms of flood control in Natura 2000 sites laid out in 2007 (OPW, 2007) was: "While the primary objective of European Sites is to maintain ecological conditions for that site, improvements to ecological values would be desirable. Drainage schemes would have reduced the ecological potential of adjoining wetland habitats, and the concept of restoration is to restore the hydrology towards pre-scheme conditions. This is a possibility where the restoration measures will not compromise the needs and rights of man." It is, however, notable that while the position of OPW appears to be moving to a more engaged position to accommodate the requirements of the WFD and Habitats Directives, its fundamental remit is governed by the Arterial Drainage Act 1945.

For the Callows, a written response on 10th March 2021 in the Irish Parliament about flooding drew the following response from Minister Patrick O'Donovan: "In December, 2019, the Government noted that the 'Shannon Flood Risk State Agency Co-ordination Working Group' agreed to provide €7 m from the OPW Vote to Waterways Ireland to implement a co-ordinated strategic programme of maintenance activities for the River Shannon and for the removal of a number of constrictions in the Callows region. These proposed works can delay flooding and also benefit navigation and agricultural lands."

With respect to the flooding of the River Shannon, it is perhaps best to accommodate the natural dynamics of the river and find other mechanisms for addressing concerns about the flooding of the land. In 1956 a report of a study by the US Corps of Engineers, a body renowned for large-scale engineering and water management schemes concluded: "The problem of Shannon River flooding has been the subject of much study over the past 150 years. Because of the flat terrain through which the river flows, the almost imperceptible gradient of the stream with its series of lakes and connecting channels, and because of the large volume and long duration of flooding, no simple or obvious solution has heretofore been found - nor has the writer now found one" (Page S-2 of Summary Report: III. General Considerations) (Rydell, 1956).

Proposed Shannon to Dublin Pipeline Scheme

A proposed scheme to extract water from the Shannon to Dublin, of up to 330 million L/day from the Shannon from below Athlone, or from upper Lough Derg, drew concerns about the effect this would have on the ecology of Lough Derg and led to a shift to a proposal to abstract water from the lower end of Lough Derg, at an approximate additional cost (as of ca 2010) of 50 million euros from the originally preferred option. The pipeline project has been proposed because of expected water scarcity in the Dublin Metropolitan area, and the insufficiency of other supplies to meet future demand. The timeline of these schemes and the original expected completion of the new pipeline in 2024 are provided in Figure 48.

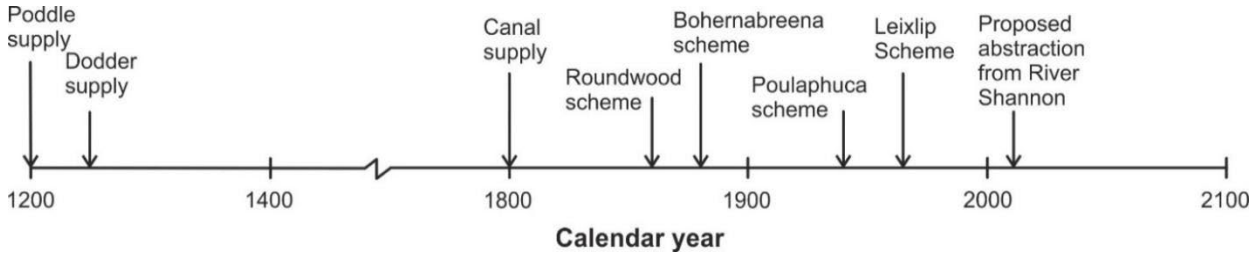


Figure 48. Timeline showing key dates in the development of Dublin City's water supply system (Kelly-Quinn et al., 2014).

It is estimated that the extracted water will reduce, on average, 2% of the volume of flowing water from the Shannon River. On the other hand, Uisce Éireann claims that more than 40% of the country's population will benefit from the project (RTE, 2016). Those who opposed the original pipeline route put forward that more than 500 farmers and landowners would be affected by this scheme, as well as impact on the Shannon habitats. Calls to fix leakages in the Dublin pipeline, reducing the dependence on the water coming from Shannon (O'Doherty, 2020) will unlikely alleviate the need because of the growth in Dublin's population, water demands and pressures exerted on available water resources from climate change.

Kelly-Quinn et al. (2014) provide an overview of the problems and the SEA, highlighting the need for improvement of efficiency, sustainability, and integrated management of water resources not only in Dublin, but in Ireland in general. Given the governance challenges, including charging, surrounding water, and historical regional positions, one thing that can be assured is that the pipeline proposal will attract considerable further debate. Given the options available for the city of Dublin, it is predictable that the scheme will at some point go ahead. The Shannon-Dublin pipeline proposal highlights the political nature of water supply and demand. At the time of writing, proposals made up to 15 years ago for ecological studies of potential effects on Lough Derg have still not progressed, and with the proposal now to extract water from Parteen, the rationale for the study is no longer connected with the pipeline scheme. Nevertheless, the controversy with some citizen groups continues, and the potential impact of even a small percentage removal could have significant effect on the flow through the Lower Shannon SAC. This potential effect places greater attention on the management of electricity generation by Ardnacrusha, and attention of the ESB to enhance environmental flows.

Annacotty Weir

The Annacotty Weir on the lower Mulkear River, is a little over 2 km upstream of the confluence with the River Shannon. The river is of major importance for a range of species: Atlantic salmon (*Salmo salar)*, sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*), brown trout (*Salmo trutta*), and European eel (*Anguilla anguilla*). The majority of the main river and its tributaries form part of the Lower Shannon SAC under the Habitats Directive. Annacotty Weir was installed in 1749 to power a paper mill, but an industrial rationale for its current existence is long gone. The current weir was installed/upgraded as a scenic amenity (W. O'Connor, pers comm).

The weir (Figure 49) is considered a significant barrier to the free movement of several fish species, and attention as to its possible removal is gaining traction, with feasibility studies underway led by IFI. Investigating the removal or modification of the weir was mentioned specifically in the draft third cycle Water Action Plan (DHLGH, 2021), with the weir designated as a high priority for fish passage improvement. There has also been a petition, with over 10,000 signatures for the removal of the weir.



Figure 49. Annacotty Weir on the lower Mulkear River. Source: Will O'Connor.

There seems little doubt that the weir is a major obstacle to salmon. There is evidence that lamprey may be able to move upriver but at reduced numbers compared with real free flow. A lamprey pass was installed at Annacotty Weir as part of the Mulkear LIFE project (2009-2014). A summary report on the European Commission LIFE website suggests some overall success of management actions, including partial removal of another weir at Ballyclough and riparian habitat rehabilitation, but the benefits of the mitigations for fish passage have been disputed. Local concerns were also expressed that the removal of Ballyclough Weir was in breach of the Habitats Directive.

The fish pass installed at Annacotty Weir in 2011 was considered to be ineffective for the passage of lamprey during the typical flow conditions of 3-11 m^3/s of the spawning season (May to July) (Rooney et al., 2015). A new lamprey-specific pass was installed in 2016. However, Bracken et al. (2019), using eDNA detected the presence of lamprey both below and above the weir in 2015, 2016 and 2017, with a positive correlation of lamprey nests and eDNA found in sampling below the weir. While concentrations of lamprey eDNA were generally greatest below the weir, it was also detected at the very uppermost sites sampled by Bracken et al. (2019), and upstream of several barriers. A reasonable overall conclusion based on the evidence so far is that some lamprey has been able to transcend a series of barriers in the Mulkear River, but this does not, overall, constitute free movement.

The process now to assess the feasibility of enhanced fish passage at Annacotty will provide an important example of the attitudes and challenges to the removal of barriers across Ireland. The opportunity to document the process well and assess changes in hydromorphology and links to fish and other ecological elements should not be missed. A review of the impact of the weir is now part of the published WAP (DHLGH, 2024a)

5.1.2 River Lee

The city of Cork at the mouth of the River Lee (Figure 50) is prone to flooding. A serious event occurred in October 2020, and coinciding with high tides and heavy onshore winds. In this incident, the early flood warnings were not enough to prevent damage. It is also claimed that the flooding is the result of changes in land-use in the catchment. Previously, in 2009, Cork faced a particularly high-intensity flood when River Lee broke its banks (Figure 51).

A timeline of the flooding is provided on the Echo live website.. As a result, water discharge of up to 500 m^3/s had a heavy impact on buildings at the University College Cork (UCC). In that particular case, the UCC claimed that the ESB did not manage consistently the two upper dams of Inniscarra and Carrigadrohid that led to the flooding (SANDRP, 2020). A legal case brought by UCC against ESB went to the Supreme Court (2020 IESC 38), which concluded that "..the ESB did owe a duty of care to landowners and occupiers downstream of the Lee Dams" with the issue of the extent of contributory negligence by UCC and actual financial damages yet to be determined by the High Court, following a successful cross-appeal by the ESB (2021 IESC 21).

In 2013, the OPW commenced the 'Lower Lee Flood Relief Scheme' (LLFRS) to address flooding issues downstream of Inniscarra Dam, but the plan was not implemented owing to local opposition to the scheme's design when presented to the public at large exhibition displays in the city over Christmas 2016. The main concerns raised at this stage were the height of the proposed flood defence walls in the city centre, and hence their effect on the people's interaction with the river and the conservation of the historic quays (The Journal, 2020). More recently, permission for flood alleviation works in the city centre in the vicinity of

Morrison's Island, to alleviate tidal flooding were upheld by the High Court. The works are envisioned to decrease the flooding risk for Lower Lee and provide flood protection to approximately 2,100 properties. Some opponents of the scheme consider a tidal barrier as a more effective means of flood defence, and that the scheme proposed by OPW would lead to a diminution of the heritage of the quays.

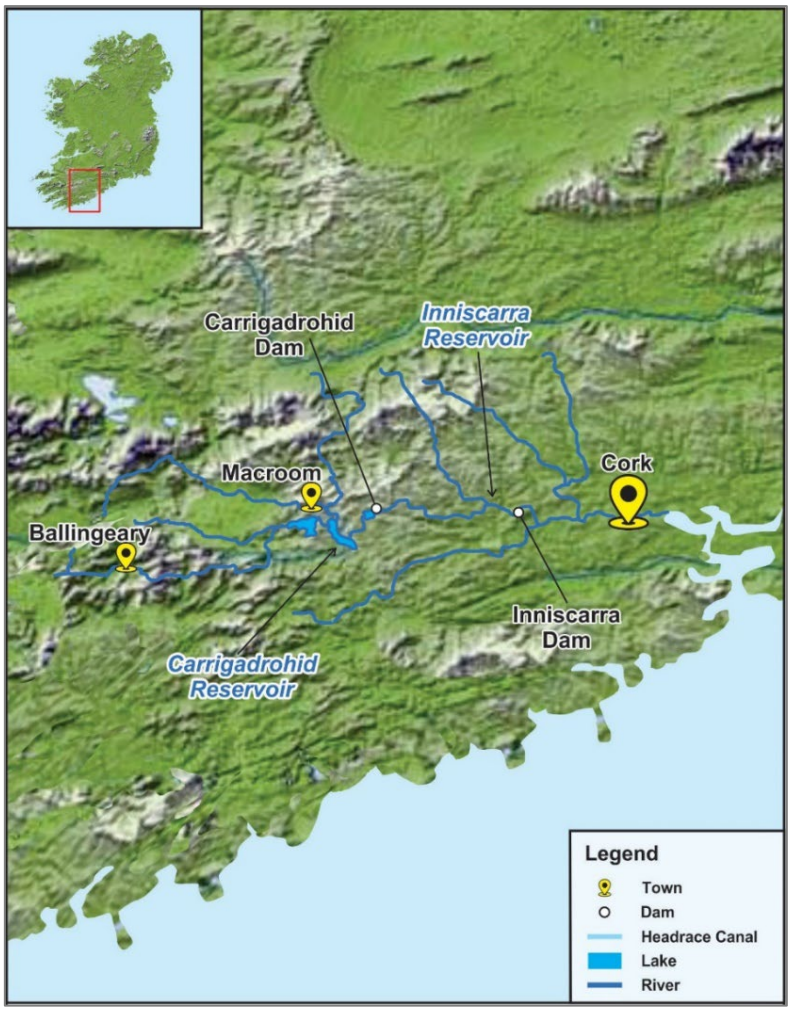


Figure 50. River Lee and its reservoirs. This figure is based on work by ESB cited at: The DEM layer is from Bing

The costs of the LLFRS were estimated in 2020 to be €140 million, with construction likely to take 6-7 years. An initial phase is designed to provide protection along Father Mathew Quay and Morrison's Quay, the lowest-lying quays in the city centre. Cork CC and OPW are planning for the works to commence in early 2024, taking two years to complete at a budget of about €22 million As of 20th October 2023, "Work to finalise the design of the Lower Lee Scheme is significantly complete. Environmental assessment and public engagement over the coming months will inform the final design options prior to seeking planning consent for this scheme."



Figure 51. Flooding on Carrigrohane Road and the Lee Fields area, November 2009 (Echolive.ie, 2019).

Some researchers have claimed that the complex ground and groundwater conditions at Cork have not been adequately assessed in the OPW proposal (Beese, 2019). A shallow gravel aquifer underlying the valley (Figures 52 and 53) is subject to tidal fluctuations and hence has been a major factor in the city's long history of flooding. There are claims that the aquifer displays high permeability, and high hydraulic connectivity both along its extent but also with the surviving channels, which have not been adequately addressed. As a result, the design does not demonstrate that surface- and groundwater flows in the city can be controlled during a flooding event. Hence, installing cut-off walls and a groundwater dewatering system at Cork is an experiment in separating two interdependent surface- and groundwater systems, which is considered likely to fail (Beese, 2019).

The case of the River Lee and the flooding of Cork illustrate how multiple factors, and opinions, provide high controversy when it comes to flood relief and the hydromorphological alterations proposed to mitigate the flooding. It highlights how alterations upstream, in the form of two reservoirs and their management, can connect with downstream economic and social interests, both in proposing and for citizens accepting solutions. The problem is accentuated by tidal effects and increasing extremes of weather.

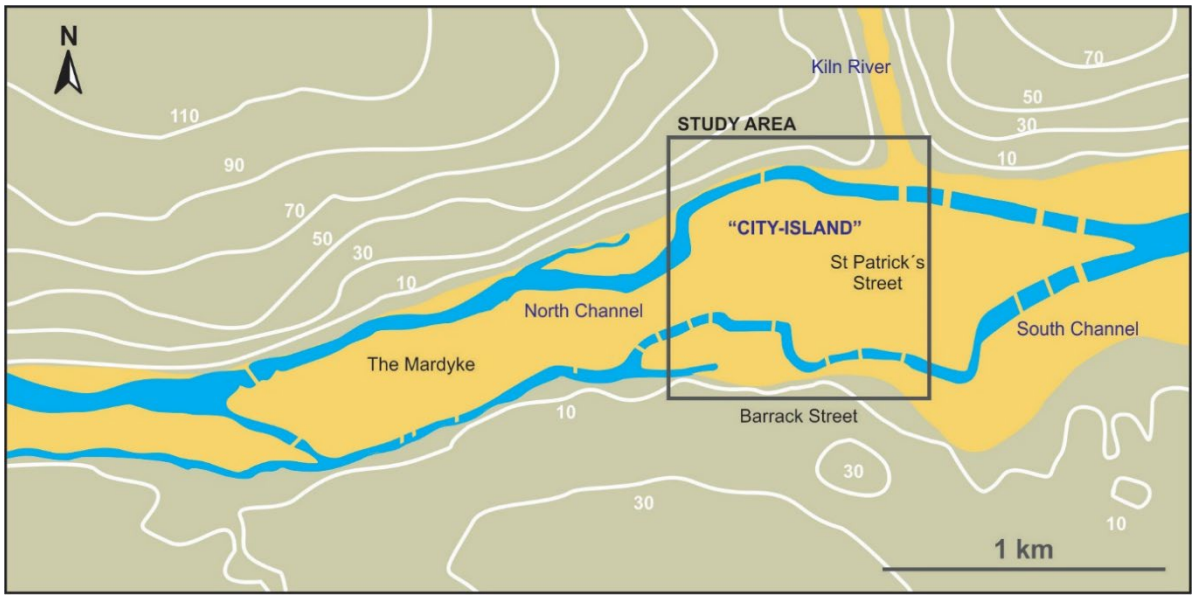


Figure 52. Map of the River Lee Valley (Ordnance Survey of Ireland) showing the extent of the gravel aquifer in yellow, as defined by areas of the floodplain that are underlain by alluvium Source: Beese (2019).

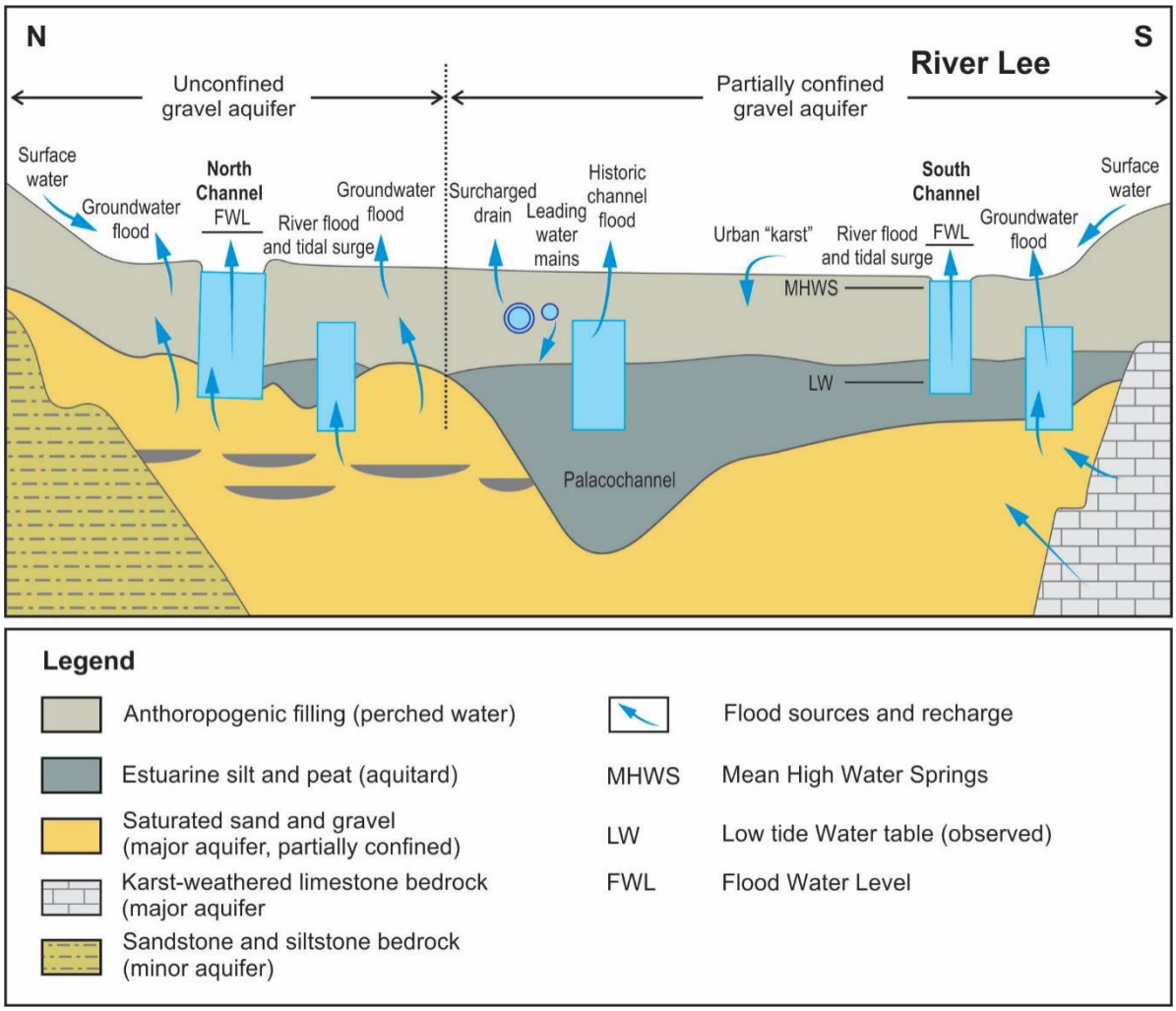


Figure 53. Schematic cross-section showing hydrogeological units and urban water systems in the Lower River Lee. Note: vertical exaggeration. Source: Beese (2019).

The large extent of the overall Lower Lee flood relief scheme will provide for additional hydromorphological alteration to river morphology, and further controversies as to the net economic and environmental costs and required mitigation within the objectives of the WFD. For classification, it raises questions on the assessment of, and compliance with, Good Ecological Potential.

5.1.3 River Liffey - Poulaphouca Reservoir

Alteration of hydromorphological condition is one of the most significant issues in rivers in the catchment of the River Liffey (EPA, 2018a). The river rises in the Dublin mountains and flows through the centre of Dublin (Figure 54). Hydromorphological pressures include excess of fine sediment and alteration of the morphology of the river channel, altering habitat conditions. This can occur as a result of, for example, implementing river and field drainage schemes, forestry activities, animal access, and discharge from quarries (EPA, 2018a).



Figure 54. Liffey River and its reservoirs. This figure is based on work by ESB cited at: The DEM layer is from Bing.

Throughout the catchment, significant hydromorphological pressures have been identified in nine water bodies. There is also an OSPAR (Oslo/Paris Convention for the protection of the Marine Environment of the North East Atlantic) requirement for flow data (EPA, 2021c). Four river water bodies within the Liffey sub-catchments are subject to extensive modification due to the presence of flood alleviation works, while one river water body is mostly culverted. Two

river water bodies of the Liffey are regulated by a dam, which in turn has impacted hydrological conditions.

Poulaphouca Reservoir (also known as Blessington Lake) is located S.E. of Blessington town in Co Wicklow. Created in 1944, the reservoir covers an area of approximately 20 km^2 and provides a source of water for the Dublin metropolitan area, linked to a chain of reservoirs (Figure 55). It is hydraulically connected to the aquifers which underlie Blessington and the broader area. It receives water from two main sources. One is the River Liffey from the northern side and the second is Kings River located at the southern side of the reservoir. It is expected that the increasing demand for water supply from the Poulaphouca Reservoir will lead to water quantity shortage and a lowering of the water level fluctuation in the reservoir. Sustainable water supply from the reservoir was also considered in the discussions that prompted the proposed building of an inter-basin transfer from the Shannon to the Dublin metropolitan area. Moreover, the construction of a hydroelectric dam on the Liffey River also plays a significant role in the reduction of water level inside the reservoir. The occasional flooding on the large sections of the Kings River (a potential water source for the Poulaphouca Reservoir) also threatens the ecological status of the reservoir (Corlett, 2019). The geographical landscape of the Poulaphouca region, with a landscape of rolling hills and gravel ridges, is largely undefined. In July 2021, hundreds of fish were found dead inside the Poulaphouca Reservoir. No business or industrial facility discharges water into the reservoir (O'Doherty, 2021). Moreover, nearby wastewater treatment plants examined by the EPA found no trace of any contamination or leakage.

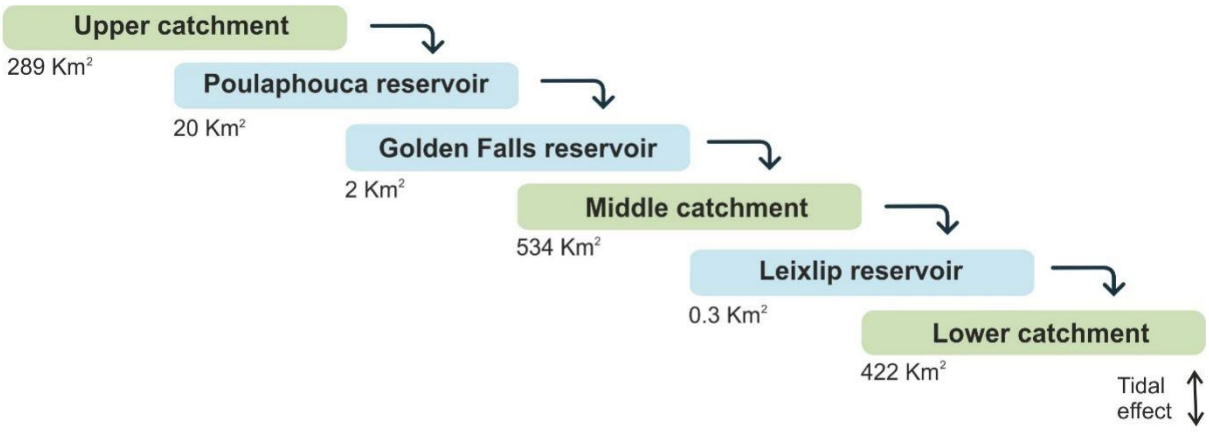


Figure 55. Schematic presentation of the Liffey reservoirs (OPW, 2012).

Uisce Éireann obtained planning permission to upgrade the Blessington Waste Water Treatment Plant (WWTP) to 9000 P.E. from Wicklow County Council Planning Authority. The Blessington WWTP discharges into Golden Falls Reservoir just downstream of Poulaphouca Power Station. The flow of water from Poulaphouca into Golden Falls Reservoir is normally by means of an intermittent flow through Poulaphouca Power Station when the station is generating electricity. Golden Falls Reservoir is known as a buffer reservoir to take the large water flows when Poulaphouca Station (28 MW) is at capacity. The water flow is then released into the River Liffey, from Golden Falls Reservoir. There is a statutory requirement to maintain a minimum a flow rate of 1.5 m^3/s at all times. When ESB are generating electricity at Golden Falls Power Station, a flow of up to up to 30 m^3/s is discharged, with a generating capacity of 4 MW.

Upstream of Golden Falls Reservoir, the flow from Poulaphouca Reservoir, can be shut off, according to the Ballymore Eustace Trout & Salmon Anglers' Association (Public consultation, 2019), and indicating that the Golden Falls Reservoir can have no water flowing into it for up to five consecutive days. This can influence the dilution of effluent from Blessington WWTP. Following an upgrade to the treatment works, effluent is compliant for measured variables except Ammonia-Total (as N) mg/l, with a mean value from 12 samples of 2.69 mg/l (Uisce Éireann, 2024).It was noted that "Based on ambient monitoring results a deterioration in BOD, Ortho-P (as P), Ammonia (as N) concentrations downstream of the effluent discharge is noted; A deterioration in water quality has been identified, however it is not known if it or is not caused by the WWTP. Other causes of deterioration in water quality in the area are unknown; and the discharge from the wastewater treatment plant does not have an observable negative impact on the Water Framework Directive [good] status."

5.1.4 River Erne

The River Erne is a transboundary catchment between N. Ireland and the Republic of Ireland and is the second-largest river on the island. Lough Erne consists of two parts, the Upper and the Lower Lough Erne (Figure 56). Both are widened channels of the River Erne.



Figure 56. The reservoirs in Erne Catchment. This figure is based on work by ESB cited at: The DEM layer is from Bing.

In the 1950s, the construction of a hydroelectric power station in Belleek altered the hydrological regime of the lake. The construction of the Kathleen's Falls and Cliff Power Stations was enabled by cooperation between the UK and Ireland resulting in the Erne Drainage and Development Act (1950). The Act that was signed in 1950, for the purposes of generating electricity from the River Erne was an early example of transboundary cooperation. The Erne is connected to the Shannon River basin by the Shannon Erne Waterway (which was constructed in the mid-19th century and re-opened in 1994). The lough has undergone a series of major alterations and increasing pressures since 1850 (Figure 57).

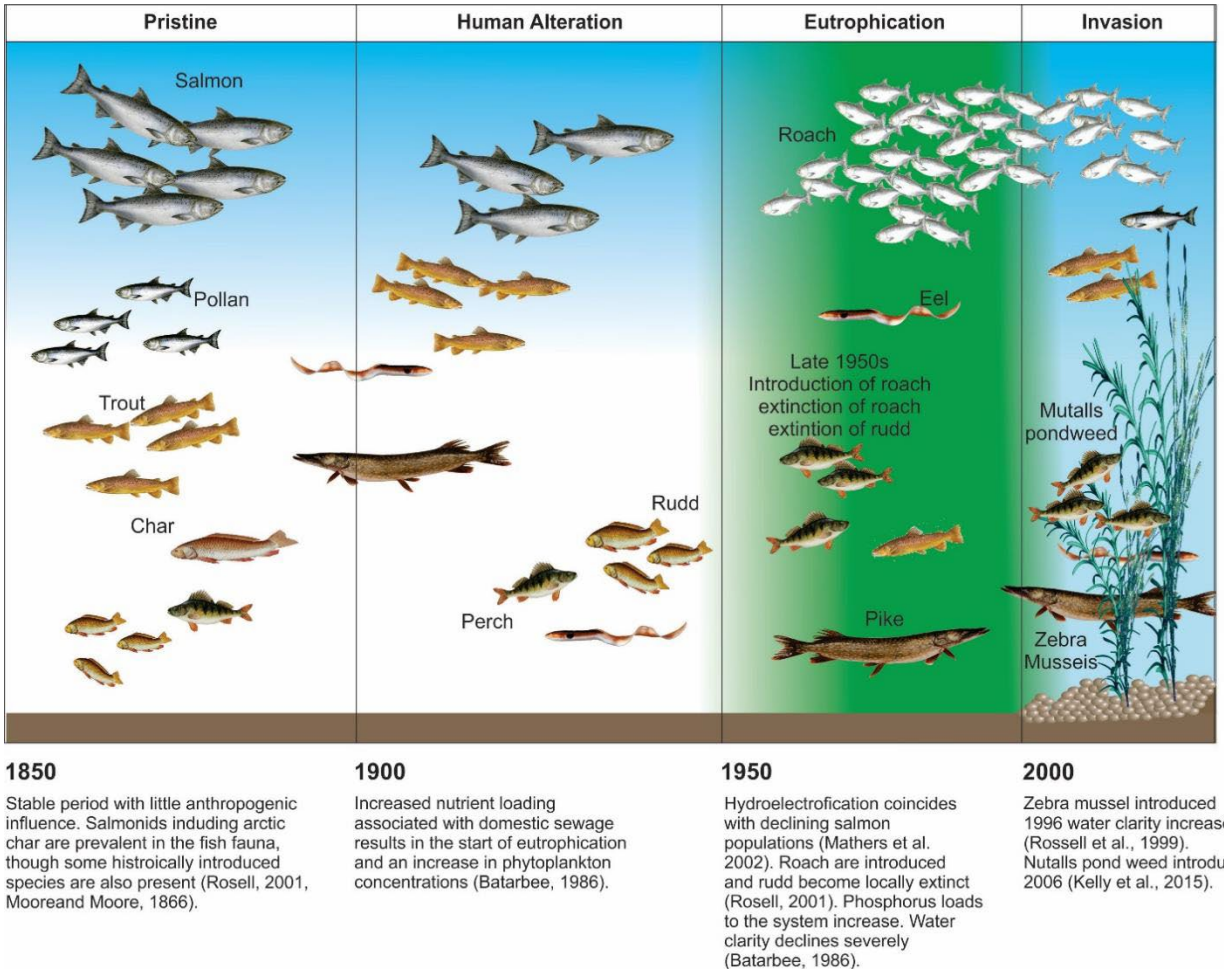


Figure 57. Overview of the major changes in the ecology of Lough Erne since 1850. Source: AQUACROSS

Under the WFD Lough Erne is a Heavily Modified Water Body (HMWB) of moderate ecological potential and the target for both upper and lower Loughs is the good ecological potential. Agricultural land is the major source of nutrients to the Loughs (DEARA, 2016). Maguire & Gibson (2005) summarised the findings of a workshop that was attended both by researchers and policymakers in 2003 and aimed at putting changes into a longer-term perspective and differentiating between natural change and change driven by anthropogenic influences. A main management output of this workshop was that while the WFD and Habitats Directive requirements may provide an opportunity to carry out mutually supportive monitoring, reducing duplication, any conflict arising from the markedly different goals should be tackled so that management of the lake is not driven in two different directions (Maguire and Gibson, 2005).

Moreover, there were views expressed about misperceptions by water users and the public about the zebra mussel (*Dreissena polymorpha*) invasion, and hence better communication between scientists and the public about ecological research was advocated.

Lough Erne sustains multiple competing activities each with different requirements in terms of ecosystem services and physical resources (O'Higgins et al., 2018). The well-informed dataset that exists for Lough Erne is one of the most comprehensive in Ireland, and has immense value for tracing ecological change and assessing different drivers such as increasing nutrient inputs and species invasions (Maguire and Gibson, 2005).

In the Lough Erne catchment, 18 invasive species have been recorded, of which seven are classified as of European Concern. The effect of the invasive species on the ecological quality and hydromorphology of the Erne system are being considered within an EU-funded Horizon 2020 project 'Knowledge, Assessment, and Management for AQUAtic Biodiversity and Ecosystem Services aCROSS EU policies' (AQUACROSS). For example, the Nutall's pond weed (*Elodea nutalli*) interferes with recreational boating and fishing activities and has demonstrated considerable economic costs. The zebra mussel has led to rapid and extensive ecological change i.e., an increase in water clarity; a decrease in both phytoplankton and zooplankton abundance; near extirpation of native unionid mussels and changes in the fish population (Russell et al., 2017). The AQUACROSS project aimed to advance knowledge and application of Ecosystem Based Management (EBM) for aquatic ecosystems to support EU 2020 Biodiversity Strategy targets, including how solutions to the problem of invasive alien species in Lough Erne will affect the objectives of the WFD and regulation on invasive alien species. In the UK, the responsibility is devolved to the regional (Northern Ireland) level. The implementation of the CAP in Ireland has affected nutrient loading from agriculture to tributaries in upstream parts of the catchment, which in turn has the potential to affect the state (i.e. nutrient concentrations) and status (i.e. ecological potential) of Lough Erne. While the RBMP aims to improve the state and status of the loughs through transboundary coordination, the driver (farming) and pressure (nutrient release) are affected by separate policy implementation in Ireland and N. Ireland (O'Higgins et al., 2018).

Although there are numerous pressures on Lough Erne, its designation as an HMWB, illustrates a difficulty in designation when for the ecology of the lake the main pressures are from land-use derived nutrients and from invasive species, while designation is based on hydromorphology. The inter-basin transfers of nutrients and invasive species allowed by a major hydromorphological alteration, through the legacy of the canal, raises other potential compliance questions, also relating to transboundary management.

Inny Basin

The River Inny, within the Shannon Basin, is subject to a range of pressures common to the Irish midlands. The main anthropogenic pressures that alter the hydromorphology of the Inny Basin include the discharge of fine particles and nutrients, disturbance by livestock through poaching and river bank erosion, peat extraction and drainage causing channel modification (EPA, 2021b; IFI, 2018). The input of sediment creates impediments to natural flow and connectivity. The 'Environmental River Enhancement Programme' (EREP) for the basin, updated in 2017 by the IFI, included a barrier assessment survey for the identification of the impact of sediments on fish movement through natural transport traps and examined the impact of these traps on fish passage and sediment transport and deposition in downstream areas of the river. This can have an impact on river condition by impeding natural downstream sediment transport.

This programme is intended to assess the feasibility of their removal or mitigation in order to improve longitudinal connectivity of upstream fish movement and downstream sediment transport. It includes the movement of gravel. Other man-made barriers to the fish passage have also been examined (CFB & ERFB, 2009). The IFI and OPW surveyed the lower Inny Catchment to assess the potential hydromorphological threats to the fish population by applying the Rapid Hydromorphology Assessment Technique (RHAT).

The Inny case study investigated twenty-nine sites in the lower Inny Basin for hydromorphology using RHAT and not a single site passed the WFD minimum requirement of good status, with 62% of the sites classified as moderate, 35% as poor and 3% classified as bad status (IFI, 2018). Bank structure, riparian land cover, and floodplain connectivity scored the lowest (1.09-1.26) on the RHAT scoring matrix for lower Inny Catchment.

The OPW and IFI proposed multiple strategies to overcome these unregulated modifications in the basin. These include the mitigation of adverse effects of barriers by improving longitudinal connectivity for upstream fish movement and downstream sediment transport. The movement of gravels aiming to aid fish passage, and sediment transport has the potential to benefit fish access to previously unreachable sections. Management measures include providing downstream dispersal of the spawning substrate via sediment transport, avoiding channel modifications, reinstatement of natural riparian cover, and encouraging fencing on riverbanks exposed to livestock.

The study was conducted during August and September 2017 and 34 sites were sampled in the catchment to determine the density, distribution, and hydromorphological factors affecting the population structure of the fish species in the South Inny Basin. The Inny Basin was specifically considered in the context of the effects of arterial drainage on fish populations (Coughlan et al., 2018). The most abundant species was brown trout (*Salmo trutta*), followed, respectively, by minnow (*Phoxinus phoxinus*), stickleback (Gasterosteidae), pike (*Esox Lucius*), stone loach (*Barbatula barbatula*), and perch (*Perca fluviatilis*). The survey results also indicated a decline in water quality over the previous three years. In 2014, 41% of the monitoring sites in the Inny River were classified as good status under WFD criteria, while in 2017 only 24% of those 41 sites were, while 11 sites were not assigned any status (EPA, 2017). OPW also conducted a Small Stream Risk Assessment (IFI, 2018) on the Inny Catchment to identify the pollution threats that decrease the water quality and concluded that much of the decline in quality is due to eutrophication from phosphorus discharge. The assessment also indicated that run-off of organic pollutants was a major problem in 57% of the survey sites.

The River Inny, comprising ten waterbodies, is subject to multiple pressures, but there are no sections considered to merit HMWB status from the first and second RBMPs. A number of sections are under consideration for the third cycle RBMP to mitigate pressures from nutrients and morphological alteration, and some putative statii for some sections remain unassigned (EPA, 2021b).

5.2 Coastal and transitional: Irish case studies

5.2.1 Tacumshin Lake

Located on the southeast coast of Ireland, Tacumshin Lake Special Protection Area (SPA) is a shallow coastal lagoon covering an area of 3.1 km^2. The lake is located 1 km southeast of Tomhaggard Village, Co. Wexford. Longshore. Over the past century, many morphological changes occurred in the lake. At the end of the 19th century, the lake was drained using a large bore pipe set through the gravel/sand bar. Some of the drained lakebed was used for growing cereal crops. There was a time when the spits and sand totally landlocked the lake and in the mid-1970s the lagoon was also closed off from the sea. During this time, its water level rose after heavy rainfall and flooded several hundred hectares of low-lying surrounding farmland. To relieve flooding the farmers reactivated the old drainage pipe and installed a second pipe at a lower level. Even so, the lagoon fills up in winter when the inflow from streams is greater than the outflow through the pipes. To speed the drainage from the lagoon two main drains were excavated leading to the landward end of the pipes (Mott MacDonald Ireland, 2009).

The lagoon which was separated from the sea by a gravel barrier and provided fine sand to the beach through an outlet stream in that barrier, is of high ecological importance. Its bed is composed of silt and sand deposited by incoming tides and feeder streams. The surrounding lands are composed of glacial till.

The discharge of sediments and fertilisers from agriculture is the most common threat to the lagoons in Ireland. To study the consequences of changing the natural morphological process of lagoon ecology and its impact on hydromorphology, Orford et al. (1988) found that the natural outlet of the Tacumshin lagoon was dammed in 1974 during work to convert it to agricultural land. The result of these extensive pressures on the lagoon reduced the natural supply of fine sand to the beach which ultimately led to the removal of the already present fine-grained sediments by longshore currents. It also steepened the natural angle of the face of the beach which made the lagoon extremely susceptible to continuous wave attacks, over-topping during storms, a decrease in the overall volume of the beach, and complete degradation of the barrier important for maintaining the ecology and conservation interest of the lake.

The main threat to the lagoon is insufficient drainage capacity, especially during times of excessive flooding. Water coming from the surrounding farmlands and sea alters the flow in the lake, impacting the drainage capacity. To overcome this, drainage pipes have been installed to enhance the drainage from the lagoon. The freshwater sources in Tacumshin Lake are multiple small streams located nearby which play a significant role in maintaining the lake's salinity of 8-19% along the eastern lake shore (NPWS, 2013). In 2009, a fish habitat survey of the littoral zone using beach seining found that three-spined stickleback (*Gasterosteus aculeatus*) is the abundant fish species in the lake followed by goby (*Gobiidae*), European eel (*Anguilla anquilla*), rudd (*Scardinius erythrophthalmus*) and flounder (*Paralichthys dentatus*) (IFI, 2009). The main aim of the project was the collection of necessary data to support the fish monitoring programme for WFD.

Compared with other coastal lakes, the species diversity in Tacumshin Lake is very low and many of them are freshwater species indicating the importance of incoming freshwater for the lake. Based on this result, WFD Moderate status was assigned to the Tacumshin Lake. In March 2021, NPWS put forward a conservative action plan (NPWS, 2018) for the restoration and maintenance of favourable conditions to conserve bird species and other ecological interests of the lagoon (NPWS, 2021) (Table 20).

Table 20. Conservation objectives for Tacumshin Lake related to hydromorphology (NWPS, 2018).

Attribute	Target
Habitat area	Stable or increasing, subject to natural processes (favourable reference area is 380.7 ha).
Habitat distribution	No decline, subject to natural processes.
Salinity regime	Median annual salinity and temporal variation within the natural range.
Hydrological regime	Annual water level fluctuations and minima within natural ranges.
Barriers: Connectivity between lagoon and sea	Appropriate hydrological connections between lagoons and sea, including where necessary, appropriate management.
Water quality: Molybdate Reactive Phosphorus	Annual median within natural ranges and less than 0.1 mg/L to ensure that excessive shading from phytoplankton does not reduce submerged colonisation of vegetation in the littoral zone.
Water quality: Dissolved Inorganic Nitrogen	Annual median within natural ranges and less than 0.15 mg/L to ensure that excessive shading from phytoplankton does not reduce submerged vegetation growth.
Depth of macrophyte colonisation	Macrophyte colonisation to maximum depth of the lagoon.
Negative indicator species (incl. Non-native alien species)	Absent or under control.

Tacumshin Lake illustrates the different interests of the WFD and Habitats Directive and, as such, necessary interactions between the EPA and NPWS. The lake has been subject to many changes over the years, driven by both human and natural processes. Defining a reference state is understandably difficult and the current classification of moderate status may be prudent so as to enable ongoing restoration actions.

5.2.2 Waterford Port Dredging (2018-2026)

The port of Waterford in Ireland has importance as a container port connecting Ireland to mainland Europe. Recently, the port of Waterford Company applied to the Department of Environment, Community and Local Government for a maintenance dredging campaign for the removal of sediments from the water channel. The site where the dredged material will be disposed of is already authorised by the EPA (Ganic, 2021). The current dredging and disposal at sea in the Port of Waterford is governed by Permit No. S0012-02, which runs from 2014 to 2021. The disposal site was licenced to dispose of dredge material excavated from Waterford Port for the 2014-2021 campaign. Two areas of dredging were proposed to be extended for navigational safety, and some minor increases in disposal tonnages were requested, so a new licence was sought (AQUAFACT, 2017).

An Appropriate Assessment Natura Impact Statement also concluded that dredging of sediment at the Waterford Harbour and in the estuary has multiple environmental impacts especially if the dispersed sediments move to the surrounding estuaries. Similarly, suspended sediments as a consequence of unregulated dredging in the port, are likely to degrade water quality even if they are not contaminated, thereby putting pressure on the benthic communities. The dredging and disposal was also expected to cause disturbance to the benthic communities through burying, although benthic communities in these areas are adapted to repeated disturbances and their recovery begins almost immediately following the cessation of the activity.

The application for an 8-year licence anticipated “an average of about 450,000 tonnes would be dredged annually mainly using a trailer suction hopper dredger.” Subject to the granting of a Dumping at Sea Permit by the EPA, the dredged material was planned be disposed of at a licenced dump site south of Hook Head, with an additional 21,000 tonnes of sediment relocated annually, also requiring a Dumping at Sea Permit. The required statutory consultation attracted a number of concerns for the potential impact of sediment affecting seabed structure and possible effects on molluscs, crustaceans and finfish, as well as “disappointment” that the application did not consider possible effects on aquaculture, and insufficient clarity on the upper limit of sediment to be dredged.

As an ongoing economic activity, the licence was approved by the Department of Housing, Planning and Local Government Water and Marine Adviser, without any specific measures for mitigation of the concerns of the statutory consultation apart from a defined upper limit of 5,565,175 tonnes including contingency, but dependent on a ‘Dumping at Sea’ permit (FS006684 Port of Waterford Dredging Consolidated Prescribed Bodies Observations). This suggests that mitigation of the impacts was not part of any approval conditions.

Following this process, the Port of Waterford applied for a ‘Technical Amendment’ to existing permit S0012-03 under s.5(4) of the Dumping at Sea Acts. Representation by the NGO Coastwatch stated that there is no such thing as a technical amendment under the Dumping at Sea Act 1996, as amended, and that the new area that dumping was applied for was according to a submission by the NGO Coastwatch was “not in fact an amendment of the existing permitted area but an expansion or extension into entirely new areas” . As a new application, there should be a mandatory EIA. The Coastwatch submission further states “The Natura 2000 sites are not in favourable conservation status either. Further, out of the estuary, there are important spawning grounds for lobster on both sides of the approved dumping area for spoil between Swines Head and Hook Head” and that “Natura Impact Statement that was prepared in 2017. is significantly out of date and was deficient even when it was prepared”, and…” related to a much smaller area of dredging than the current application.” Relevant to this current report, the Coastwatch submission claims “The Water Framework Directive has not been considered by the port company. The Barrow Nore Suir transitional water body only has a moderate status and according to the third cycle Draft Barrow Catchment Report has multiple pressures including complaints of mass die-off of mussels, norovirus impacts and concern re sodium hypochlorite use (point source) and is under significant pressure from agriculture. The Waterford Harbour coastal water body has significant pressures from agriculture and urban runoff and again only has a moderate status. Adding to these pressures with increased dredging will further reduce the possibility of the water bodies attaining the required status of good by the WFD deadline.”

In conclusion, it appears that the process for the extension of dredging in relation to the needs of the WFD was deficient in process and detail.

5.2.3 Bantry Bay

Bantry Bay forms part of the Dunmanus-Bantry-Kenmare Catchment, encompassing the input to the tidal waters between Mizen Head and Glanearagh Head, Co. Kerry, draining a total area of 1,898 km² (EPA, 2021d). Bantry Bay was a demonstration project for Integrated Coastal Zone Management (ICZM) under European Commission LIFE funding (1997-2000) and, therefore, just prior to the implementation of the WFD. Many of the goals of ICZM have been superseded by the WFD, with its inclusion of transitional and coastal water bodies. The Bantry Bay project aimed for the development of ICZM and was one of the first projects with such an aim in Ireland.

The project developed a Charter that set out an action programme for each of a series of proposals. The ICZM strategy aimed at achieving sustainable ecological conservation of the coastal areas in Bantry Bay by adopting a conservation strategy which involved stakeholders and, novel at the time, information-retrieving technologies mainly GIS. The main objectives were to inform the stakeholders about the coastal and marine issues that threaten the hydromorphological characteristics of Bantry Bay. The hydromorphological characteristics, flow variations and external pressures were extensively studied using the GIS technology which incorporated 120 datasets (Connolly and Cummins, 2001). However, the information has not been updated since the end of the project, likely at least in part because of the shift in attention to the WFD. A study conducted by EPA in 2018 found that the hydromorphological pressures on Bantry Bay relate to run-off, drainage and soil erosion, mainly from agriculture and bring phosphorus and ammonia to surface water (EPA, 2018b). Drainage of peat was also identified as a significant pressure on the water body.

5.3 Urban Flood Relief Schemes

While the River Lee was featured as a case study above, that was mainly in the context of rivers. In this section, there is a greater focus on urban flood relief schemes in general, with information used from published and web-based sources and, in the case of Blackpool, direct engagement with local knowledge.

There are many places in this report where the importance of Nature Based Solution (NBS) for water management, and especially flood control, has been mentioned. This has been highlighted by numerous international reports, and greater attention is paid to natural water retention measures to support the objectives of the WFD in the third cycle of Ireland's RBMP. While such opportunities are also increasingly referred to by the OPW (2022), the messaging from that body can appear redolent of traditional hard engineering solutions to flood control. A recent ruling on a case taken by IFI against a contractor employed by OPW in the flood defence scheme of the Bandon River that resulted in a fish kill in 2017, prompted the judge in the ruling of the case (22 July 2022) to remind OPW of "a duty of care," and that there was "no indication" that comments from members of the public had been taken on board at consultation stage" and "a lesson to the OPW when there are other works that they are very honest and transparent." The flood defence also involved construction equipment driving down the middle of the river, compacting interstitial habitats. According to a news report in the Irish Examiner, the judge characterised the attitude of OPW as:

"We have the money, we do the work, we dig up the river, we put a road down the middle of it, and it will all be grand.". Cases such as this, which are also widely disseminated on social media are extremely damaging to the reputation of OPW, and not helpful for a more considered approach to urban flood management.

The perception of a politically motivated view on flood management hinders open discussion of water management at the river basin or national scale, and the merits of a softer NBS approach to flooding. Examples of a *Seanad* debate on the matter, illustrating the local and political nature of flooding. Extreme rainfall events will become more prevalent, which will also reveal the legacy of poor planning related to building in floodplains. In the following section, we explore some case studies of Flood Relief Schemes that have attracted criticisms, and to what extent alternatives to hard engineering to achieve the stated objectives of flood alleviation were considered.

5.3.1 Qualifying schemes and conditions

Since the Arterial Drainage (Amendment) Act 1995, the OPW has commenced a programme of Flood Relief Schemes. As part of the rolling programme of Flood Relief Schemes in 2020, 44 schemes were completed, 12 were at construction, and a further 80 were in various planning and design phases with an additional 60 to be commenced as part of the current National Development Plan 2018-2027 (Gilligen and Quinlan, 2020). Updated information on flood relief schemes can be found on the Floodinfo website. .

The 1995 Amendment of the Act (under Section 4(1)) provides for the execution of arterial drainage of:

a. "…any catchment area for the purpose of preventing or substantially reducing the periodical flooding of lands in that area or of improving by drainage lands in that area, *or*

b. any watercourse or any part of a watercourse for the purpose of preventing or substantially reducing the periodical flooding of lands in the area of that watercourse or such a part or of improving by drainage lands in that area,

[It] shall be lawful for the Commissioners to prepare a scheme (in this Act referred to as a drainage scheme) for the execution of such works and for that purpose to make such engineering, environmental, valuation and other surveys of the said area as shall appear to them to be necessary or expedient."

The Act allows for schemes to provide flood protection for cities, towns and villages. Under Section 9 of the Amended Act 1995, the Commissioners may consent to alterations to existing water courses or structures in Drainage Schemes if the proposed works would not increase the risk of flooding or have a negative impact on drainage of land. The section applies to regrading or relocation of water courses, replacement or relocation of embankments and various other works on Drainage Schemes. Applications under this section are dealt with on a case-by-case basis, with applications addressed to the appropriate OPW regional office.

The apparent onus would seem to be that drainage, and especially the continuation of that drainage, is the expected position taken by the OPW. Furthermore, Section 47: Arterial Drainage Act 1945, states that "any person planning to erect or alter a weir must first get consent from the Commissioners or all the affected land owners."

The Commissioners may grant consent only where the applicant meets stringent requirements. The ESB is exempt from this requirement as a separate statutory process is in place.

From information provided in relation to flood relief and management:

- "…all individual flood risk management projects that meet an Environmental Impact Assessment (EIA) threshold, require anticipated environmental effects to be published in an Environmental Impact Assessment Report (EIAR). The primary application of an EIA is for large Flood Relief Schemes, which typically are EIA scale projects;
- all flood risk management activities which potentially impact European Natura Sites, for example, SACs or SPAs, carry out Screening for Appropriate Assessment or full Appropriate Assessment (AA) including producing a Natura Impact Statement (NIS) as required. AAs are carried out on an ongoing basis for Arterial Drainage Maintenance operations with AAs also carried out for all Flood Relief Schemes which potentially impact on a Natura Site; and
- cases occur where some flood risk management activity is proposed but no other form of environmental assessment is required. In the event that there are some potential environmental sensitivities that need further consideration, an Ecological Assessment (EcA) will be carried out. The typical application for EcAs are for small flood alleviation works and drainage maintenance activities that do not require an EIA or an AA."

SEA is required for the rolling arterial drainage programme, but individual schemes affecting urban areas appear to be based on a case-by-case basis. Many urban Flood Relief Schemes court increased controversy.

The River Lee scheme in Cork (reported above) highlighted some of the issues and promoted an investigation by the independent journalism of Noteworthy in 2020. The report is useful and informative in presenting the various sides of the debate.

A key conclusion is that, while there is evidence of public engagement and extensive studies, and a shift in attitudes within the OPW, the Irish flood defence process is rooted in a hard engineering tradition and generally a low level of public engagement. This is described by Revez (2014) as a "definite problem with legacy." The Noteworthy report refers to a collaborative Irish-Dutch project, Irish Rivers 2040, quoting a landscape architect that the team found "about 80% of the sites studied in Ireland were using walls to stop the water", and that in 43 areas of flooding marked for improvement, "the clear majority of the projects being proposed under the current process comprise structural flood protection solutions."

Overall, it appears that a more engaged and open interaction between the OPW and stakeholders is needed to move towards a more modern approach to flood management that can be adaptive to the increased frequency of extreme weather events. NGOs and citizens continue to express concern about the way schemes are implemented and the real, or perceived, level and quality of engagement with Local Authorities and the OPW.

The 'Irish River Project' maintains a list of OPW flood defence schemes. Below we look in further detail at three recent schemes, respectively, Clonakilty, River Deel and Crossmolina, and Blackpool. All have attracted critical attention from environmental groups.

5.3.2 Clonakilty Flood Relief Scheme

Summary information on the OPW website is that the scheme is designed to protect the town of Clonakilty from fluvial flooding from the Ballyhalwick River, the River Fealge, the Cappeen Stream and the Garage Stream along with tidal flooding from Clonakilty Bay. The works comprise a flood storage area upstream of the town to protect against fluvial flooding and new flood defence walls from Emmet Square to the Croppy Road to protect against tidal flooding (Figure 58). A Public Exhibition period from the 15th of December 2014 to the 20th of January 2015, with further comments invited up until 20th February 2015. The scheme was subject to an EIA, a Natura Impact Statement, and Appropriate Assessment. The scheme was completed, with an unveiling of the flood defences in the town, in 2021 (Figure 59).

The Environmental Impact Statement (EIS) (now referred to as the Environmental Impact Assessment Report (EIAR)) refers to the requirements under the EU Directive on the Assessment and Management of Flood Risks (2007/60/EC) for increased use of non-structural and flood impact mitigation measures. The scheme included the design for upstream water storage areas on agricultural land to reduce flood risk from the catchment. The flood defence walls in the town are designed to reduce tidal flooding. The studies done in preparation of the schemes are reported in the EIS: “The study has shown that the construction of the drainage scheme will have low to medium impacts on the hydromorphology of the river and estuary. However, the reinstatement of damaged sediment bed features once construction is complete will sufficiently mitigate these impacts. Monitoring will be required when the scheme is operational.” This can lead to further interventions. During the preparation of the EIS, the NPWS and IFI were consulted. Seaward of the works is Clonakilty Bay Special Area of Conservation (SAC), Special Protection Area (SPA) and proposed Natural Heritage Area within the study area. The River Fealge contains Habitats Directive Annex I habitat H3260 of *Ranunculion fluitantis* and Callitricho-Batrachion vegetation, and gravel beds suitable for fish spawning. Otter (*Lutra lutra*) habitat, but not resting areas, was likely to be disturbed.

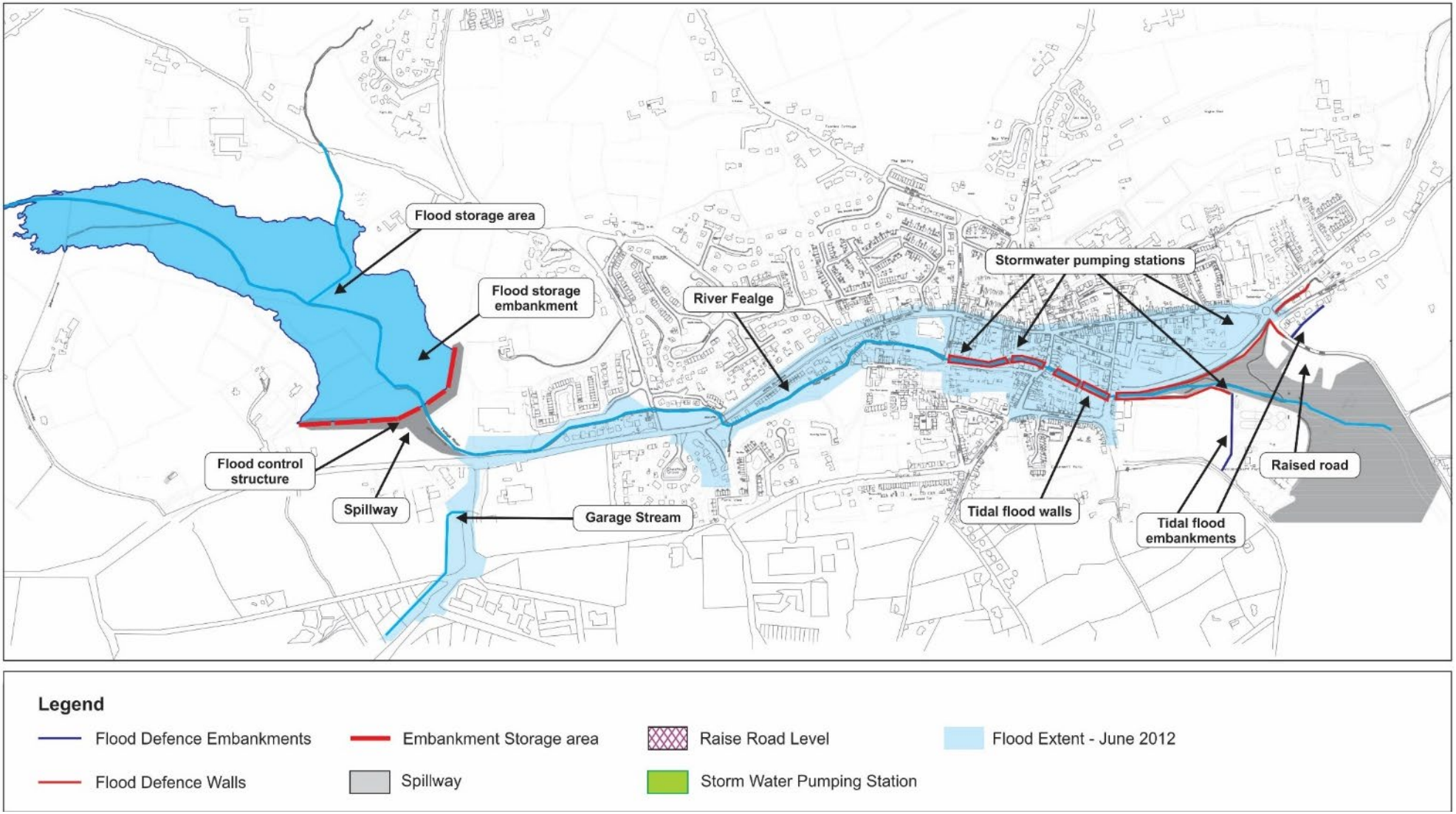


Figure 58. An overview of the River Fealge (Clonakilty) Drainage Scheme. Reproduced from the Environmental Impact Statement non-technical summary. Source: JBA Consulting (2014).

The estuarine and intertidal habitats were evaluated as being of “considerable importance”, but no construction works were planned within the protected areas, although sediment flushes could have an impact. To avoid impact from disturbance on overwintering birds, any construction works around Clonakilty Bay would be scheduled in the summer months.

On potential impact on the visual landscape, the EIS recognises that the “historic stone walls, the character and ambience of the old town, the bay, the river and views and prospects and amenity spaces all add to the character of Clonakilty” and that “protection is afforded through the designation of scenic routes, scenic landscapes, Protected Buildings and an Architectural Conservation Area.” Hard engineering is a feature of the central town area (Figure 59).



Figure 59. Minister O’Donovan, local dignitaries and officials of the OPW exhibiting the flood defence wall in the town of Clonality. Image downloaded from OPW Twitter feed.

Based on the EIS, there has been an accommodation of the use of water storage areas upstream of Clonakilty to better manage water release during periods of increased flood risk following heavy rainfall. This fits with the statement on the need for the scheme: “Flooding in the town was recorded in 1961, 1963, December 1996, 2004, 2006, 2008, three times during 2009, 2010, and five times in 2012. *In the vast majority of these cases, flooding was attributed to rivers and streams*” (italics added here for emphasis). However, “The storage measure does not mitigate upstream fluvial flood risk. Therefore, localised protection works are required at Killgarriff Bridge and on the Ballyhalwick Stream” (OPW, 2015). Justification and elaboration of these works are hard to find in the EIS. A search through the EIS found little evidence to justify current engineering works to safeguard from tidal flooding.

The Hydromorphology report (as Appendix 10 of the EIS) had a recommendation that: “Improved upstream storage and floodplain reconnection would be beneficial in areas where the channel is currently disconnected from its floodplain, as this will act to reduce fine sediment within the channel and also benefit spawning habitats.” Other than the area designated for flood water storage it is unclear how the project will achieve this. For the storage area itself, the EIA states: “There is a possibility that parts of the current grassland nearest to the embankment could be replaced by vegetation more typical of wetland or wet grazing. This could be perceived as a negative impact by some people but be visible only from a few residences to the north including a small area zoned for residential development, but also the grounds of the Fernhouse Hotel at a distance.” The wet grassland area could be seen by others as a positive effect. A report in the Irish ‘Southern Star’ newspaper (11th January 2022) indicated that the Clonakilty Flood Defence Scheme cost €29.8 million and was designed to protect 296 properties. In the EIS, 500 properties are mentioned as prone to flooding in the centre of Clonakilty.

Key points that come from this case study are: 1) the recognition of the potential of upstream storage area as part of the planning for flood alleviation; and 2) how reconnection with the floodplain brings also other ecological benefits. A key consideration is the extent that these recommendations will be pursued and including any key enabling conditions needed for that.

5.3.3 The River Deel and Crossmolina Flood Relief Scheme

The scheme is described as a diversion channel with a capacity of 110 m^3/s to redirect flood waters away from the town, directly to the floodplains of Lough Conn. The scheme will be designed to cater for the 1% Annual Exceedance Probability (AEP) flood event (also known as the 100-year flood event) but will also cater for a larger flood event as the diversion channel has additional capacity. This will safeguard against flooding associated with potential future climate change that could increase the size of the 100-year flood event..

An ‘Ecological Constraints Study’ centred around the scheme’s potential impact on the River Moy SAC and Lough Conn and Lough Cullin SPA and especially the River Deel, Lough Conn and surrounding alluvial woodlands, the Mullenmore Springs and associated stream, and the protected species salmon (*Salmar salar*), lamprey species *(Lampetra* spp *& Petromyzon marinus)* and European eel (*Anguilla Anguilla*). pearl mussel (*Margaritifera margaritifera*) is found in the River Deel, although no live mussels were recorded in the vicinity of the proposed works in surveys done in 2019 and 2020. Whiteclawed crayfish (*Austropotamobius pallipes*) are found in the River Deel and Mullenmore Springs.

The original preferred options were for a hard engineering solution, presented publicly in September 2012, with an initial report presented in 2013. This, and the public consultation, revealed that a bridge in the town was structurally unsafe and that the citizens preferred an alternative to a walled solution. This led to the new preferred solution of a diversion that discharged directly into Lough Conn. The formal Public Exhibition was held in May/June 2018, with an acceptance of the new option (Figure 60). An EIAR and NIS (in 2020) concluded that, with mitigation measures in place there would be no significant environmental impact caused by the scheme.

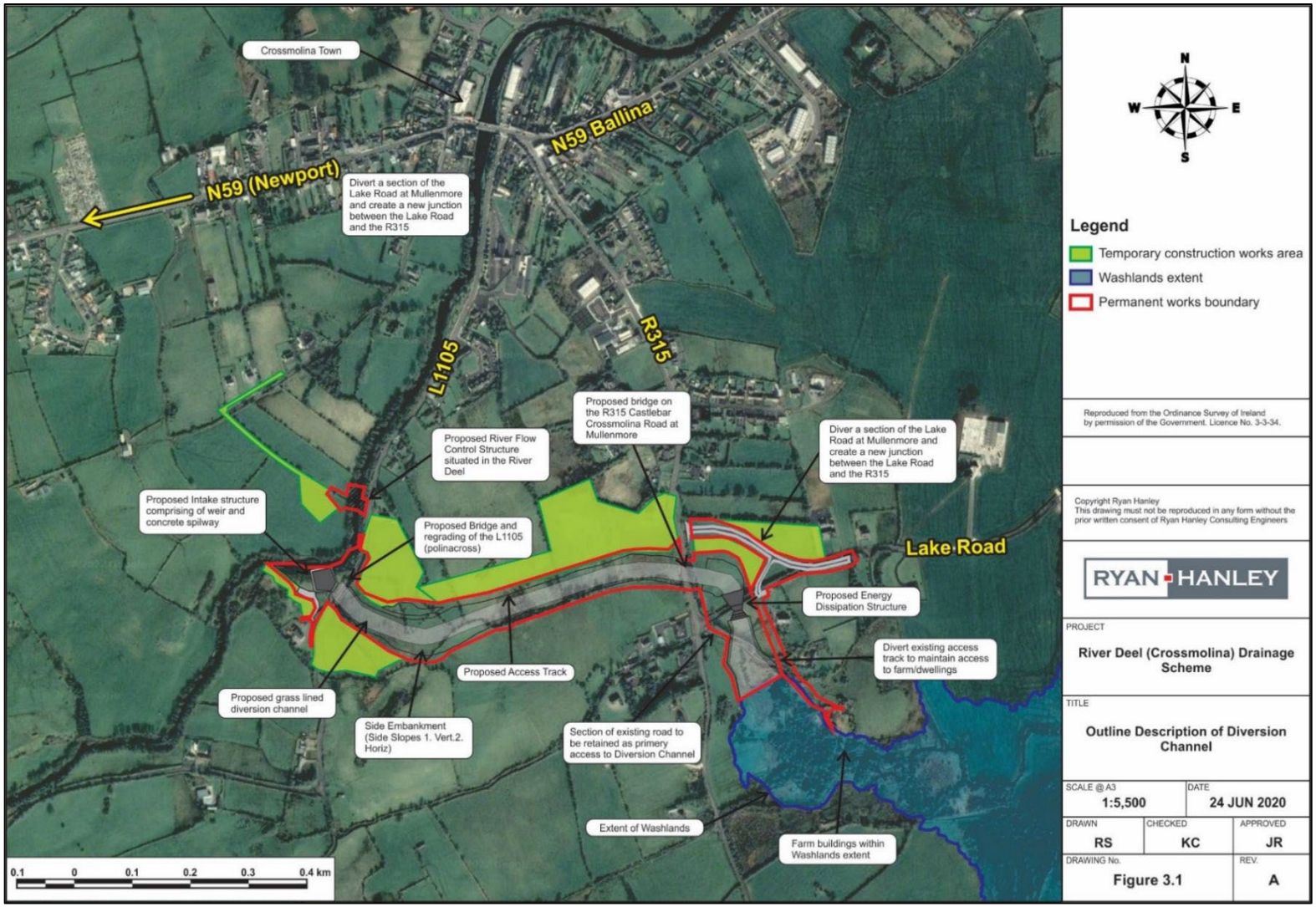


Figure 60. River Deel (Crossmolina) Drainage Scheme reproduced from Ryan Hanley/MKO (2020). Environmental Impact Statement Non-technical summary.

The nature of the River Deel is described in the EIAR as lacking any attenuation upstream of Lough Conn, and being a “flashy river, prone to rapid increases in flow, and consequential flood risk.” This can describe a natural flowing river, for which the diversion channel will provide an alteration.

The, mainly grass-lined, diversion channel will include concrete reinforcements and culverts, and the creation of washlands of “mostly marginal agricultural lands” between the end of the new channel and Lough Conn.

Mitigation measures are reported in the EIAR to alleviate any impacts to the hydromorphology of the River Deel, and rather a suggestion that “the construction of the diversion channel will divert flood waters away from the lower reaches of the River Deel which would otherwise have significant effects in terms of mobilisation and transport of suspended sediment and nutrients downstream.” An energy dissipation structure and associated scour protection in the new channel is anticipated to” mitigate against increased water volumes on natural in-stream conditions of the Mullenmore Spring and associated stream during overflow events.” The “extensive hydrogeological assessment” of the EIAR study is considered to show a permanent “imperceptible negative impact” on the Mullenmore Spring, and “no significant effects are anticipated.” Overall, the existing hydrological regime of the river is anticipated to be unaltered except when the river is in flood.

Two key factors stand out from this case study. First, the original scheme was advised to be a traditional hard engineering intervention through the town, but the public consultation period appeared to have led to an alternative option of the water diversion channel during high flood events. This is, nevertheless, a hydromorphological alteration, but appears not to be recognised as one. The River Deel and Crossmolina Flood Relief Scheme is projected to cost €13.5 million (excluding VAT) and designed to protect 116 properties.

5.3.4 Blackpool Flood Relief Scheme

Blackpool Village is a peri-urban area on the outskirts of Cork City. The area has had a history of flooding and incrementally construction of culvert systems since the early 1980s (OPW, 2016a). A flood of 16.23 m^3/s was recorded in 1968 (McKeogh, 2003), with more recent major flooding in 2002, 2012, and 2013. Maximum flooding was reported in June 2012 (OPW, 2016b, 2016a). Measurement of flow rates from that time appear unavailable. A draft Catchment Flood Risk Management Plan was published in February 2010. Following the floods of 2012 and 2013, the OPW commissioned a review of the flood risk and plans for its alleviation. Details of the OPW Flood Relief Scheme can be found on the Floodinfo website.

The Bride River comprises the main stem served by the Glenamought Stream and the Glen River (Figure 61), and several smaller inlets as it transcends through Blackpool Village. A number of residential and commercial areas are adjacent to the river in the urban area, and isolated homes and agricultural areas further upstream. The main N20 road passes along the eastern edge of the catchment. Several locations along the river are identified by OPW as “Critical Areas of Risk” (Figures 62 and 63).

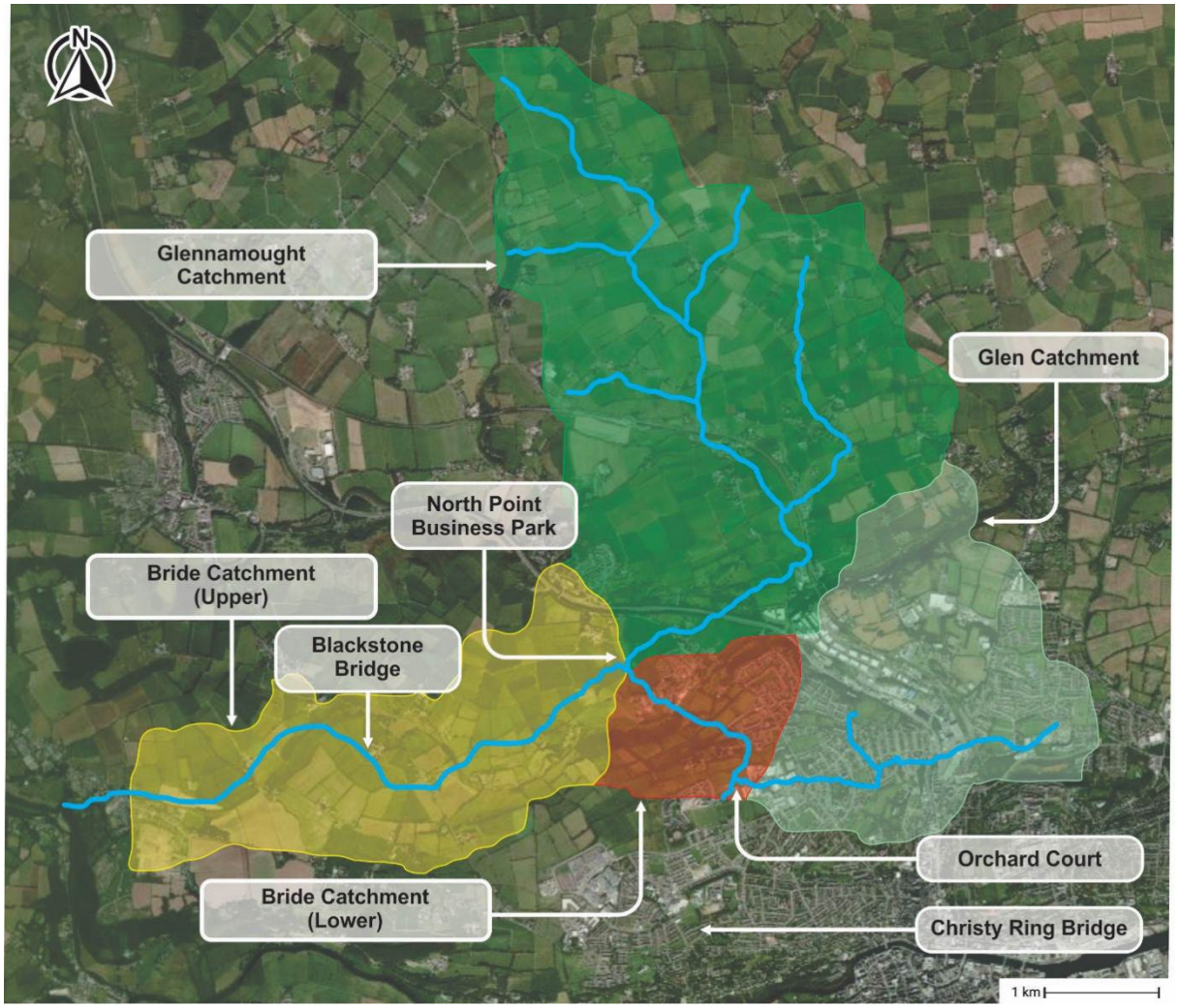


Figure 61. The North Bride River and catchments. Reproduced from OPW (2016).

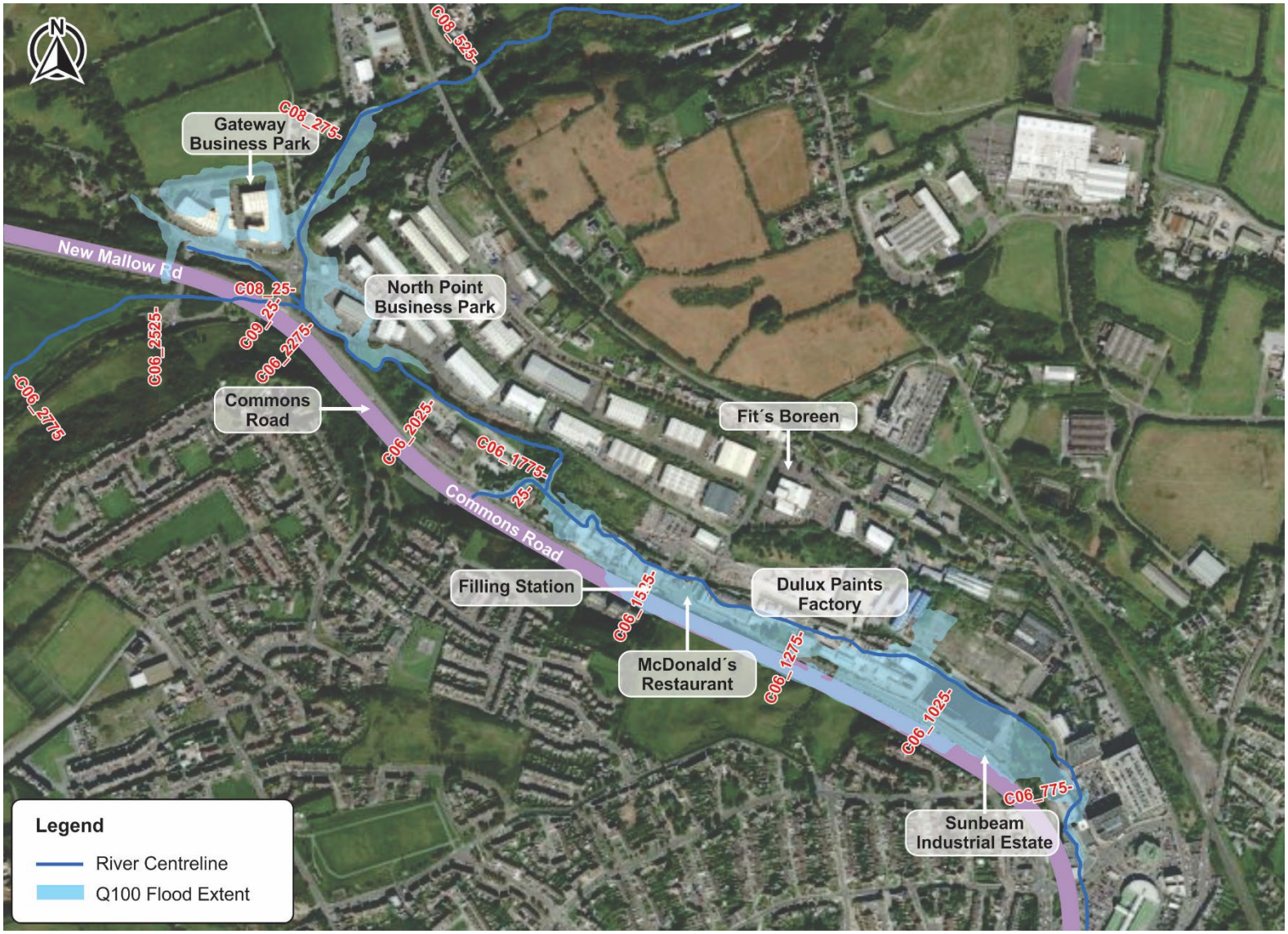


Figure 62. Critical Areas at Risk of flooding towards the north of the area. Reproduced from OPW (2016b).

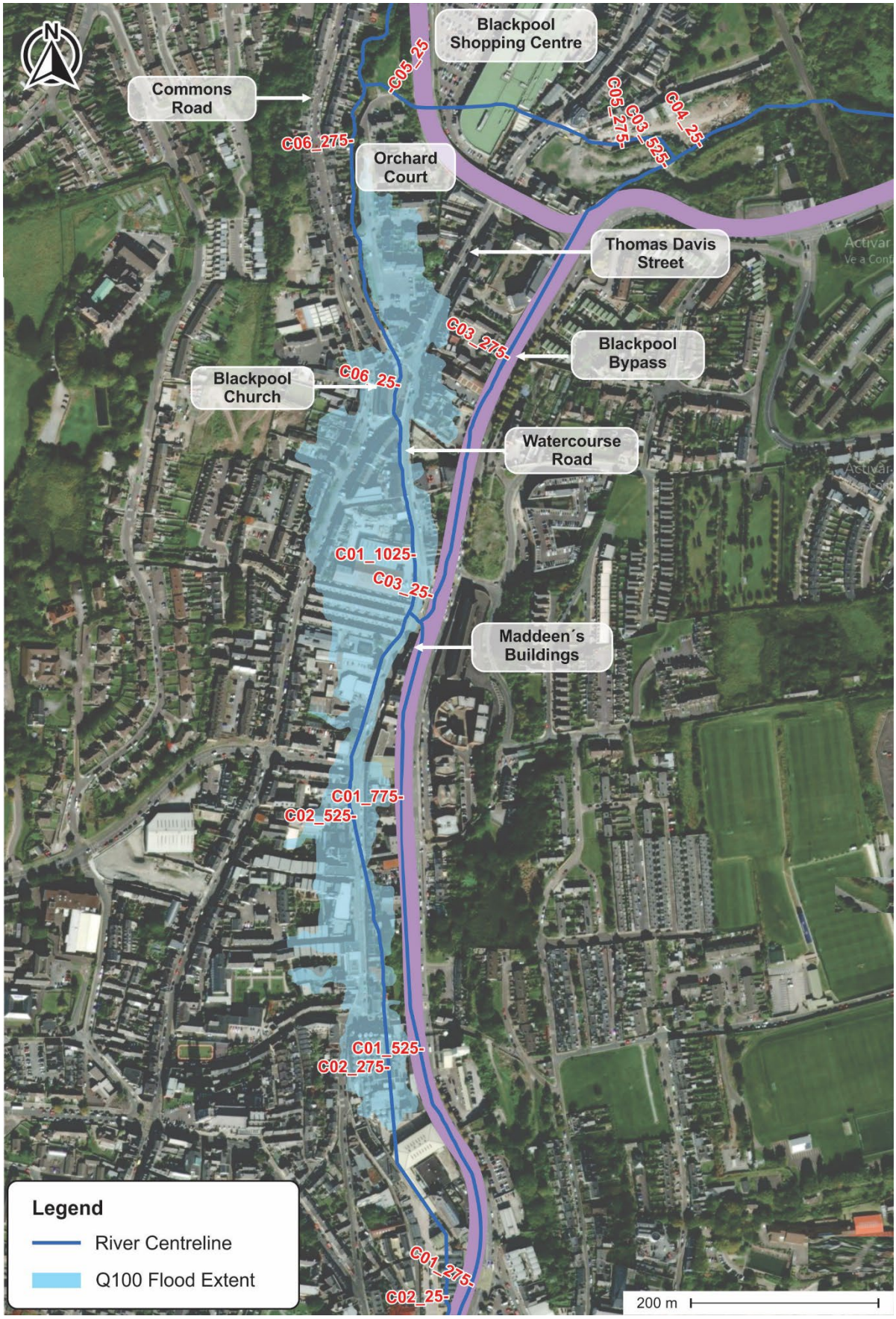


Figure 63. Critical Areas at Risk of flooding towards the south of the area, running through Blackpool Village. Reproduced from OPW (2016b).

The Flood Relief Scheme commissioned by the OPW included a full Environmental Impact Assessment (EIA) and assessment of alternatives (OPW, 2016b). The Environmental Impact Assessment Report (EIAR) was comprehensive and included detailed hydrological modelling. Estimates of peak flows in a one-in-a-hundred-year flood (OPW, 2006b) are shown in Figure 64. Key components considered for flood relief are summarised and discussed below.

Upstream Storage

The modelling and Options Reports (OPW, 2016a, 2016b) that supported the EIAR concluded that upstream storage was the preferred and most cost-effective option to alleviate flood risk to Blackpool in times of high rainfall events. As this would likely diminish over time and necessitate more storage areas, it was concluded by OPW that this was not a feasible approach and involved too high uncertainty to its effectiveness. It was also clearly not considered feasible that flood management would depend on multiple areas functioning together, although such integrated water management is common in other jurisdictions. It was, however, also recognised that "future planning control to facilitate upstream storage was an important adaptation to climate change", and that "Compliance with Planning System and Flood Risk Management guidelines will be important to ensure that flood risk is not increased as a result of future development in the catchment." This supports the view that planning control was not considered as an important aspect of land-use and flood management of the area before 2016. It was also not considered a major feature in the Options Report (OPW, 2016b), although later (page 11) under "Non-Structural Measures" (OPW, 2016b, page 11) it is stated: "Modifications to land drainage systems within the catchment can reduce the rate at which rainfall is conveyed into the river channel and thus help to reduce peak flows. This option would take a long time to implement and would not reduce the flood risk to an acceptable level and therefore has not been carried forward for further technical assessment. The proposed scheme would not, however, prevent such methods being implemented in the future."

OPW (2016b) states that: "In order for the upstream storage measure to be considered technically viable, it must have the capacity to reduce the peak flow through the Blackpool culverts to approximately the capacities of the existing culvert. The existing culvert capacity through Blackpool Village is approximately 22 m^3/s while the 1 in 100-year flow at Blackpool Village is estimated to be 34.44 m^3/s. A storage area with capacity to reduce the peak of the 1 in 100-year event in Blackpool Village by approximately 10 m^3/s to 12 m^3/s would, therefore, be needed to be considered technically viable." Previous estimates for the 1 in 50-year flood from 1982 and 2003 studies were, respectively, 36 m^3/s and 24 m^3/s, which after considerations of reasons for the discrepancies between the 1982 and 2003 studies values arrived at an estimate of 34 m^3/s for the 1 in 100-year flood (McKeogh, 2003). Notably, this is also the value estimated (or used) by OPW (2016b).

Various options were considered for upstream storage, but: "No suitable storage areas of sufficient size were identified on the Bride (North) between its confluence with the Glenamought River *(C06_2306)* and Orchard Court *(C06_0440)*. This is due to the heavy urbanisation of the river valley in this area", and "The 1 in 100-year flow on the Bride North, upstream of the confluence with the Glenamought, is 11.67 m^3/s. This suggests that in order for storage on this river reach to be deemed technically viable, the peak flow would have to be reduced by approximately 85%."

An area on the Bride North River catchment at Killard was estimated to have the potential for storage of 116,000 m^3 of water but was considered unsuitable because: “only 10% of the total catchment to North Point Business Park (including the Glenamought) would be captured”, as well as the need for the construction of extensive flood defence walls. A second option on the Bride North River catchment upstream of Blackstone Bridge was estimated to have the potential for storage of 87,000 m^3 of water, but was discounted because it “would not sufficiently reduce the flow downstream at the areas at risk” and “given the significant defences that would be required, this location *alone* (italics added) is not considered to be a technically viable solution.”

On Glenamought River, a pastoral area upstream of Ballincrokig was estimated to have the potential to store approximately 191,000 m^3, providing a “significant reduction in peak flow of the 1 in a 100-year design flood event” (OPW, 2016b). Owing to “the potential to reduce the peak flow of the design event by circa 10 m^3/s, this option [was] deemed technically viable […] for further assessment.”

A fourth potential storage area of approximately 96,000 m^3 was identified at the Glen Recreational Park upstream of the North Ring Road. However, this was not considered a feasible option because the hydrological modelling “found that the resulting decrease in maximum flood level at Orchard Court was negligible. This is because the primary reason for elevated water levels at Orchard Court is because of insufficient capacity in the Bride Culvert upstream of the confluence with the Glen Culvert which itself has ample capacity for a design event on the Glen.” This culvert was upgraded around 2005.

An obvious consideration is the use of combining the potential of flood storage areas, but the potential of that was also not considered a viable option: “A possible alternative to using a single storage area to achieve the necessary reduction in the peak flow would be to use a combination of two or more storage areas. A combination of storage areas would require an active control system to ensure that the timing of the releases from the storage areas can be managed, which would increase the complexity and cost of the option significantly. Since the required reduction could likely be achieved by one passive impoundment on the Glenamought, a combination of storage areas is deemed to be economically unviable.” It is worth noting that integrating the management of water storage and releases is not overly complicated, as illustrated on a daily basis in the water management of the Netherlands. The OPW (2016b) expanded with: “Furthermore, lack of historical gauged data on spatial variation of rainfall would also limit the ability to optimise the design of such a solution.” The lack of historical hydrological gauging of the catchment limits the reliability of the modelled outputs used to predict risk. Four hydrometric gauges were installed by the OPW at representative locations in 2013, and a culvert flow survey was done in 2014/15 (OPW, 2016a).

Given the recognition in several places in the report of the potential effects of climate change, a more thorough gauging of the catchment would appear necessary and, in any case, a cost-effective measure. The OPW (2016a) also stated that ”It is worth noting that in terms of adaptation for climate change, reduction of the peak flow from the Glen may warrant further consideration in the future given the finite capacity of the Kiln culvert system downstream of the confluence” and that “throughout the course of modelling that the North Point Business Park culvert is a notable impediment to flow on the Glenamought River, just upstream of the confluence with the Bride” (see below, *Storage and climate adaptation*).

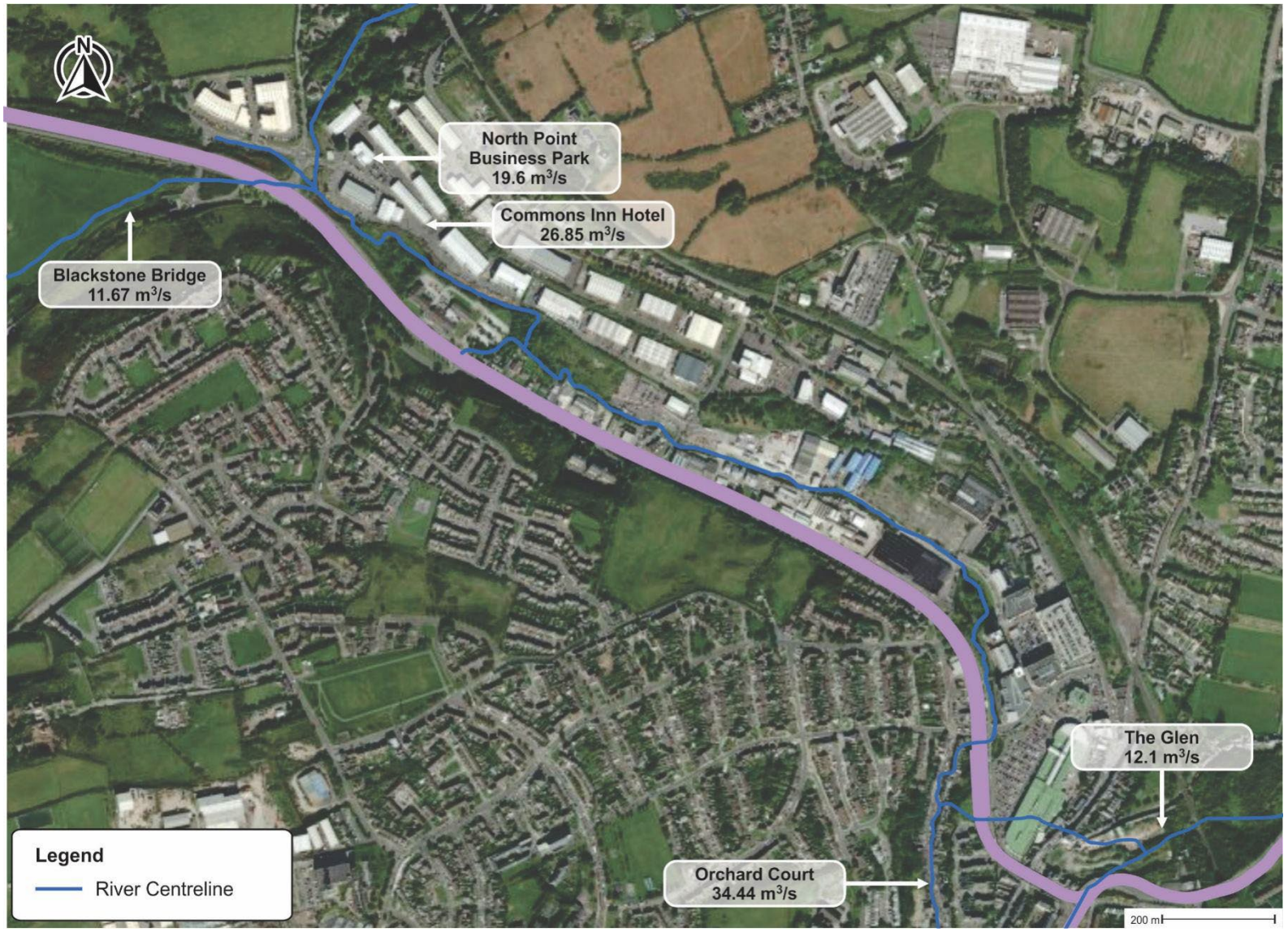


Figure 64. Existing Peak Flows for the Design Event (1 in 100 years). Reproduced from OPW(2016b).

Hard flood defence embankments

Since 2002 flooding has inundated several commercial and residential properties. The modelling for the 1 in 100-year flood risk led to proposals for building or expansion of flood defences; to contain future floods within the channel and modify or create new culverts to facilitate downstream flow of flood waters. Details of these options are outlined in OPW (2016b).

Removal of barriers to flow

Local opinion raised the possibility that accumulation of debris in a culvert thrash screen and subsequent collapse during the 2012 flood event led to a surge of water. Thrash screens were installed along the Bride under bridges or at inlets or outlets to culverts, comprising various designs. Thrash screens not only alter flow patterns in rivers but also require maintenance to remove accumulating debris (Figure 65).



Figure 65. Thrash screen under the access road to the Blackpool shopping centre showing accumulation of debris, November 2009 (photo C. Moody).

There are five culverts along the 1.14 km stretch of the River Bride through Blackpool Village to the outlet at the River Lee. A report was commissioned by Cork County Council (2013) on the potential role of thrash screens in accentuating the flooding in March 2012 and June 2013. Thrash or safety screens of various designs were installed at the inlets and outlets of some of the culverts. The trash screens at Orchard Court and Blackpool Shopping Centre were installed following flooding in 2003. OPW report following the flooding in 2012 (referred to in Cork County Council (2013) and evinced by early-morning video footage) stated that “the cause of flooding is considered to be culverts both at Orchard Court and south of Blackpool Church that were not capable of conveying the flood waters in the Bride River, and that in the view of the local engineer that “both the culverts at Orchard Court and adjacent to the church were clearly overwhelmed by the flood, but that on a previous occasion in about 2001, the culvert at the church clearly had spare capacity while the culvert at Orchard Court was overwhelmed.”

However, although in 2014, at a meeting with the local 'Blackpool Flood Group', County Engineers expressed the view that there was insufficient capacity in the culvert between the church and Maddens building junction of the river, doubt remains regarding the role of the thrash screens in the earlier floods. With respect to the flooding in June 2012, the commissioned Cork County Council (2013) report states that "It was not possible for Cork City Council to be definitive whether the rainfall event was outside the designed capacity of the culvert or that there was an inhibition of the culvert capacity due to a restriction within it. For the March 2013 flood, the Cork County Council (2013) report documents "a large flow in the Bride with its channel and culverts coming close to the full capacity. However, a blockage of the screen at Orchard Court caused sufficient restriction for channel capacity to be exceeded and overflow the banks locally. Overflows also occurred upstream at Commons Road and Killeens Road." Further insight quoted in Cork County Council (2013) is provided by the "Lee CFRAMS Hydraulic Reports shows that the footbridge where the existing Orchard Court trash screen is located (Ch. 113) may be expected to overtop (resulting in flooding of Orchard Court) for a 20% AEP fluvial event, i.e. flooding may be expected to occur with a chance of 1 in 5 chance in any given year. Any reduction in the Orchard Court trash screen area due to blinding by debris would increase the risk of flooding at Orchard Court."

The Cork County Council (2013) report concluded that a) under *Trash and Security Screen* guidance produced by the UK Environment Agency (2009), a trash or security screen on the River Bride culvert system was not required; and b) the effect of the trash screen at Orchard Court restricted flow capacity, leading to the River Bride overtopping its banks upstream. The trash screen at Orchard Court has subsequently been removed.

As well as debris screens (even when effectively maintained) that act as barriers to flow, low bridges, maintenance, some modifications of water channels, and sediment accumulation, cause water to back-up in the channel. Maintenance works, vigilance, monitoring of channel obstructions, and civic awareness and information campaigns are required to reduce flood risk (OPW, 2016b). Local observations suggest that monitoring by Cork City Council for potential obstructions is very limited, with an expectation of public reporting. Photographic evidence indicates that large items, such as mattresses and shopping trolleys are from time to time dumped in the river.

Pumping of water to a by-pass channel

The option of pumping water during flood risk events was considered by OPW (2016b) but not considered feasible for a diversion of the excess 10 m^3/s needed to avoid flood risk during peak events. The estimated capital cost of construction of a rising main was 2-3 million euro, excluding maintenance costs. Finding a suitable location for this was viewed as "extremely difficult", with likely "significant negative environmental and social impacts." Neither of these two points were elaborated on, although acknowledged that "localised pumping would still be required in areas where surface run-off would be predicted to pond behind flood defences or adjoining surcharged culverts during a flood event."

Selection of the preferred option

Based on the considerations outlined above, and following initial screening, a number of options were considered for the flood relief of the Blackpool area. There were:

“Option 1: ‘Do-Minimum’.

Option 2: Ballincrokig flood storage, combined with conveyance improvements and direct defences at Common’s Road/Blackpool.

Option 3: Conveyance improvements and direct defences (with high walls in Orchard Court).

Option 4: Conveyance improvements and direct defences (with culvert through Orchard Court).

Option 5: Conveyance improvements & direct defences (culvert replacement from Orchard Court to Madden’s Building).”

All options included debris and sediment management. The consideration of the options (OPW, 2016b) resulted in a preference for Option 4 (Figures 66 and 67), and a total estimated project cost of about 12 million euro **(**more recent estimates of cost for Option 4 is €20.5M). In OPW (2016b) this is offset against “tangible” and “intangible” damages. The estimation of damages, over and above estimates costs of property itself, are extremely difficult to quantify (see Section 6.3.4.1 of OPW (2016)) for arriving at the estimated cost-benefits of a scheme.

Options 3, 4 and 5 necessitated extensive hard embankments and works on culvert realignment. The preferred option has led to local controversy, especially around three key components: the decision of the OPW not to implement the most cost-effective and least environmentally disruption option of upstream storage; and the other two, involving details of modification of culverts and flood defence walls. It is also worth pointing out that a potentially key historical consideration has been the incremental alteration of hydromorphology over the last 30 years that may have accentuated current flood risks.

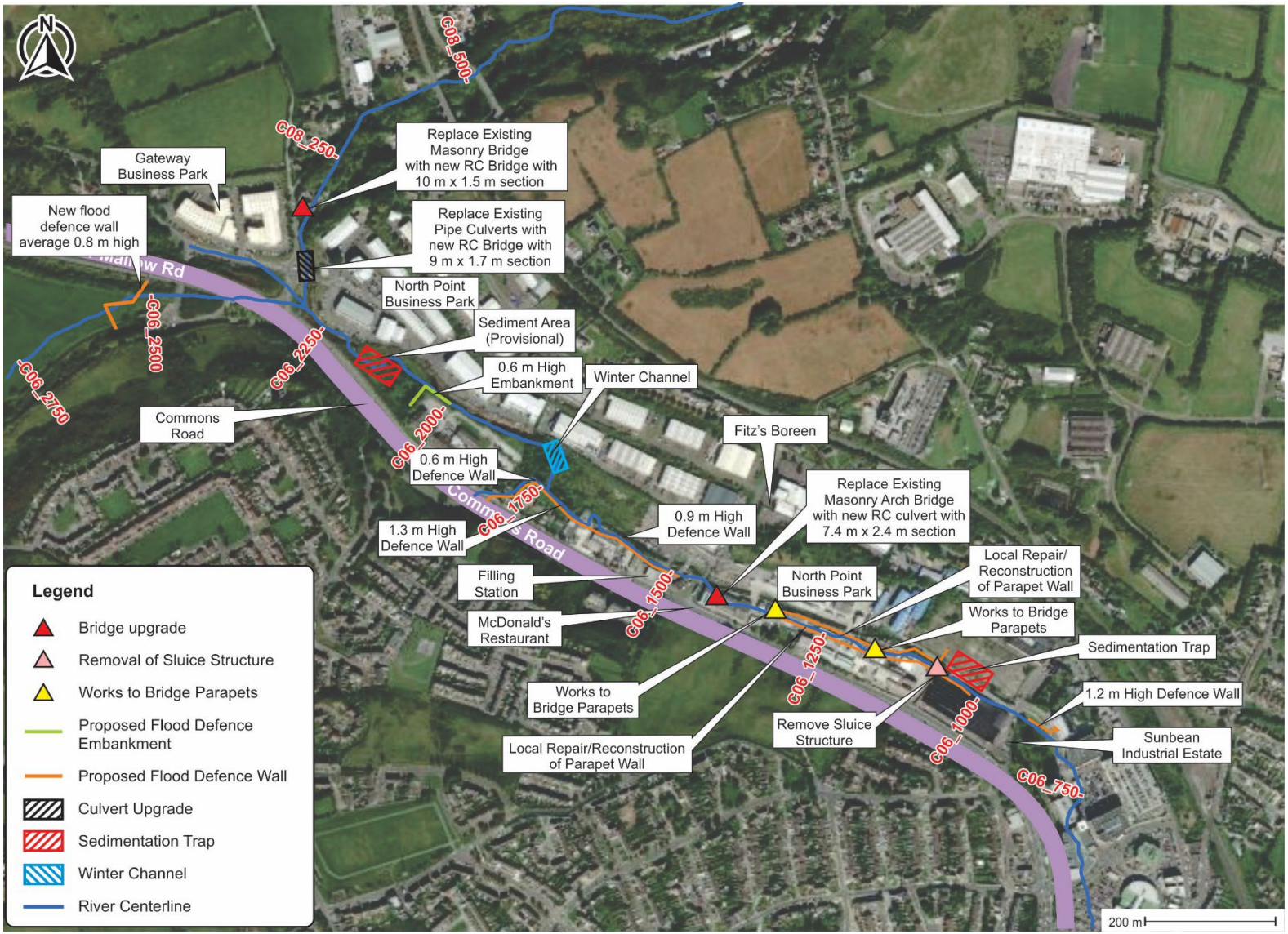


Figure 66. Overview of the works associated with the preferred option for Blackpool flood relief, Common's Road. Reproduced from OPW (2016b).

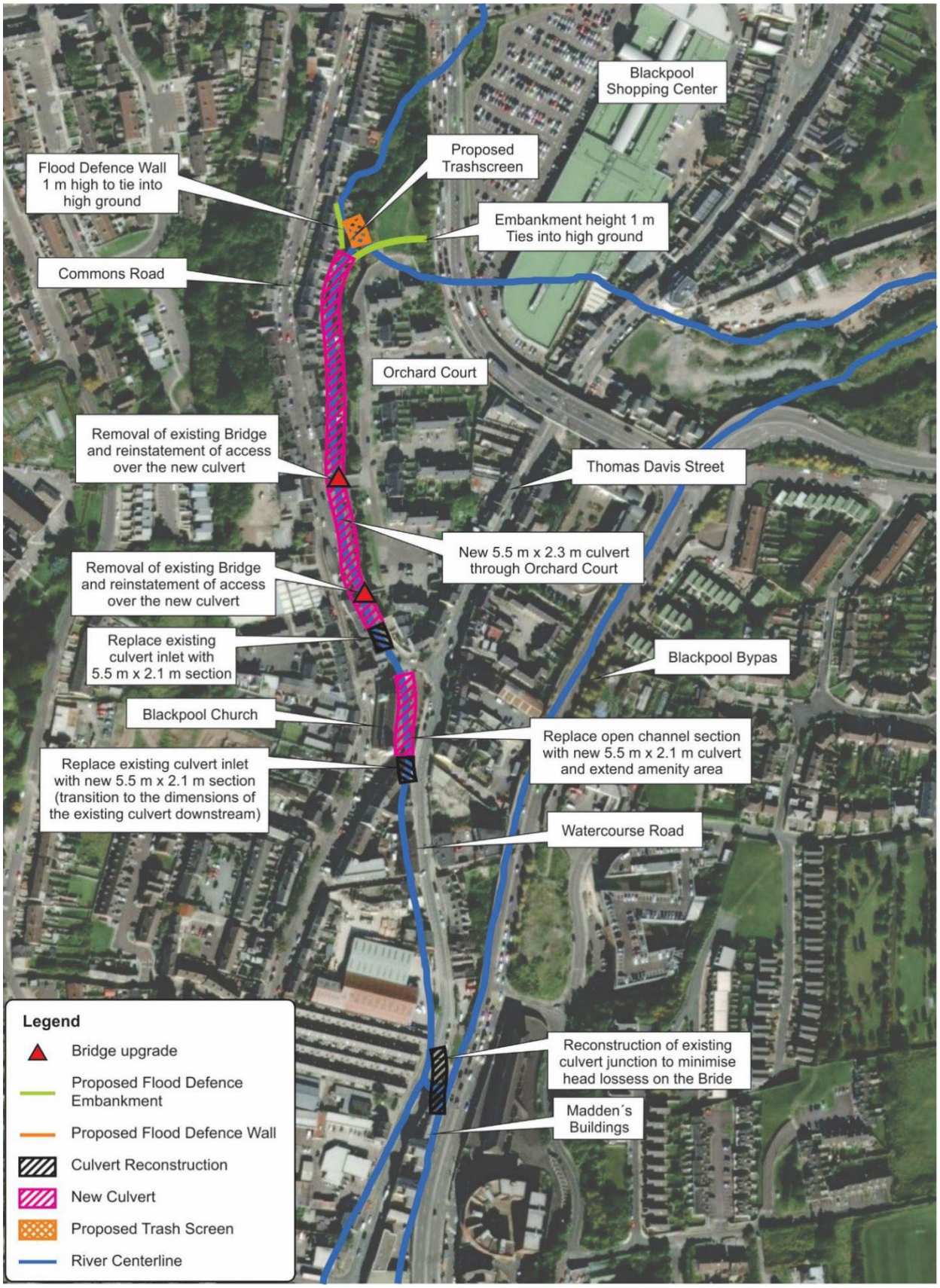


Figure 67. Overview of the works associated with the preferred option for Blackpool flood relief, Blackpool Village. Reproduced from OPW (2016b).

Storage and climate adaptation

The EIAR identifies that upstream storage options for flood relief options that passed the initial screening are considered to "diminish as climate change takes hold" although no reference to climate model predictions is made (or seemingly included in the model predictions for any option). General statements are made that upstream storage *could* (italics added) be considered as a longer-term strategy for climate change adaptation: "If storage is not chosen as the preferred option for the current scheme, we would recommend that the following be considered as part of the ongoing flood risk management strategy for the catchment to facilitate a potential future storage area at Ballincrokig and/or potential on the Glen upstream of the Blackpool Bypass:

1. "Planning Control – Liaise with Cork County Council to ensure appropriate zoning of potential storage areas (such as the potential Ballincrokig storage area or the Glen Storage area) and the related downstream at-risk area (area potentially affected by a breach of any future storage area) to ensure that any future development does not diminish the potential for a storage area at this location in the future.
2. Planning Control – Liaise with Cork County Council to ensure that planning policy in the Bride/Kiln Catchment (including Glenamought and Glen sub-catchments) requires that any new development (or redevelopment) incorporates attenuation and SuDS to attenuate peak run-off in the 1% AEP event to Greenfield run-off rates (so as not to erode the standard of defence of the current scheme).
3. Consider the installation of permanent rain gauges at suitable locations which will complement the existing flow gauge network recently installed to provide good quality rainfall data which will allow a greater understanding of spatial variation in rainfall within the catchment in the medium term and inform any future hydrological assessment of the catchment. Such gauges could also be integrated into any telemetered flood forecasting/operational system which might be considered in the future to actively manage peak flows from the various sub-catchments."

As the information to be gathered from item 3 above would by necessity take a considerable period of time, it appears that this solution may be more suited as a solution which would be implemented as part of a future climate change adaptation of a Flood Relief Scheme, rather than being undertaken now. Replacement of some culverts to increase capacity is more feasible than others. For the Bride/Kiln Catchment, in 2019 Cork City Council made a boundary extension since 2016 restricting development.

Culverts and embankments

The engineering associated with the preferred option comprises alteration of culverts and raising and strengthening of embankments. In specific recommendations, there is a mix of both immediate needs and those proposed as part of climate change adaptations. These are also linked to the potential for upstream storage. For example (OPW 2016b, Section 8.2): "In terms of the Blackpool area, the significant throttles at Fitz Boreen and Sunbeam can reasonably be replaced and enlarged in the short term. However, the replacement of the under-capacity culvert between Blackpool Church and Madden's Buildings is more problematic."

Because of the geometry and structure of the previous culvert installation, the narrowness of the street and the proximity of the old adjoining terraced housing, its replacement with a suitably sized larger culvert in the short term would prove very difficult, be very expensive and with a high risk of adjoining property damage. For this reason, it may be […] holding this option in reserve for climate change adaptation." Furthermore "It should also be noted that the Brewery Branch is a fundamental part of the system in conveying the combined flow from the Bride and the Glen as far as the River Lee. In the climate change scenario, the combined capacity of both culverts will be insufficient to cater for any increased flow, meaning that unless upstream storage is utilised to decrease peak flows, one or both culverts will need upgrading. As the new Kiln Culvert is the newer and larger of the two and located under the primary road artery into the city from Limerick, it appears prudent to plan for the upgrade/replacement of the old Brewery Branch. Some sections of the Brewery Branch will have sufficient capacity, but others will need upgrading. This could be done in a piecemeal fashion as the various land holding are developed." This culvert was built in the 1800s, and a 2012 video survey suggests that it is in poor condition in places. It was not designed for the flows of recent years.

It is clear, therefore, that a number of options put forward by the consultants involved both shorter and longer-term planning, necessitating liaison with Cork County Council over Planning Control: "to ensure that a potential future corridor for a replacement/relocated Brewery Branch is identified and ensure that any future development along or in the vicinity of this corridor is required to take account of the potential future requirement to install a larger replacement culvert along its route."

It appears that consideration of water conveyance determines the plans for the embankments. In particular, the EIAR options report states: "Therefore, the heights of flood defences required to be constructed as part of a proposed scheme to address the current flood risk would decrease across the entire scheme if the flood storage option was implemented as part of the current scheme." As storage options were not included as part of the defences design, the hard engineering solutions dominated the flood defence design. Similarly, it is stated that: "Flood defence heights at the lower end of the system would similarly be reduced if the culvert downstream of Blackpool Church was upgraded as part of the scheme." It is also highly notable that, although no upstream storage is proposed to be implemented, the report clearly states that: "In this particular scheme, it is envisaged that the defence heights downstream of Sunbeam could not be reasonably extended in the future to take account of climate change due to the likely impact of the significant increase which would be required because of the sensitivity of the downstream culvert system. For this reason, it is considered that the climate change adaptation policy in this reach would be either the introduction of upstream storage or the replacement of the downstream culvert (so that increases in the required wall height would not be required)." This is of significance because it suggests the need for land-use (and planning) changes at some indeterminate time in the future, while implying that the current proposal will not provide a safeguard against climate change.

Internal and Public Consultation

In the EIAR (options) (OPW, 2016b), a Multi-Criteria Assessment (MCA) process is described. However, only core persons involved in the creation and tendering of the report were involved leading to an outcome "subject to professional judgement exercised by the project's designers/steering group […] through a workshop forum held with key representatives of OPW, Cork City Council, Cork County Council, Arup and Ryan Hanley/McCarthy Keville O'Sullivan (environmental consultants for the scheme)."

Furthermore, the weighting of opinions seems extremely arbitrary, perhaps also determined by the core team. The claims in the report that: “This ensured that the combined expertise and experience of all relevant specialists and disciplines were brought to bear in a transparent fashion in the scoring of each option” seems hardly representative of the diversity of interested stakeholders.

Global weighting of scores was applied as done nationally for OPW schemes, scoring ‘economic return ’and ‘risk to global health ’as maximum (weighing of 30). In contrast, meeting requirements of the WFD and Nature (Birds and Habitats) Directives attracted a weight of 15, and fisheries a weight of 5. It is unclear on what basis these weightings are decided, although Adamson et al. (2016) document a process for determining national criteria for weights based on public consultation from 65 locations and a questionnaire survey of about 1,000 participants, resulting in different weightings. These were further modified in OPW (2021b), suggesting these decisions are subject to alteration over time.

During the study to investigate options, two public information days were held on, respectively, 17th July 2013 and 29th July 2014. The first of these was to outline the process and preparation of the Flood Relief Scheme for the Lower Lee, of which the Blackpool Scheme would be a part of. The second was to present the preferred option. Both events requested feedback from the public which “was taken onboard and helped to inform the development of the preferred option.”

Although it is stated in the River Bride (Blackpool) Options Report (OPW, 2016b) that: “Regular meetings were held between the Design Team, Cork City Council and Blackpool Flood Committee during the preliminary design of the options. The meetings facilitated an open dialogue on the developing options and allowed useful local knowledge to inform the scheme development”, and that “Significant Public Consultation was carried out throughout the project”, local opinion suggests otherwise, in that there was an emphasis towards consultation with business interests that were subject to flooding. Although local commerce is clearly a main stakeholder group, it is also natural that such a group would have strong views on measures to protect their interests.

In response to a petition against the granting of the Blackpool Flood Defence Scheme, the Department of Public Expenditure “agreed to consent to an order reverting the evaluation of the Blackpool Flood Relief Scheme back to an advanced stage of further public consultation. In agreeing to this, the Department of Public Expenditure has conceded the matter on a single ground related to public consultation procedures on certain information as part of the confirmation process” (Press release OPW, www.floodinfo.ie/frs/en/blackpool/news/opw-response/). The lapse in the public consultation process appears to lie with shortcomings within the Department of Public Expenditure and Reform. Submissions on Environmental Impact Assessment (EIA) and Appropriate Assessment (AA) of the proposed Glashaboy River (Glanmire/Sallybrook) Drainage Scheme were invited from the public for one month from 23 January to 27 February 2020 in relation to the environmental impacts of the scheme. The response was overwhelmingly against the proposals (CAAS Ltd, 2020). Of six submissions from statutory consultees, one (Cork County Council) was positive, three were neutral and two (Inland Fisheries Ireland and An Taisce) raised negative issues. Addendums to the EIAR were not made available to the public during this consultation.

Floodplain Management

It has been recognised for decades that appropriate upstream catchment and floodplain management alleviates flood risk. In particular, increasing water dendritic density through land drainage increases the rate that water moves from the land into river channels. Commercial or domestic building on floodplains is an established means to increase flood risk, as well identified by planning authorities and insurance companies. Climate change, with more extreme weather events (higher precipitation over shorter time periods) has already led to devastation flooding globally, including northern and western Europe. These risks are expected to increase (IPCC, 2022). In the case of the flooding of Blackpool, it is unclear, but entirely feasible, that previous modifications of the catchment and river channel (Figure 68) played a role in urban flooding. It is also unclear to what extent flood risks from either urban or agricultural areas has been a focus of Cork County Council Planning Department or how the Cork County Council Climate Adaptation Strategy (see below) has been applied to the Bride. The Blackpool Shopping Centre Car Park drains to the Bride without attenuation and is acknowledged (from an AIE request) by OPW that the volume of water draining from the shopping centre is "significant". There is no indication of any OPW supported Arterial Drainage Schemes upstream. It is clear, however, that from local information compiled on the river, there have been successive modifications made to the hydromorphology (Figure 69). Modifications to the course of the River Bride have led to less sinuosity and, therefore, a more hydraulically powerful flow regime.

The 2003 re-routing of the River Bride arose from the development of a commercial area north of the Blackpool Shopping Centre. An assessment of the hydrology at the time (McKeogh, 2003) concluded that after the channel modifications, the new channel and culvert system would be able to accommodate 30 m^3/s, while (OPW, 2016a) states: "A primary characteristic of flooding in Blackpool Village in recent events has been the restriction in culvert capacity and the ability for flow to escape from the channel at Orchard Court and travel overland into the channel adjacent to Blackpool Church and the Watercourse Road." The report of OPW (OPW, 2016b) states that the existing culvert capacity through Blackpool Village is approximately 22 m^3/s, while the 1 in 100 years flow is estimated as 34.44 m^3/s. The work of McKeogh (2003) is not referred to in the hydrology modelling report of OPW (2016a). An Access to Information on the Environment (AIE) request revealed that the Blackpool shopping centre car park drains to the Bride without attenuation of run-off. The adjacent retail park may have some attenuation (from planning drawings) but it is unclear if this was implemented. The OPW in communication with the owners of the shopping centre refer to the volume of water as 'significant' (AIE request). Risks to enhance flooding from riparian and floodplain developed along the river continue. The extent that these are considered in Planning is a matter for Cork City Council. As of October 2023, recent infilling of the floodplain area on the Bride in Lower Killeens, near Blackpool was under investigation by the planning enforcement section of Cork City Council. An update in Planning records from March 2024 was that the situation had "been resolved" (pers comm. C. Moody).

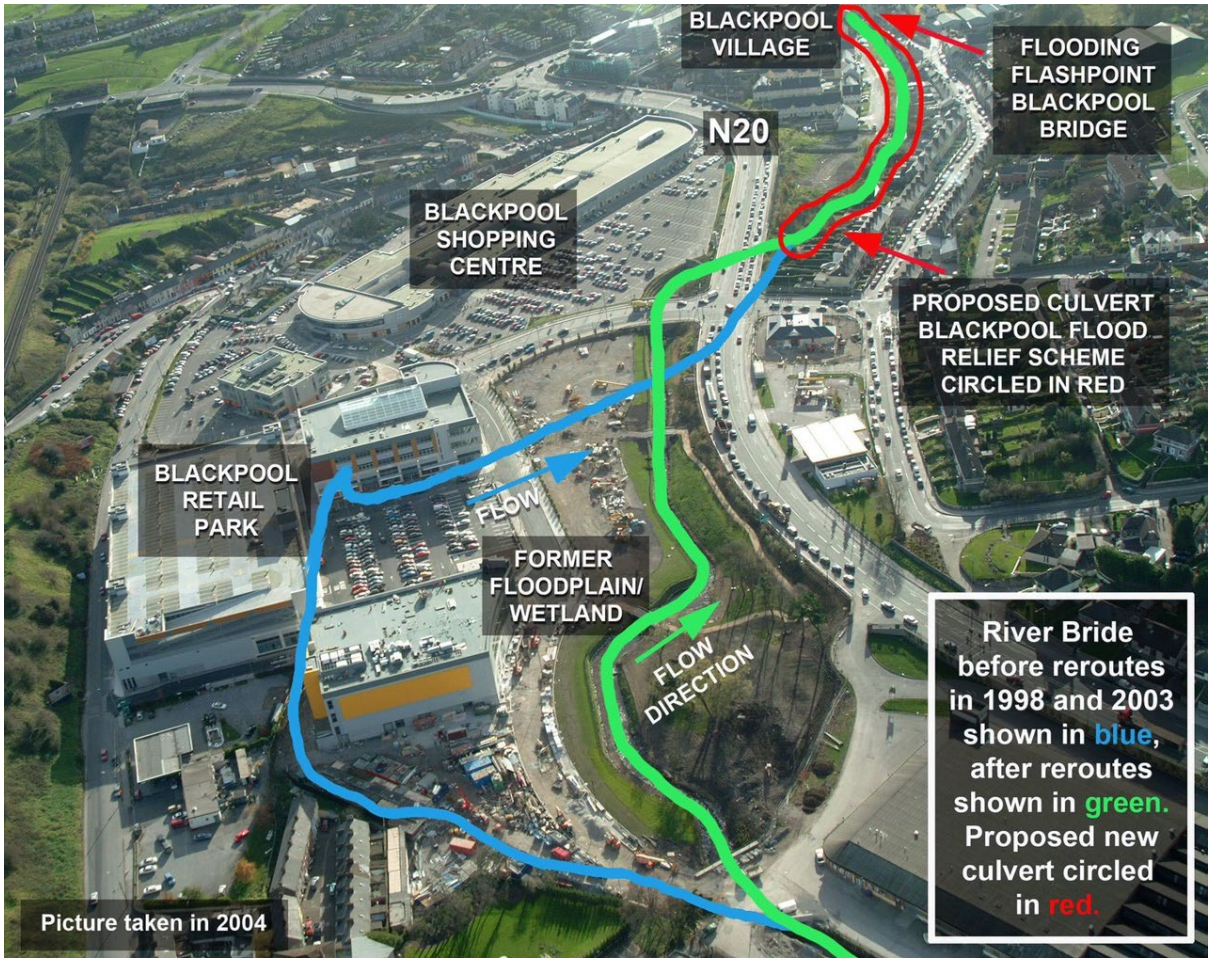


Figure 68. Realignment of the river channel and encroachment of wetland areas in the Blackpool area. Source: C. Moody

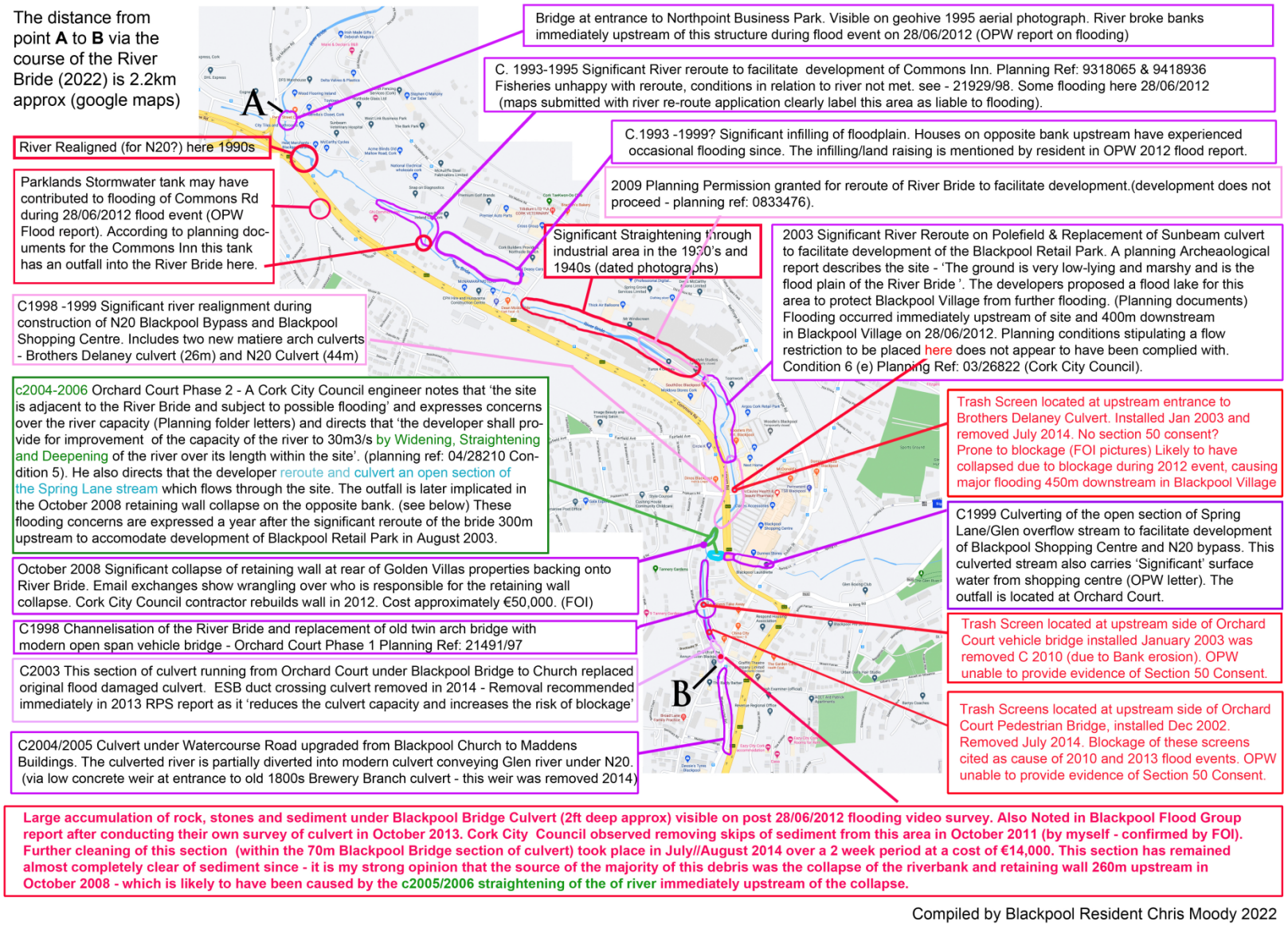


Figure 69. River Bride works in years leading up to flooding in Blackpool Village at (B) on dates: 21/11/2002, 27/11/2002, 12/01/2010, 28/06/2012 and 21/03/2013 (Compiled by Chris Moody).

Conclusion and climate change

Flooding in the Bride has been reported since the 1960s, with more serious flood events occurring in urban areas in more recent years. Over the last twenty years, there has been encroachment on the floodplain of particularly commercial development, including the re-routing of the river in the early 2000s. No detailed studies of alteration of land-use or alterations of groundwater flow upstream of the urban area were found in writing this report. Arterial drainage appears not to be a relevant feature. The flooding of 2012 and 2013 promoted plans for a Flood Relief Scheme, supported by detailed modelling and flow measurements. These were limited in time and by the techniques used, and gauging stations were put in place as part of those studies, but not present at the time of the serious earlier flooding (OPW, 2016a). The maximum flow recorded (7.5 m^3/s) during the monitoring period in assessing the current hydrology was considered as "modest". The absence of a large event negated reliable calibration of the hydrological models (OPW, 2016a).

Although sediment accumulation in the Bride affects river flow, sediment movements and management measures were not included in the modelling work, although it was recommended that this would be examined further as the scheme progressed (OPW, 2016a).

The modelling and Options Reports (OPW, 2016a, 2016b) that supported the EIAR concluded a preferred and most cost effective option to alleviate flood risk with the aim of increasing to increase the capacity of upstream storage of water in times of high rainfall events. The final decision concluded that this was not feasible as it would necessitate a number of storage areas. However, a number of areas functioning together were not considered as a feasible option.

The scope of the modelling supporting the decision-making for flood relief, data gaps in the hydrological record and difficulties in piecing together the effect of a combination of potential flood alleviation approaches from upstream storage limits a definitive overview of an optimal flood management regime under both recent and future, climate scenarios. Attention to alternative views of looking at drainage schemes using more nature-based thinking is a fairly new development in Ireland, and that legacy appears to have restricted the exploration of options for the River Bride.

Of particular note is that the current proposed scheme acknowledges the need for future climate-proofing options necessitating potential land-use change, and the use of the planning system to achieve that. Cork County Council (CCC) has developed a Climate Adaptation Strategy (Cork County Council, 2019) in response to the Irish Climate Action and Low Carbon Act 2015. A review of climate events that have affected County Cork did not include the River Bride. Nevertheless, in general terms key risks were projected that included a 20% increase in winter and spring stream flow likely by mid-century and a >40% decrease simulated for the end of the century for rivers with low groundwater buffers. It is recognised that catchments with fast response times are likely to be most at risk.

In the CCC Climate Adaptation Strategy, fluvial flooding is considered "critical", requiring an approach that: "Must not be accepted as part of routine (unadopted) operational procedures; urgent attention at the most senior level required; adaptation measures that function to diminish risk must be proposed and acted on immediately." Adaptation Goals for land-use are "To integrate climate action considerations into land-use planning", and for drainage and flood management "To adapt to the increased risk and impact of flooding. To liaise and work with other bodies responsible for management of water resources."

Included in “Adaptation Options” are “Green Actions: Ecosystem-based approaches that use the multiple services of nature.” The intention is to: “Manage and oversee the effective mainstreaming of Adaptation measures into all plans, programmes, strategies and policies of Cork County Council.”

For *Infrastructure and Built Environment,* the Climate Adaptation Strategy includes to “Integrate climate considerations into the design, planning and construction of all roads, footpaths, bridges, public realm, coastal and other construction projects and make provision to incorporate green infrastructure as a mechanism for carbon offset within projects as well as for wider environmental benefits such as providing shade to alleviate heat stress, supporting urban bio-diversity, water retention and flood alleviation.”

For *Land-use and Development*, the set of recommended actions are: “Enhancing the role of the natural environment to promote climate adaptation through promoting green infrastructure; Continuing to take a risk-based approach to development in areas at risk of all types of flooding (coastal, fluvial, pluvial and groundwater); Designing urban areas to incorporate shading/ cooling areas and water features to provide for urban heat reduction; Promoting climate resilient designs and materials; and Evaluate and implement best practice in Sustainable Drainage Systems (SuDS) in the context of climate change.”

For *Drainage and Flood Management* the strategy is to: “Work with the OPW and other organisations in information sharing in relation to flood risk and in the development of major and minor flood protection and flood proofing schemes throughout the county, encouraging a whole of catchment approach to the flood management and promote the requirements of our natural and cultural heritage in relation to flood relief works which may be carried out in the context of climate change” and to “Explore opportunities to install systems similar to those currently operating in the County in areas subject to flooding with reference to CFRAMS.”

It is noteworthy that while the text of the CCC Climate Adaptation Strategy, refers briefly that the “requirements of the SEA Directive and Habitats Directive will be critical considerations in the implementation plan as is necessary and appropriate and as they apply to individual projects in the course of their progression and development”, the WFD appears entirely overlooked. This suggests strongly that the considerations of WFD and hydromorphology are not (yet) in the mainstream thinking of Cork County Council and how this might support climate adaptation, the protection of freshwater bodies and, it would appear, their application in the mitigation of climate effects.

Two final points are worth noting in this summary. First, the proposed management of the River Bride included recommendations that a “maintenance regime must be strictly adhered to as any accumulation of debris at sensitive locations could make certain measures ineffective” (OPW, 2016a) as the study found “unexpected” amounts of debris. Debris in a river, and especially at the entrance to culverts has a major effect on the water level upstream and as well as increasing velocity of water moving downstream. Local observations during the 2012 and 2013 reports include the high amount of debris accumulated in the thrash screens. While there may be good reasons for a predominantly hard engineering approach to the flood relief in Blackpool, and upgrade of the culvert system, the information collated in this case study suggest that, overall, other options could have been more thoroughly considered, and that future climate risks may even undermine current plans it. It would also be a costly error if accumulated thrash was the driver of the favoured option for Blackpool Flood defence.

Finally, the case study of the River Bride raises important questions about the implementation and associated monitoring and classification within the WFD itself. The River Bride is not an 'assigned water body' for routine WFD monitoring but has been identified as a 'Priority Area for Action' (PAA). The Local Authority Waters Programme (LAWPRO) completed a desk study on the river in late 2021 (LAWPRO, 2021). The summary report identifies two water bodies within the PAA. These are: 1) Bride (Cork City)_010 to the west of the sub-catchment in Ballycannon townland, flowing east to the confluence with River Bride; and 2) Bride (Cork City)_020 flowing south to Lee (Cork) Estuary Upper at Christy Ring Bridge, and incorporating the Glen River tributary that merges with the main channel in the Blackpool area. A third river, the Glennamought (Trib (Bride)_010) joins Bride (Cork City) _020 in a culverted stretch near North Point Business Park. The report states that: "The Bride PAA is in one of the EPA's catchments of concern because of high nitrate levels." It is also known to have high organic loads. The LAWPRO report also identifies phosphates, ammonium and sediment as potentially notable pollutants, and recognises that: "river habitat may also have been altered because of drainage works in Bride (Cork City) _010 and culverting in Bride (Cork City) _020."

Although 'unassigned' a WFD status class, this will be provided by the EPA by 2027 (the next cycle of the River Basin Plans, and the extended date (from 2015) for meeting WFD environmental objectives). The LAWPRO summary report makes brief reference to hydromorphological pressure but does not provide a follow-up assessment of this. The intended action is that "LAWPRO's catchment scientists will carry out fieldwork to identify the areas with the highest risk of organic pollution and nutrient and sediment loss to the river system." The River Bride in its current state, and more so if the intended flood alleviation works are done, provides an example of hydromorphological alteration of a small river, and where that fits into the WFD protocols and reporting, and the need as recommended by ECOSTAT (Kampa et al., 2019) to assess hydromorphological status across all classes of quality. This suggests the likely need for the River Bride's water bodies to be designated as an HMWB and consequential classification for its ecological potential.

An update on the River Bride flood defence scheme is that the OPW has again submitted the Blackpool Flood Relief Scheme to the Department of Public Expenditure, with a public consultation period that ran from 5th September to 10th October 2025.

Chapter 6

6 Legal Overview

Note: The chapter endeavours to state the law as it stood at November 2025 (with the exception of an update on the Nitrates Action Programme) on the basis of materials available to the lead author. The text is intended as general legal commentary for those with an interest in the subject matter and does not constitute legal advice.

6.1 Overview of chapter

This review briefly considers the law relating to hydromorphological alterations within the meaning of the Water Framework Directive 2000/60/EC (WFD) and, in particular, the planning and other requirements affecting such alterations, as that law stood at November 2025 during the transitional period preceding the widespread commencement of the Planning and Development Act 2024.

Legal provisions with respect to the implementation of the WFD are subject to changing legislation and subject to both the development of new knowledge and responses of the Government of Ireland to rulings from the Court of Justice of the EU. Aspects of the legislation naturally permeate this whole report. Summaries of some key legislation and guidance from the EU Commission as relevant to hydromorphology are provided in Chapters 1 -3, and a view on the implementation of River Basin Management Plans (RBMPs) in Chapter 4. There is, therefore, some overlaps between the information provided in early chapters and this one

Some notable gaps and overlaps in the existing framework of laws are identified, reflecting how the law has evolved to deal with particular uses of various water bodies, the roles played by different stakeholders in respect of those bodies of water, all overlain by the complex of EU environmental legislation that Ireland has implemented. These include general measures such as the Birds Directive, the Habitats Directive, the Strategic Environmental Assessment Directive, the Environmental Impact Assessment Directive, those specific to WFD, certain risks to water (the Nitrates Directive) or from water (the Floods Directive), as well as issues arising from other water uses, including the Drinking Water Directives, the Bathing Water Directives, and the Urban Wastewater Directive (the latter three sets of Directives beyond the scope of the current review).

It seems clear from the review that the current patchwork of laws is not fit for purpose in the 21st century, especially in the context of climate change and the predicted changes that will occur to Ireland's water and wider environment. Significant reductions are expected in average levels of annual, spring and summer rainfall, while forecasts are for a substantial increase in the number of heavy rainfall events in autumn and winter. Adapting to expected climate change will require fresh thinking and approaches to management of water bodies, both in terms of ameliorating and in forestalling some of the more adverse impacts predicted from climate change.

Several recommendations are made in the review to address the legal lacunae and inconsistencies in current approaches to water and issues of hydromorphology, and to create

a more coherent schema of law to better meet current and expected requirements. These recommendations, along with others, are distilled and summarised in Chapter 7.

In relation to hydromorphology specifically, in its most recent 'Fitness Check of the WFD and Floods Directive' (European Commission, 2019b) the Commission found that hydromorphological alterations are not due to any one source but arise from several pressures: alterations associated with water storage, irrigation, flood protection, navigation, urban development and changes in land use. Understanding the overall relevance of hydromorphological alterations requires an understanding of how different uses each interact with the planning and regulatory framework to produce the current status of Irish water bodies.

That status quo is deeply unsatisfactory. On the current performance trajectory, good ecological status or good ecological potential, will not be attained by all Irish water bodies, as required, by the end of the third cycle of river basin planning in 2027. The EPA report 'Water Quality in Ireland 2019-2024' (EPA, 2024b) surveyed the conditions in over 4,000 surface water bodies and 514 groundwater bodies.

It found that just over half (52%) of surface water bodies are in satisfactory ecological health as classified under the WFD (good, or better, ecological status), with 48% of water bodies being in the moderate, poor or bad quality categories. Good or better status could be ascribed to just 1,523 rivers (48% of the total), in contrast to the relatively better condition of lakes (68%) and coastal waters (81%). Transitional waters, with just 30% achieving good or better status, were the worst performing type of water body. In the period since the previous five-year survey (covering 2016-2021), there was a 2% decline in the number of river bodies in satisfactory condition, and a 0.5% reduction in the number of lakes in satisfactory condition.

The primary causes of the reduction in the quality of water bodies are attributable to (human) activities that release pollutants from land to water, damaging aquatic habitats. These activities result in the run-off of nutrients, sediments and pesticides from agriculture and forestry. Changes ensuing from land drainage, navigational dredging and man-made structures such as dams, weirs or culverts placed in water courses also reduce the physical integrity of water bodies. Since the previous assessment period (2016-2021), the ecological status of 1,723 monitored river water bodies remains unchanged, 387 declined while 294 improved. This represents a net decline in status of 93 water bodies since 2016-2021. Clearly, significant changes to current practices and approaches are required if there is to be a realistic prospect of achieving the desired objectives for water bodies set out in the WFD.

6.2 Water Framework Directive provisions

Chapters 1 and 3 provide a general account of the WFD and its transposition in Ireland. Some repetition occurs here so as to provide a self-contained chapter addressing the legal issues, and to remove the need for referral back to the general account.

The purpose of the WFD is to "establish a framework for the protection of inland surface waters, transitional waters, coastal waters and ground waters." The WFD therefore covers conditions in five different types of surface water body: (1) river, (2) lake, (3) transitional, (4) coastal and (5) artificial or heavily modified water body (HMWB). The primary objectives of the Directive are to prevent a deterioration in the status of surface water bodies ("surface water status" defined in Article 2(1) as the general expression of the status of a water body determined by the lowest assessment of its ecological status and chemical status) and ensure that EU Member States achieve good surface water status within 15 years of entry into force of the WFD or, in "duly justified cases", by 2027, at the latest. Extensions beyond this time

limit are not permitted under Article 4(4) of the WFD, except where all relevant measures have been taken and "…where the natural conditions are such that the objectives cannot be achieved within this period."

Good surface water chemical status is defined under Article 2(24) of the WFD by reference to the chemical status required to meet the environmental objectives for surface waters established in Article 4(1)(a) of the WFD, that being the chemical status achieved by the water body in which concentrations of pollutants do not exceed the relevant environmental quality standards set out in Article 16(7) and Annex IX to the WFD, as well as any other relevant EU legislation.

The emphasis of this review is, however, on the ecological aspects of the WFD, and hydromorphology, in particular, so issues pertaining to chemical status will not be specifically considered. The interface of the WFD with the Nitrates Directive is, however, considered in section 6.5 below. The requirements to achieve good quantitative and good chemical status for groundwater, as opposed to surface water bodies, are also beyond the scope of this review.

For present purposes the focus is, therefore, on the obligation that EU Member States have to achieve at least good ecological status as defined in Article 2(22) of the WFD (remembering that both good ecological status and good chemical status must be attained to achieve overall good surface water status) in respect of the first four types of water bodies, and good ecological potential as defined in Article 2(23) in respect of Artificial Water Bodies (AWB) and HMWBs (essentially meeting the criteria for similar unmodified water bodies as far as possible taking account of the human use modifications that have occurred).

Good ecological status is defined by reference to three broad headings, covering: (1) biological elements, such as the composition, abundance and structure of the biological elements; (2) physical and chemical elements supporting the biological elements of the water body (water temperature and salinity, for example); and lastly (3) hydromorphology elements (hydrological regime, river continuity and morphological conditions) supporting the biological elements.

Underlining the complexity of the Directive, there is no single definition of hydromorphology – the elements comprising it depend on the type of water body in question. For ease of exposition, this review uses the definition set out at paragraph 1.1.1 of Annex V to the WFD, relating to rivers. There, it means alterations to:

- the hydrological regime of a river (the quantity and dynamics of flow, connection to groundwater);
- continuity (ability of sediment and migratory species to pass freely up and down rivers and laterally within the floodplain); and
- morphology (the physical habitat – the composition of substrate, width/depth variation, the structure of bed, banks and riparian zone).

Article 4(5) of the Directive allows Member States to apply a less stringent objective to a water body where it has been so affected by human activity (as determined in accordance with Article 5(1)) or the natural condition of the water body is such that the achievement of good status would be "infeasible or disproportionately expensive." Four further conditions must each be satisfied by the AWB or HMWB. These conditions relate to: (i) a requirement that the environmental and socioeconomic needs served by the human activity cannot be achieved by other means which are a significantly better environmental option not entailing disproportionate costs; (ii) a requirement to achieve the highest possible ecological and chemical status for the water body commensurate with the (reasonably) unavoidable impacts of human activity or pollution; (iii) a requirement of no further deterioration in the status of the

water body; and (iv) a specific justification for the less stringent objective to be set out in the relevant management plan for the water body concerned and the periodic review of that justification.

The hydromorphological elements required for unmodified high-status rivers are summarised in Table 21. Broadly similar elements apply to the other types of water body, with some changes to individual constituent elements reflecting the particular characteristics of the water body concerned (in lakes, for example, 'flow' is not a relevant quality element but 'residence time', or the mean time that water or another dissolved substance spends in a lake, is a key hydromorphological consideration).

Table 21. Hydromorphological Quality Elements for high status rivers (adapted from Table 1.2 and 1.2.1. Annex V WFD).

Element	Requirements
General	There are no, or only very minor, anthropogenic alterations to the values of the physico-chemical and hydromorphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions.
	The values of the biological quality elements of the surface water body reflect those normally associated with that type under undisturbed conditions, and show no, or only very minor, evidence of distortion. These are the type-specific conditions and communities.
Hydrological regime-rivers	The quantity and dynamics of flow, and the resultant connection to groundwaters, reflect totally, or near totally, undisturbed conditions.
River continuity	The continuity of the river is not disturbed by anthropogenic activities and allows undisturbed migration of aquatic organisms and sediment transport.
Morphological conditions–rivers	Channel patterns, width and depth variations, flow velocities, substrate conditions and both the structure and condition of the riparian zones correspond totally or near totally to undisturbed conditions.

For rivers of good ecological status, the value of the biological quality elements must show low amounts of distortion resulting from human activity and deviate only slightly from those usually associated with the river under undisturbed conditions. The other conditions (hydrological regime etc.) are required to be consistent with the achievement of the (good status) values for the biological quality elements. A similar characterisation is applied to rivers of moderate status, except that here, the biological quality elements deviate moderately from undisturbed conditions, with the values shown displaying moderate signs of disturbance from human activity, being more disturbed than under conditions of good status. The hydrological, morphological and other conditions are required to be consistent with the achievement of the (moderate) values for the biological quality elements. Finally, no specific description is given for a river classified as poor or bad – its conditions are to be deduced from the conditions described for rivers of good or moderate status.

Article 5 of the WFD requires the characterisation of River Basin Districts, including the identification of significant anthropogenic pressures on surface water bodies in accordance with point 1.4 of Annex II to the Directive, and the assessment of the susceptibility of those bodies to such pressures, in accordance with point 1.5 of Annex II. Article 5 also requires an economic analysis of water use be undertaken in accordance with Annex III, to support the

principle of cost recovery of water services from different economic sectors (at a minimum industry, households, agriculture) required by Article 9 of the Directive. These characterisations and analyses are required to be updated periodically.

In a recent infringement proceeding (Case C-204/24) concerning Ireland's transposition of the WFD, the European Commission complained that Ireland had not correctly transposed points 1.4 and 1.5 of Annex II into domestic law by the relevant deadline. The Commission contended that Ireland had not implemented these specific requirements, although the 2022 Surface Waters (Amendment) Regulations incorporated other elements of Annex II.

Ireland argued that responsibility for implementation rested with the competent authorities, coordinated by the EPA, and that it was unnecessary to set out the detailed technical requirements of Annex II in legislation.

The Court found that Ireland had failed to adopt a sufficient legal framework to guide and constrain the discretion of the competent authorities in identifying pressures and assessing susceptibility, as required by points 1.4 and 1.5 of Annex II. The Court clarified that while verbatim incorporation of the provisions of WFD was not required, a framework ensuring proper implementation was necessary.

Having established the status of a water body in accordance with Article 4, Member States are next required to undertake monitoring in accordance with Article 8 and the detailed specifications sets out in Annex V to the WFD. Some hydromorphological conditions such as hydrology are required to be assessed continuously, while less frequent monitoring periods are stipulated for different biological elements (between six months to three years) and for testing of hydromorphological elements (river continuity and morphology) - at least every six years.

This monitoring serves two purposes. In the short-term, it provides the necessary baseline against which impacts arising from a particular proposal affecting a body of surface water may be assessed. Longer-term, it informs the programme of measures required by Article 11 of the WFD to be drawn up for each River Basin District (RBD), enabling the authorities to respond to the identified pressures for that water body with suitable measures to allow the body of water to reach good status.

The programme of measures (POMs) is then incorporated into the relevant River Basin Management Plan (RBMP), being both a description of the status of that River Basin District and an action plan for its management, as required by Article 13 and Annex VII to the WFD. The RBMP is required to be updated (after an initial review no later than 15 years after the coming into force of the WFD) every six years thereafter[6].

6.2.1 The WFD and Weser (Case C 461/13)

The Court of Justice of the EU (CJEU) considered the environmental objectives of the WFD in *Case C 461/13 Bund für Umwelt und Naturschutz Deutschland eV* (Weser) which concerned a proposal to dredge the river Weser (classified in part as natural and, in part, as artificial and heavily modified) in order to facilitate the passage of larger container vessels to inland harbour cities in Germany. Bund, an environmental NGO, challenged the decision of the authorities to permit the dredging, which decision was taken by the authorities on the basis that it would not

[6] In May 2024, the European Commission initiated proceedings against Ireland (Case C- 346/24) for failure to review and update the second river basin management plan by 22 March 2022. The case was subsequently discontinued, with Ireland ordered to pay costs.

reduce the river's overall ecological status. Bund argued against this decision, stating that any adverse change to a body of water, even if did not trigger a change in ecological status class, nonetheless constituted a deterioration for the purposes of the WFD.

The CJEU, in a request to it for a preliminary ruling concerning the interpretation of Article 4 (1) (a) (i) to (iii) of the WFD, found that the WFD imposed two key requirements (i) an obligation to prevent deterioration and (ii) an obligation to enhance:

38. The environmental objectives that the Member States are required to achieve are specified in Article 4(1) of Directive 2000/60.

39. That provision imposes two objectives that are separate, although intrinsically linked. First, in accordance with Article 4(1)(a)(i) of Directive 2000/60, the Member States are to implement the necessary measures to prevent deterioration of the status of all bodies of surface water (*obligation to prevent deterioration*). Second, pursuant to Article 4(1)(a)(ii) and (iii), the Member States are to protect, enhance and restore all bodies of surface water with the aim of achieving good status by the end of 2015 at the latest (*obligation to enhance*).

Significantly, in Weser, the CJEU resolved the issue, open until then, of whether the WFD was aspirational in nature – were Member States required *to endeavour* to achieve certain objectives, or were Member States actually required to *achieve* those objectives? Some considered that the objectives of the WFD were mere management-planning objectives with no link to, or effect on, individual projects. The Court ruled firmly in favour of the binding nature of the environmental objectives specified in Article 4(1) (a) with respect to bodies of surface water, provided that the derogations outlined in Article 4(7) did not apply.

The Court clarified what was meant by the obligation to prevent deterioration. Deterioration would be established where the status of one of the quality elements of the water body concerned, within the meaning of Annex V to the WFD, falls by one class (e.g. from high to good) even if this does not affect the overall classification of that water body. If the quality element concerned was already in the lowest status class (e.g. bad) any deterioration in that element, albeit remaining within the same status class (bad), however, would amount to a deterioration in the status of that water body. Otherwise, not to class this as deterioration might mean that heavily damaged water bodies in the lowest status class would, in effect, be left unprotected. In confirming the binding nature of the environmental objectives of the WFD specified in Article 4(1), the Court also underscored the obligation on Member States under Article 4(1)(a) (ii) and (iii) to protect, enhance and restore all bodies of surface water with the aim of achieving good surface water status by the end of 2015.What steps should be adopted, following Weser, by authorities in deciding whether or not to give permission for a new project which may affect a body of surface water?

In the first instance, it is now amply clear that the WFD applies to individual projects affecting water bodies and is not just a tool for the programmatic management of decisions affecting water bodies as a whole. Furthermore, Article 4(1)(a)(i) to (iii) of the WFD, as interpreted in Weser, means that a Member State is obliged (unless a derogation is granted under Article 4 (7)) to refuse authorisation for an individual project where it may cause deterioration in the status of a body of surface water (that status being determined by the poorer of its ecological status and its chemical status) or where it jeopardises the attainment of good surface water status or good ecological potential and chemical status, by the date laid down by the WFD.

"Deterioration" is to be assessed by reference to the existing status classification of the water body and accompanying detailed quality elements listed in Annex V to the WFD for the

particular type of water body. It is the potential change in the values of the quality elements, stemming from implementation of a particular project, which will establish whether or not a deterioration of the status of a water body will occur from a WFD perspective. The limit values for high, good and moderate status were set out in Commission Decision 2013/480/EU of 20 September 2013[7], following an intercalibration exercise among Member States. As mentioned above, the tables in 1.2 of Annex V provide the normative definitions of high, good and moderate status used in classifying[8,] the water body concerned.

In sum, the WFD imposes clear obligations on relevant authorities both to prevent a deterioration in the status of a surface water body and, in parallel with that obligation, imposes a second obligation, to ensure that the water body concerned attains at least good surface water status in line with the prescribed timetable. The WFD is clear as to how the conditions of a water body are to be assessed – in accordance with the quality headings outlined in Annex V, the values of their respective constituent elements, with overall classification in accordance with the scheme provided in Annex V, such to be tracked in accordance with the monitoring required under Article 8.

It is also clear from the WFD that where a derogation under Article 4 (7) is sought to be applied in respect of a particular project affecting a water body (such being a *new* modification to the physical characteristics of the water body or the result of *new* sustainable human development activities), this may only be granted by authorities where all of the relevant criteria have been complied with, including the *"...* condition that all practicable steps have been taken to mitigate the adverse impact on the status of the body of water concerned and that the programmes of measures and management plans have been adapted accordingly."

A 2022 ruling in a preliminary reference to the CJEU (Case C-525/20) considered whether the obligation to prevent "deterioration" in the status of water bodies included just effects of a permanent nature or whether it also included temporary effects to status. The Association France Nature Environnement (AFNE) had brought an action against the Premier minstre Ministre de la Transition écologique et solidaire, seeking the annulment of a decree which provided that, in assessing the compatibility of programmes and administrative decisions adopted in the field of water to prevent the deterioration of water quality, "no account shall be taken of the temporary, short-term impacts which are without lasting consequences."

AFNE argued that the decree infringed the WFD, which prohibited any deterioration, be it temporary or long-term, in the status of bodies of water. The French authorities argued that Article 4 (7) of the WFS was engaged by the proceedings. Article 4(7) of the WFD covered deteriorations in the status of a body of water resulting from new sustainable human development activities and was the subject of an accompanying CIS Guidance Document No. 36 'Derogations from the Environmental Objectives according to Article 4(7)'. That guidance explicitly provided that when such activities have only a temporary, short-term impact on the status of a body of water and are without lasting consequences, they may be authorised without that authorisation being made subject to compliance with the four conditions set out in Article 4 (7) of the WFD.

The CJEU found that it was clear from Article 4 that a deterioration of the status of a body of water, even if transitory, is authorised only subject to strict conditions, as set out in Article 4(6) and Article 4(7) and that, consequently, the threshold beyond which breach of the obligation to prevent deterioration of status of a body of water is found must be set as low as possible.

[7] Subsequently replaced by Commission Decision (EU) 2018/229

[8] Note that the classification system only includes definitions for high, good and moderate status, with waters achieving a status below moderate being classified as poor or bad

The Court held that:

"… Member States, when they assess the compatibility of a particular programme or project with the objective of preventing the deterioration of water quality, [are required] to take into account temporary, short-term impacts which are without lasting consequences, unless it is clear that such impacts have, by their nature, little effect on the status of the bodies of water concerned and cannot lead to a 'deterioration' of that status, within the meaning of that provision. Where, as part of the authorisation procedure for a programme or project, the competent national authorities determine that that programme or project could lead to such a deterioration, that programme or project may be authorised only if the conditions set out in Article 4(7) of that directive are met, even if the deterioration is temporary in nature."[9]

The limits of the Weser obligations of ensuring no deterioration in the status of a water body and not jeopardising the attainment of good water status were considered in a High Court[10] challenge brought by an airline to the grant of consent for the construction of a subterranean underpass at a Dubin airport, which entailed the culverting and diversion of a heavily polluted water body, the Cuckoo stream. The judge rejected the suggestion that the WFD required the taking of positive steps in any development consent decision in order to restore or improve the status of a water body, finding "There is no principle that permission must be refused if a project doesn't contribute positively to the attainment of WFD objectives. In Weser, the CJEU has phrased the requirement negatively. There is no authority to support that and such authority as exists firmly rejects that notion…."

Citing "*In R. (Tarian Hafren Severn Shield CYF) v Marine Management Organisation"* [2022] EWHC 683 (Admin), [2022] P.T.S.R. 1261, [2022] 3 W.L.U.K. 3752, the judge found "…A similar logic applies here. The applicant hasn't pointed to anything in EU legislation or jurisprudence or that of member states or former member states to support such an interpretation – that isn't a surprise because such an interpretation is obviously unworkable. A vast number of projects won't contribute positively to water quality – the directive only requires that they don't make things worse. This isn't a point on which any reasonable doubt arises."

6.2.2 Implementing the WFD in Ireland

The *European Communities (Water Framework) Regulations, 2003* ("the 2003 Regulations") (as amended) are the primary regulations implementing the WFD in Ireland, as supplemented by other Regulations, including the *European Communities (Surface Water) Regulations, 2009* ("2009 Regulations") (as amended) which sets out the environmental standards and objectives for bodies of surface water, to be attained in accordance with the applicable river basin management plan (RBMP).

The 2003 Regulations set out the basic framework for RBMPs in Ireland that:

[9] In October 2025 the European Commission announced (13706/25) that it had reached a provisional political agreement with representative of the European Parliament on a directive, which updates the lists of pollutants affecting surface waters and groundwater and corresponding regulatory standards. It amends the Water Framework Directive, introducing a new Article 2 (43) defining deterioration and a new Article 4 (7) (a) permitting temporary deterioration in (biological) quality elements of water for between one and three years maximum, thus recognising the impacts of Weser and AFNE respectively. The measure is due to be transposed by December 2027.

[10] [2025] IEHC 74

- established seven areas as River Basin Districts (RBDs), for Ireland, three of these being shared with Northern Ireland, in line with Art. 3(1) of the WFD requiring that individual river basin districts be identified, the same districts being used, in accordance with Article 3(4) of the WFD, to coordinate the programme of measures required under Article 11, for the RBMP specified in Article 13;
- required local authorities in an RBD, to be the competent authorities (along with the EPA) for the purposes of an RBD, and, acting jointly in relation to the particular RBD, to establish environmental objectives and accompanying programmes of measures, to make and agree river basin management plans and to establish river basin district advisory councils;
- made provision for co-ordination and guidance in respect of these matters, at the national level by the Minister and the EPA, which was charged with identifying and characterising each RBD, classifying the relevant quality, chemical and ecological status of the RBD water bodies, establishing the requisite monitoring programmes and reporting to the European Commission; and
- required all public authorities to take measures appropriate to their functions to promote or achieve implementation of the WFD, including coordination and cooperation with other authorities (including authorities in Northern Ireland) and to encourage the active involvement of all interested parties.

Regulation 3 of the 2003 Regulations specifically requires each public authority (local authorities, plus a range of statutory bodies listed in Schedule 1 to the Regulations, including the EPA, Waterways Ireland, the central/regional fisheries boards (now Inland Fisheries Ireland), the Commissioners of Public Works, Bord na Móna, Irish Water and Coillte to exercise their respective statutory functions in a manner which is consistent with the provisions of the WFD and which achieves or promotes compliance with the WFD, and to take such actions as is appropriate in the context of their respective functions to secure compliance with the WFD and with the provisions of any RBMP or programme of measures established under the Regulations. What this actually means in practice is unclear. However, and as far as can be established, this general obligation has rarely (if ever) been the determining factor for the public bodies subject to it. In the recent WFD infringement case (Case C- 204/24) cited earlier, Ireland in part sought to rely on this general duty as giving effect to its obligations under the WFD, a proposition rejected by the CJEU which found that the obligations in question (under Article 7 (3) of WFD) required to be appropriately anchored in domestic law with identifiable responsibilities assigned to relevant authorities .

For the second RBMP cycle (2018-21), and subsequently, Ireland adopted a single RBD, made up of 46 catchment management units, sub-divided further into 583 sub-catchments, the previous structure of seven RBDs having proved too unwieldly. Two international River Basin Districts are shared with Northern Ireland. Policy is formulated by the Minister for Housing, Local Government and Heritage, with advice from the Water Policy Advisory Committee (established under the *European Communities Water Policy Regulations,* S.I. 350 of 2014). The EPA oversees the national monitoring programme and chairs the National Technical Implementation Group.

Finally, local authorities coordinate the implementation of the appropriate programmes of measures, being coordinated through structures combining the relevant local authorities in five regions (Borders, Midlands and Eastern, Southeast, Southwest and Western), supported

by a shared service structure in the form of the Local Authorities Waters Programme (LAWPRO).

At the centre of WFD implementation is the programme of measures required under Article 11 of the WFD. These are the basic measures which must be implemented by all Member States in respect of each River Basin Management Plan. The Article provides:

[11] 1. Each Member State shall ensure the establishment for each river basin district, or for the part of an international river basin district within its territory, of a programme of measures, taking account of the results of the analyses required under Article 5, in order to achieve the objectives established under Article 4. Such programmes of measures may make reference to measures following from legislation adopted at national level and covering the whole of the territory of a Member State.

Where appropriate, a Member State may adopt measures applicable to all river basin districts and/or the portions of international river basin districts falling within its territory.

2. Each programme of measures shall include the 'basic' measures specified in paragraph 3 and, where necessary, 'supplementary' measures.

3. 'Basic measures' are the minimum requirements to be complied with and shall consist of (a) those measures required to implement Community legislation for the protection of water, including measures required under the legislation specified in Article 10 [11] and in part A of Annex VI [12];

Note that the programme of measures required is not limited to those water bodies which are regarded as being At Risk of not achieving good ecological status – it applies equally to all water bodies, no matter their individual status. The Article also provides for additional or supplementary measures to be taken as required, depending on the circumstances of an individual water body:

[11] 4. 'Supplementary' measures are those measures designed and implemented in addition to the basic measures, with the aim of achieving the objectives established pursuant to Article 4. Part B of Annex VI contains a non-exclusive list [13] of such measures.

Obligations in respect of HMWBs

The clear intention of the WFD is that water bodies are required to be protected, enhanced and restored to their natural state, although the obligation in respect of HMWBs is somewhat lesser, being stated as "protect and enhance." Articles 4(1) (a) (ii) and (iii) of the WFD provide that:

(ii) Member States shall protect, enhance and restore all bodies of surface water, subject to the application of subparagraph (iii) for artificial and heavily modified bodies of water, with

[11] Dealing with point and diffuse sources of discharges to water.

[12] Bathing Water Directive (76/160/EEC); (ii) Birds Directive (79/409/EEC) (1); (iii) Drinking Water Directive (80/778/EEC) as amended; (iv)Major Accidents (Seveso) Directive (96/82/EC) (2); (v) Environmental Impact Assessment Directive (85/337/EEC) (3); (vi) Sewage Sludge Directive (86/278/EEC); (vii) Urban Waste-water Treatment Directive (91/271/EEC); (viii) Plant Protection Products Directive (91/414/EEC); (ix)Nitrates Directive (91/676/EEC); (x) Habitats Directive (92/43/EEC) (5); (xi) Integrated Pollution Prevention Control Directive (96/61/EC).

[13] These include such measures as ..(iv) negotiated environmental agreements, (vii) recreation and restoration of wetland areas, and (xiii) rehabilitation projects.

the aim of achieving good surface water status at the latest 15 years after the date of entry into force of this Directive, in accordance with the provisions laid down in Annex V; and

(iii) Member States shall protect and enhance all artificial and heavily modified bodies of water, with the aim of achieving good ecological potential and good surface water chemical status at the latest 15 years from the date of entry into force of this Directive, in accordance with the provisions laid down in Annex V, subject to the application of extensions determined in accordance with paragraph 4 and to the application of paragraphs 5, 6 and 7 without prejudice to paragraph 8;

Article 4(3) of the Directive sets out the provisions relating to the designation of water bodies as HMWBs, modifying the general WFD imperative to achieve good ecological status, in favour of good ecological potential, provided the relevant criteria for designation as HMWB are each fully met:

4(3) Member States may designate a body of surface water as artificial or heavily modified, when:

(a) the changes to the hydromorphological characteristics of that body which would be necessary for achieving good ecological status would have significant adverse effects on:
  (i) the wider environment;
  (ii) navigation, including port facilities, or recreation;
  (iii) activities for the purposes of which water is stored, such as drinking water supply, power generation or irrigation;
  (iv) water regulation, flood protection, land drainage, or
  (v) other equally important sustainable human development activities; and

(b) the beneficial objectives served by the artificial or modified characteristics of the water body cannot, for reasons of technical feasibility or disproportionate costs, reasonably be achieved by other means, which are a significantly better environmental option. Such designation and the reasons for it shall be specifically mentioned in the river basin management plans required under Article 13 and reviewed every six years.

Article 4 (3) (a) sets out that a proposal to designate a water body as a HMWB may be permitted if the changes required to restore that body to its natural state would have significant adverse effects on a range of factors, including the wider environment, navigation, water storage purposes, water regulation, flood protection, land drainage or other important sustainable human development activities.

These stipulations are bracketed with another stipulation set out in paragraph (b) of Article 4(3), namely that the objectives served by the required changes to the water body cannot be achieved by other means because of the technical infeasibility of those alternatives, or the disproportionate costs of the alternatives which significantly better meet environmental (including WFD) needs. The latter criterion of “disproportionate” suggests, indeed requires, that some level of additional costs must be acceptable to the authorities carrying out the works – perhaps even a significantly increased cost - if that alternative option (not involving a modification to the water body) is to be realistically considered alongside the water body-modifying but cheaper alternative. So, while a greater cost may be entailed by adopting the water body-favouring option, that is very clearly contemplated by, and acceptable in, the framework established by the WFD.

There is also a requirement for a sexennial review of HMWBs once designated and the re-justifications for same, preventing a static view of the water body and associated human uses

being adopted and fixed in administrative or regulatory aspic for all time. Designation is not intended to be a means to avoid the application of the WFD, either temporarily or permanently – there is a requirement that each designation of a HMWB be reviewed and appropriately justified in every cycle of River Basin planning.

Guidance Document No. 4 on the Identification and Designation of Heavily Modified and Artificial Water Bodies (European Commission, 2003f) in the context of the second RBMP cycle clearly envisages that HMWBs (and Artificial Water Bodies) would be reviewed on an ongoing basis: "The designations of HMWB and AWB must be reviewed every six years."

A recent study by the EPA (2022a) – 'Review of Ireland's Heavily Modified Water Body Designations for the Third Cycle River Basin Management Plan' considered the designation of Irish water bodies as HMWBs, with further guidance provided in the published RBMP Water Action Plan (DHLGH, 2024a) and (DHLGH, 2025), as discussed in Chapter 4 above.

In the first and second RBMPs, some 33 water bodies were designated as heavily modified, but now, following the study, some 466 water bodies are assessed as meeting the criteria for designation as HMWBs, including 433 rivers, 20 lakes and 13 estuarine and coastal waters. Of particular interest is the proposed designation of some 325 river water bodies as HMWBs owing to changes caused by arterial drainage schemes (from an original total of 672 candidate river water bodies with that characteristic). The specified use owner, the Office of Public Works (OPW), indicated that "…on the basis of the best available information*"* the measures required to restore the river bodies concerned could not be implemented without affecting the specified use (for agriculture). Given the large number of rivers now proposed for designation as HMWBs, it would be helpful to understand precisely what information was available to the OPW in respect of each individual river in making this assessment and whether that 'best available information' was a sufficient basis for the conclusions reached that restoration measures could not be implemented without affecting the current agricultural use of land or indeed, without consideration of alternative, potentially superior, uses of the land concerned.

The EPA also reported that no technically feasible alternative options to the existing arterial drainage schemes, which the OPW is obliged to maintain under the Arterial Drainage Acts (1945, 1995), were available. Whatever the eventual designation, of these candidate rivers, they are not, however, removed or exempt from the obligations and scrutiny imposed by the WFD. The rivers concerned, if designated as HMWBs, are obliged to attain good ecological potential in place of good ecological status, while their status as HMWBs is subject to periodic review and re-justification in each cycle of the RBMP.

6.3 Planning and Development Acts

Planning in Ireland is currently regulated by the Planning and Development Act, 2000 (as amended) (PDA, 2000) and accompanying *Planning and Development Regulations, 2001 (as amended)* (PDR, 2001) which flesh out much of the detail of the parent Act. The PDA, 2000 [14] contemplates a hierarchy or framework of plans and strategies at a national, regional and local level which together provide the basis for proper planning and sustainable development. Collectively, these plans form the physical planning framework against which applications for development permission are assessed, including those bearing on developments near to, or

[14] The 2024 Act makes this hierarchy explicit: at the apex will be a National Planning Framework, followed by three regional assembly Regional Spatial and Economic Strategies, thirty-one local authority Development Plans and finally, Area Plans set as required by local authorities. Plans lower down in the hierarchy must align to those higher up.

affecting bodies of surface water or groundwater. While this Act is replaced by the Planning and Development Act, 2024, for the purpose of the treatment that follows, the 2000 Act is considered, with references to the 2024 Act, as appropriate, as not all of the provisions of the new legal framework (much to be fleshed out in Regulations) are known.

Section 18 of the Planning and Development (Amendment) Act, 2018 provides for the incorporation of the National Planning Framework (NPF) in the PDA, 2000, setting out a medium to long-term planning and development context (to 2040) for local authorities. The NPF aims to achieve balanced regional development across the three planning regions (North & West; East and Midlands; Southern) tasked under section 21 of the PDA, 2000 (as substituted) with preparing a regional spatial and economic strategy in conjunction with relevant local authorities. The intent of these regional strategies is to better coordinate with the individual county development plans, to accommodate an anticipated one million increase in population between now and 2040, requiring an additional 500,000 dwellings. Section 21 of the PDA, 2024 creates the basis for future National Planning Frameworks requiring the Government to prepare and publish the NPF with strategic objectives for planning and sustainable development. A transitional measure is included which provides that the NPF already in force under the PDA, 2000 continues in effect and is deemed to be the first NPF under the PDA, 2024. In preparing a development plan for the required consultations with the Office of the Planning Regulator, a planning authority is obliged to take due account of the requirement under Section 53 (1) (a) of the PDA, 2024 that the plan be materially consistent with, inter alia, the National Planning Framework.

At the core of the planning system are the 31 local authorities which are charged under section 9 of the PDA, 2000 with the production of a development plan for the functional area of the local authority. This must be done every six years[15] and may be done independently or in coordination with adjoining local authorities. Under section 10 of the PDA, 2000 it is required that the development plan set out an overall strategy for the proper planning and sustainable development of the area of the development plan, consisting of a written statement and the development objectives for the area in question. It is specified that the development objectives be consistent "as far as practicable" with national and regional development objectives and with specific planning policy guidelines set by the Minister under Section 28 of the PDA, 2000. The PDA, 2024, by its section 6, repeals this provision, and subject to transitional arrangements for existing guidelines, replaces it with National Planning Statements to be issued by the Minister, with the approval of the Government, under section 25 of the PDA.

Under section 10 (2) (b)(i) of the PDA, 2000, the development plan must include objectives for the promotion of compliance with the environmental standards and objectives established for bodies of surface water under the 2009 Regulations, the standards and objectives being those set out in the relevant river basin management plan (as specified in Regulation 13 of 2003 Regulations).

The PDA, 2024 requires that a planning authority must prepare a development plan that contributes to "proper planning and sustainable development," which, perforce, encompasses environmental protection obligations. Section 42 (3) (a) of the PDA, 2024 requires such plans to "[be] an integrated overall strategy for the proper planning and sustainable development of the functional area to which the development plan relates" and Section 42 (3)(b) "[set out] policies and objectives that are necessary for the purposes of such a strategy" thus promoting integration of environmental objectives into development plans, as opposed to the

[15] Revised to every ten years under Section 42 of the Planning and Development Act, 2024.

former, less satisfactory, approach of listing of objectives in development plans. Section 42 (8) (c) of PDA, 2024 also requires planning authorities when reviewing a development plan to "take due account of the protection of water sources", requiring its mandatory consideration and (some) weight to be accorded to that objective, for evaluation purposes.

Additionally, the development plan is required , inter alia, under Section 49 of the PDA, 2024 to set out a strategy for the conservation, protection and improvement of the environment (including the facilitation of climate adaptation and mitigation) as respects its functional area, including Section 49 (2) (b) "the promotion of compliance with environmental standards in relation to water quality and status, having regard to the Water Framework Directive" giving further weight to WFD considerations in the making and review of development plans

The 2009 Regulations set out the duty of public authorities with respect to the WFD in the following terms:

PART II DUTIES ON PUBLIC AUTHORITIES AND OTHER PERSONS

[4]. A public authority shall, in so far as its functions allow, comply with the requirements of these Regulations and take all reasonable steps including, where necessary, the implementation of programmes of measures to: —

(a) ensure that—

(i) surface water bodies comply with the relevant environmental quality standards specified in the Schedules contained in these Regulations, and
(ii) protected areas achieve compliance with any standards and objectives laid down for such areas at the latest by 22 December 2015 unless otherwise specified in the national legislation under which the individual protected areas have been established.

Where one or more of the objectives or standards under this sub-paragraph relates to a given body of water, the most stringent shall apply.

[5]. A public authority shall not, in the performance of its functions, undertake those functions in a manner that knowingly causes or allows deterioration in the chemical status or ecological status (or ecological potential as the case may be) of a body of surface water.

"Public authority" is defined very widely in Regulation 3 and Schedule 1 to the 2009 Regulations and includes the EPA, local authorities, *An Bord Pleanála*, Inland Fisheries Ireland, the ESB, Bord Na Móna, Coillte, and Waterways Ireland.

The last component of the planning framework is a Local Area Plan which may be adopted by local authorities pursuant to section 18 of the PDA, 2000 setting out the objectives for the zoning of land in that local area, together with the phasing of that zoning, along with details of community facilities and amenities, the design standards applicable to development and the environmental impact of implementing the plan. The Local Area Plan will be superseded by three distinct types of plans under Part 3, Chapter 6 of the 2024 Act: Urban Area Plans, Priority Area Plans and Coordinated Area plans when the relevant provisions of the Planning and Development Act, 2024 are applied.

6.3.1 Planning and WFD

Section 32 of the PDA, 2000 provides that planning permission is required for any development of land occurring after 1st October 1964, unless the development in question is an "exempted" development. Section 3(1) of the PDA, 2000 defines what is meant by "development":

[3 (1)]

"… except where the context otherwise requires, the carrying out of any works on, in, over or under land or the making of any material change in the use of any structures or other land.[16]"

Section (4)[17] of the PDA, 2000 provides that certain activities may be considered to be "exempted" development, including the following:

[4 (1)]

(a) use of land for the purpose of agriculture and development consisting of the use for that purpose of any building occupied together with land so used;[18] .

(aa) development by a local authority in its functional area….

….

(e) development consisting of the carrying out by a local authority of any works required for the construction of a new road or the maintenance or improvement of a road.

(f) development carried out on behalf of, or jointly or in partnership with, a local authority.

….

(l) development consisting of the carrying out of any of the works referred to in the Land Reclamation Act, 1949, not being works comprised in the fencing or enclosure of land which has been open to or used by the public within the ten years preceding the date on which the works are commenced or works consisting of land reclamation or reclamation of estuarine marshland and of callows, referred to in section 2 of that Act.

Thus, proposed developments affecting the use of land for agriculture (e.g. the conversion from tillage to pasture and associated stocking of the land with cattle, with clear potential implications for water quality) do not require planning permission, nor do developments being carried out in its own functional area by a local authority, either on its own, or in partnership. Land reclamation activities of the type described in subsection 4 (l) carried out by the Minister are also exempted development, although other obligations may nonetheless apply.

Aside from these exemptions, there are further exemptions relevant to WFD requirements set out in the Planning and Development Regulations, 2001 (as amended). Article 6 of those regulations provides for further inclusions in the definition of "exempted development" for planning permission. Article 6 (3) states that: -

[16] Section 2 of the 2024 Act provides that development shall include "the carrying out of works …(ii) on, in, over or under the maritime area or… (ii) the making of a material change in the use of the sea, seabed or any structure, in the maritime area, and includes the reclamation of land in the nearshore area.

[17] Replaced by Section 9 of the PDA, 2024. Note that developments which require an environmental impact assessment or an appropriate assessment may not be exempted developments.

[18] It is expected that regulations to be made under Section (9) of the 2024 Act will continue the usual exemption for agriculture, except where the farming activity in question requires environmental impact assessment, appropriate assessment or relates to or modifies an unauthorised development.

> "Subject to article 9, in areas other than a city, a town or an area specified in section 19(1)(b) of the Act or the excluded areas as defined in section 9 of the Local Government (Reorganisation) Act, 1985 (No. 7 of 1985), development of a class specified in column 1 of Part 3 of Schedule 2 shall be exempted development for the purposes of the Act, provided that such development complies with the conditions and limitations specified in column 2 of the said Part 3 opposite the mention of that class in the said column 1."

Looking, for example, at the exemption provided for minor development comprising drainage and/or reclamation of wetlands, Part 3 of Schedule 2 to the PDR, 2001 provides as follows:

Part 3

Article 6 Exempted Development—Rural

Column 1	**Column 2**
Description of Development	Conditions and Limitations
…	…
Land reclamation	
Class 11	
	1. The area to be affected shall not exceed 0.1 hectares.
Development consisting of the carrying out of drainage and/or reclamation of wetlands.	2. Where development has been carried out within a farm holding under this class, the total area of any such development taken together with the area of any previous such development within the farm holding shall not exceed the limits set out in 1. above.

Thus, where the wetland area so affected by the proposed drainage (taken together with other previous wetland drainage works) does not exceed 0.1 hectares, then the drainage works are to be regarded as a class (Class 11) of exempted development under Part 3, Schedule 2 to the PDR, 2001.

Another exemption arises under Class 35 as specified in Part 1 of Schedule 2 to the 2001 Regulations. This Class covers development comprising:

(a) the carrying out by or on behalf of a statutory undertaker of any works for the maintenance, improvement, reconstruction or restoration of any watercourse, canal, river, lake or other inland waterway, or any lock, quay, mooring, harbour, pier, dry-dock or other structure forming part of the inland waterway or associated therewith, and any development incidental thereto,

(b) the erection or construction by or on behalf of a statutory undertaker of facilities required in connection with the operation, use or management of a watercourse, canal, river, lake or other inland waterway.

This exemption is subject to certain conditions relating to the floor area of any building constructed, its height or the number of car park spaces provided.

Accordingly, subject to compliance with these conditions and to the statutory exclusions applicable to exempted development, certain works of maintenance, improvement, reconstruction, or restoration being carried out by a statutory body in respect of a water body may not require planning permission. This could include maintenance or improvement works affecting hydromorphological characteristics of water bodies such as rivers, for example, by widening or deepening channels or removing vegetation proximate to the riverbank.

The exemption does not apply, however, where the proposed development would require environmental impact assessment or appropriate assessment, nor does it permit a public authority to derogate from its general obligation not to exercise its functions in a manner that knowingly causes or allows deterioration in the chemical status or ecological status (or ecological potential as the case may be) of a body of surface water.

Hydromorphological alterations

An infringement proceeding brought by the European Commission in Case (C 2024-24) considered 14 complaints relating to how Ireland had transposed the WFD. Among the issues considered was Ireland's implementation of Article 11 (3) (i) relating to the basic measures to be taken in a programme of measures pertaining to surface water bodies to ensure …."that the hydromorphological conditions of the bodies of water are consistent with the achievement of the required ecological status or good ecological potential for bodies of water designated as artificial or heavily modified. Controls for this purpose may take the form of a requirement for prior authorisation or registration based on general binding rules where such a requirement is not otherwise provided for under Community legislation. Such controls shall be periodically reviewed and, where necessary, updated;"

The Commission contended that there was no regime in Ireland for controlling changes to the hydromorphology of watercourses in a manner that was consistent with the WFD. Ireland's implementation was challenged as fragmented and insufficient to monitor and control hydromorphological impacts on surface water bodies. In particular, Ireland had not established a system of prior authorisation or registration based on general binding rules, subject to periodic review and update, as envisaged by the Directive.

The Commission also argued that Ireland's measures should address groundwater, because hydromorphological interventions in surface waters could have indirect effects on groundwater status.

In its defence, Ireland argued that there was no specific obligation, contrary to what the Commission suggested, requiring that the controls referred to in Article 11 (3)(i) take the form of prior authorisation and registration, and that the measure did not apply to groundwater.

The Court found that Ireland's transposition of Article 11(3)(i) did not set out general binding rules of domestic law, as required, although detailed control regimes had been adopted in specific instances Therefore, the first part of the Commission's complaint concerning surface waters was well founded. However, regarding the second part of the complaint, the Court held that Article 11(3)(i) applies only to surface water bodies, and the Commission had not demonstrated that Ireland was required to adopt measures for groundwater. Consequently, the complaint relating to groundwater was rejected.

Given the need to implement this judgment, and Ireland's reference during its defence to its consideration of the possible adoption of a dedicated hydromorphology Act, change in this area, long overdue, may now be expected.

The same ruling also considered, among other things, whether Ireland had correctly implemented Article 11 (3) (e) of the WFD pertaining to controls over the abstraction of fresh surface water and groundwater, and impoundment of fresh surface water, including a register or registers of water abstractions and a requirement of prior authorisation for abstraction and impoundment. The Court found that that the then 2018 Abstractions Registration Regulations incorrectly transposed the relevant Article, noting that "…Member States are authorised to exempt from the controls provided for in that provision only abstractions or impoundments

which have no significant impact on water status. It in no way appears – nor has it been argued by Ireland – that a surface water and groundwater abstraction threshold of less than 25 m³ could ever and in any way have a significant effect on the status of those waters." Consequently, the Court found that it must be held that the 2018 Abstractions Regulations incorrectly transposed Article 11(3)(e) of Directive 2000/60.

Assigning waterbody status

The WFD requires that all water bodies be assigned a status so that it can be determined whether a water body is achieving the relevant objective – good surface water status. In Weser, the Court of Justice held (at 51) that:

> "Article 4(1)(a)(i) to (iii) of Directive 2000/60 must be interpreted as meaning that the Member States are required—unless a derogation is granted—to refuse authorisation for an individual project where it may cause a deterioration of the status of a body of surface water or where it jeopardises the attainment of good surface water status or good ecological potential and good surface water chemical status by the date laid down by the directive."

In Ireland, until recently, only 60% of surface and groundwater bodies were assigned a water quality status as a result of monitoring by the EPA. This posed an obvious question as to how development may be permitted in cases where the water body concerned has not been assigned a status. In a recent High Court case, Sweetman v An Bord Pleanála [2021] IEHC 16, concerning a privately owned lake (Loch an Mhuilinn) of just over 8 hectares in size, the Court held that An Bord Pleanála has an obligation under EU law to refuse planning permission if either a deterioration in water body status or a jeopardisation of the attainment of that status would occur.

The Court, in quashing the decision of An Bord Pleanála to grant permission for the proposed development, noted that:

130. "The WFD, as interpreted by the CJEU, requires a Member State to ensure that the requirements of Article 4 are met before permission is granted. It cannot be so satisfied in respect of development affecting a water body whose status has (in breach of the WFD and the implementing regulations in Ireland) not been assigned by the EPA.

131. The EPA as the relevant authority in Ireland have an obligation to carry out the analysis required by Article V of the WFD in respect of surface water bodies and determining their status. If, as in the instant case, it does not fulfil its obligation in respect of any given surface water body, its failure to do so unfortunately has implications for any application for permission that potentially affects that water body."

Following that judgment, a question arose as to whether Loch an Mhuilinn needed to be characterised under the WFD, an issue not raised during the original hearing. According to the EPA, under Guidance Document No. 2 relating to the Identification of Water Bodies produced by the European Commission (2003a), such characterisation was required only for lakes greater than 50 hectares in surface area (which Loch an Mhuilinn was not) or if the Member State considered that the lake was otherwise considered significant in the context of the WFD's purposes and provisions.

Re-opening the earlier judgment, in Sweetman v An Bord Pleanála [2021] IEHC 777, Ms Justice Hyland decided to refer certain questions to the CJEU for determination:

"Question 1

(a) Are member states required to characterise and subsequently classify all water bodies, irrespective of size, and in particular is there a requirement to characterise and classify all lakes with a topological surface area below 0.5 km²?
(b) To what extent is the position different with respect to water bodies in a protected area, if at all?

Question 2

If the answer to question 1(a) is yes, can a competent authority for the purposes of development consent grant development consent for a project that may affect the water body prior to it being categorised and classified?

Question 3

If the answer to question 1(a) is no, what are the obligations on a competent authority when deciding upon an application for development consent that potentially affects a water body not characterised and/or classified?"

In April 2024, the CJEU delivered its judgment (Case C-301/22). The court found, in relation to the first question, that Member States were not obliged to establish type-specific reference conditions for surface water bodies like lakes with a surface water area of below 0.5 km^2, irrespective of whether the Member State used classification system A (as provided for in section 1.2 of Annex II of the directive) or system B (as also provided for in Annex II). Nor were Member States obliged to establish the ecological status of such lakes in accordance with Article 8 of the WFD or to establish programmes for the monitoring of the status of lakes below 0.5 km^2 in surface area.

In its judgment, the court referred to the *travaux préparatoires* for the Directive, noting the threshold for the size of the lakes covered by the directive had increased over the WFD's legislative process, reflecting the fact that inclusion of a large number of very small water bodies would have created an enormous administrative burden. This would not preclude Member States, however, from establishing a lower threshold for lakes below 0.5km" in surface size, if considered appropriate. The court did not address the second part of the first question, having clarified that Loch an Mhuilin did not lie within a Special Area of Conservation (SPA), but was linked to one (Kilkieran Bay and Islands) by a direct tidal connection.

The court did not consider the second question – whether a competent authority could grant development consent for a project potentially affecting a water body prior to the water body being categorised and/or classified – given its answer to the first question, namely, that surface water bodies like lakes below a certain size threshold did not have to be classified and monitored.

In respect of the third question, the obligations of competent authorities in dealing with a project potentially affecting a water body not subject to characterisation or classification (in this instance, a lake below 0.5 km^2 in surface area) the court ruled that in order to assess the effects of a project potentially affecting such a lake, it would also be necessary to take into account the effects of the changes ensuing to the lake on the other water bodies to which that lake is connected. In circumstances where a competent authority of a Member State could not rule out a deterioration in the status of a "connected" water body subject to characterisation in line with Article 5 of, and Annex II, of the WFD, as a result of a project, Member States would be obliged (unless a derogation was granted under Article 4(7)) to refuse consent for that project.

In the context of Loch an Mhuilin, the CJEU held that it was a matter for the Irish court to determine whether or not the project would affect the status of the other lakes and stretch of coastal water to which it is linked and which have been, or should have been, identified as a surface body type for the purposes of the WFD. The CJEU also considered that the referring court would have to ascertain whether the particular project was compatible with the programme of measures adopted by Ireland in respect of the River Basin District concerned. [19] As to the scope of the water bodies included in programmes of measures, the CJEU noted that these were not confined to surface water body types subject to characterisation under the directive, and that basic measures in that programme applied, as suggested by Guidance Document No 2, to so-called "small elements of water". This was necessary in order to not compromise the achievement of objectives for other water bodies. For this reason, controls over the abstraction of water might need to be applied to surface water bodies otherwise not subject to classification as water body "types" on account of their size.

6.4 The WFD and interface with the Nitrates Directive and the Floods Directive

Before considering EU general environmental legislation relevant to the WFD, it is useful to first consider two other EU Directives which have a significant relevance to the attainment of WFD objectives. The first of these is the Nitrates Directive (91/676/EEC) and the second is the Floods Directive (2007/60/EC).

Nitrates Directive

Council Directive 91/676/EEC on *the protection of waters against pollution caused by nitrates from agricultural sources* (the Nitrates Directive) was adopted in December 1991, coming into force in December 1993. The aims of the Directive are to reduce water pollution caused or induced by nitrates (defined as any non-gaseous nitrogen-containing substance) from agricultural sources and to prevent any further pollution from this source. "Pollution" is defined as the discharge, direct or indirect, of nitrogen from agricultural sources into the aquatic environment, which may cause harm to human health, living resources and to aquatic ecosystems or cause harm to amenities or constitute interference with other legitimate uses of water. The Directive requires measures to be taken with respect to the storage and application on land of all nitrogen compounds and the adoption of certain land management practices relating to same:

i. Article 3(1) of the Directive requires waters affected by pollution and waters at risk, if actions are not taken, to be identified by the Member State concerned, having regard to the criteria set out in Annex 1 to the Directive;

ii. Article 3(2) requires Member States to designate as "vulnerable zones" all known areas of land in the state which drain into the waters identified pursuant to Article 3(1) and which contribute to pollution; and

iii. Member States are required under Article 5 of the Directive to establish action programmes in respect of the vulnerable zones designated by them with a view to preventing or solving the water pollution caused by nitrates from agriculture.

Article (5) (4) of the Nitrates Directive sets out the content of 'Nitrate Action Programmes' (NAPs):

[19] Ireland's river basin management is based on a single national river basin district

[5(4)] Action programmes shall be implemented within four years of their establishment and shall consist of the following mandatory measures:

(a) the measures in Annex III; and

(b) those measures which Member States have prescribed in the code(s) of good agricultural practice established in accordance with Article 4, except those which have been superseded by the measures in Annex III.

Annex III sets out the measures that must be taken, including rules adopted:

ANNEX III

MEASURES TO BE INCLUDED IN ACTION PROGRAMMES AS REFERRED TO IN ARTICLE 5 (4) (a)

[1]...

periods when the land application of certain types of fertilizer is prohibited;

the capacity of storage vessels for livestock manure; this capacity must exceed that required for storage throughout the longest period during which land application in the vulnerable zone is prohibited …limitation of the land application of fertilizers, consistent with good agricultural practice and taking into account the characteristics of the vulnerable zone concerned, in particular: (a) soil conditions, soil type and slope; (b) climatic conditions, rainfall and irrigation; (c) land use and agricultural practices, including crop rotation systems….

The Annex envisages that these measures will ensure that the amount of livestock manure applied to the land each year, including by the animals themselves, does not exceed 170 kg nitrogen (N) per hectare, with the possibility of derogation to allow a higher amount (initially, up to 210 kg N per hectare, but no limit after the first four years of the action programme) subject to notification to the Commission and a review of justification in accordance with Article 9(2) of the Directive.

Ireland, along with Denmark and the Netherlands has enjoyed a derogation from the general 170 kg N ha limit. In Ireland, individual farmers are allowed higher livestock stocking rates (and hence production of nitrogen) provided certain conditions are fulfilled, relating to the type of farm (at least 80% grassland), its use for grazing livestock, and possession of sufficient storage for all livestock manure, soiled water and silage effluent. Famers must participate in an environmental training course and adhere to conditions relating to nutrient management, soil testing and management, manure and slurry spreading, grassland management and biodiversity. Eligible farmers were allowed up to 250 kg N per hectare on so-called “derogation farms.” In line with the European Commission Implementing Decision (EU) 2022/696 granting the derogation, Ireland was required to undertake a two-year review of water quality in 2023. Following the unfavourable results of that review, Ireland’s nitrates derogation limit was reduced to 220 kg N /ha from January 2024 in certain “at risk” areas.

Originally, in implementing the Directive, Ireland, rather than designating vulnerable zones, opted instead, under Article 5, to apply its action programme throughout the “national territory”. Ireland also opted to include both nitrogen and phosphorus control measures within the scope of regulation, one of the few EU Member States to do so. The first Nitrates Action Programme commenced in 2006 under the *European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2005* (S.I. 788 of 2005) which set out the periods when application of fertiliser to lands is prohibited, established limits on the amount of fertiliser that

may be applied to land, provided for the storage requirements applicable to livestock manure and set out provisions for the monitoring of the effectiveness of the measures in terms of agricultural practice and the impact on water quality.

Successive Nitrate Action Programmes (2010, 2013 and 2017) and regulations to give effect to the accompanying programme of measures have followed the first Nitrates Action Programme, culminating in the most recent expression – the Sixth Nitrates Action Programme– which followed a European Commission decision of 22 December, 2025 (C(2025) 9263 final) and regulations implementing that decision, the *European Union (Good Agricultural Practice for Protection of Waters) Regulations, 2025* (S.I.588 of 2025) ("GAP Regulations") [20]. This Nitrates Action Programme acknowledges that just over half (52%) of Ireland's monitored surface water bodies have satisfactory water quality, representing a decline from the previous assessment (2016-2021) when 54% were satisfactory. Coastal waters had the highest percentage of waters in high or good ecological status (82%) followed by lakes (68%), rivers (48%) and transitional waters (30%), which have the worst water quality.

The EPA Report on Water Quality in Ireland (2019-2024) which provides the scientific information underpinning the Nitrates Action Programme notes "Similar to 2016-2021, only 42% of our 334 high status objective river water bodies are achieving their target status. Nitrogen concentrations in the east and southeast have shown reductions in the most recent period, 2019 2024; however, many of our rivers still have concentrations that are too high. High phosphate concentrations continue in many rivers in parts of the east, northeast, southwest and southeast of the country. Despite the recent improvements in nitrate, these excess concentrations of nutrients, coupled with physical habitat damage, are harming the ecology of our rivers.

The key issues identified include:(1) run-off of nutrients, sediment and pesticides from agricultural lands and farmyards; (2) activities such as land drainage, navigational dredging and the presence of barriers such as dams, weirs or culverts in water courses; (3) discharges of poorly treated sewage from urban wastewater treatment plants, domestic treatment systems and storm water overflows; (4) run-off from hard surfaces in urban environments of sediment and contaminant loaded water; and (5)_run-off of nutrients and sediment from forestry operations. The most widespread issue is elevated nutrient concentrations (nitrogen and phosphorus) in a significant proportion of water bodies and the continuous and sustained decline in water quality.

Consequently, as well as strengthening existing provisions within the Good Agricultural Practice (GAP) Regulations, the Sixth Nitrates Action Programme introduces new measures relating to: (1) farm-level nutrient balancing; (2) rules for nutrient spreading and better distribution of manure and fertilisers; (3) increased farm storage capacity requirements, improved record-keeping and tracking of organic manure movement; (4) adjusted chemical nitrogen allowances and application timing rules; (5) farming for Water and Agricultural Catchments Programmes; and (6) advisory and training support through an expansion of the Agricultural Sustainability Support and Advisory Programme and enhanced inspection focus under the EPA National Agricultural Inspection Programme. In respect of the latter, the 3rd River Basin Management Plan (Water Action Plan, 2024) envisages strengthened local authority inspection and enforcement relating to agricultural diffuse pollution.

[20] In a case (C-576/22: European Commission v. Kingdom of Spain (2024)), the CJEU found that Spain had inadequately reviewed and designated nitrate vulnerable zones or implemented necessary measures to combat nitrate pollution, as required.

Article 11(1) of the WFD requires that "Each Member State shall ensure the establishment for each river basin district…of a programme of measures, taking account of the results of the analyses required under Article 5, in order to achieve the objectives established under Article 4." Article 11(2) specifies that the programme of measures shall include basic measures and, where required, supplementary measures. Article 11(3) sets out that "basic" measures shall consist of:

[11(3)] (a) Those measures required to implement Community legislation for the protection of water, including measures required under the legislation specified in Article 10 and in part A of Annex VI;

The Nitrates Directive is specified both in Article 10 and in Part A of Annex VI to the WFD as being within the scope of the programme of measures to be taken. The third cycle RBMP (page 63) notes the development of the (Fifth) Nitrates Action Programme, including the revisions to the GAP Regulations, and the various additional measures to be taken outside the scope of the GAP Regulations, including tighter controls on nitrogen and phosphorus inputs by farmers and enhanced enforcement.

Following Weser, it seems clear that Member States must decline to authorise an individual project where it might cause a deterioration of the status of a surface water body or where it risks the attainment of good surface water status or, good ecological potential. In that case, the CJEU clarified that:

> *"31*. It should be noted that… the wording of Article 4(1)(a)(i) of Directive 2000/60, which provides that 'Member States shall implement the necessary measures to prevent deterioration of the status of all bodies of surface water', attests to the binding force of that provision. The words 'shall implement' involve an obligation on the Member States to act to that effect;
>
> 32. It is necessary, as the referring court has done, to construe authorisation of an individual project as such implementation; and
>
> 33. Furthermore, as provided in Article 4(1)(a) of Directive 2000/60, it is '[i]n making operational the programmes of measures specified in the … management plans' that the Member States adopt the measures necessary in order to achieve the objectives of preventing deterioration of the status of bodies of surface water and protecting and enhancing their status. The use of the words '[i]n making operational' supports an interpretation of that provision to the effect that it entails obligations which must be complied with by the competent authorities when approving individual projects in the context of the legal regime governing the protection of waters."

….

[and]:

> "51. In the light of all the foregoing considerations, the answer to the first and fourth questions is that Article 4(1)(a)(i) to (iii) of Directive 2000/60 must be interpreted as meaning that the Member States are required — unless a derogation is granted — to refuse authorisation for an individual project where it may cause a deterioration of the status of a body of surface water or where it jeopardises the attainment of good surface water status or of good ecological potential and good surface water chemical status by the date laid down by the directive."

It is relevant to note here that Article 4(7) of the WFD only permits derogations in respect of *new* modifications to the physical characteristics of a surface water body or as the result of

new sustainable human development activities, provided certain strict conditions are met. The Article does not apply to modifications to water bodies arising from other causes such as wastewater or other chemical sources, such as nitrates.

At this juncture, it seems there is a very real question as to whether the Sixth Nitrates Action Programme could, let alone should, be adopted in the light of the Weser ruling: can it be established that the Action Programme will not cause a deterioration in the status of individual water bodies or that it would not jeopardise the attainment of good surface water status or of good ecological potential by 2027?

In 2022, An Taisce launched proceedings to judicially review the then Fifth Nitrates Action Programme, with judgment delivered in July 2024[21]. Following that judgement, nine questions were the subject of a preliminary reference to the CJEU[22]. Broadly, the questions concern the Nitrates Directive and its interplay with other Directives – the Habitats Directive, the Water Framework Directive and the Strategic Environmental Directive as well as fundamental EU legal principles.

In broad terms, paraphrasing and summarising the lengthy questions referred, these concern the following issues

1. Whether the Nitrates Action Programme should be assessed in respect of the farming activities that would be permitted via derogations under its aegis, and not just from the perspective of the protective measures it contains?
2. If question (1) is answered negatively, what are the implications in situations like Ireland's where farming activities are carried out under individual farm derogations not assessed under EU environmental law?
3. Whether the Nitrates Action Programme must be assessed and demonstrate that it, along and/or with other environmental rules, will not cause deterioration in the status of a water body or jeopardise the attainment of the relevant water quality status? deterioration in water quality?
4. If it is established that the NAP is required to be assessed in accordance with Article 4 of the WFD and that the NAP is be assessed in respect of the farming activities permitted under its derogations, does this mean that a Member State must refuse to adopt a NAP where it cannot be assured that the permitted farming activities would not worsen water quality or jeopardise the attainment of good status for surface waters?
5. If the answer to questions 3 and 4 is "no" (the NAP does not have to be assessed in respect of its impact on water), does this hold in situations like Ireland's where individual farm derogations are not assessed with respect to their impact on water quality?
6. Whether the authorities before adopting a NAP must satisfy themselves that the NAP would not cause a deterioration in the status of any surface water body type or compromise the attainment of good surface water status or good ecological potential and good chemical status for that water body and that the NAP is compatible with the programme of measures adopted for the River Basin District concerned?
7. Does the SEA environmental report on the NAP have to include specific detailed information on the monitoring programme to be deployed to show that it meets the

[21] [2024] IEHC 472

[22] Case C-531/24, An Taisce

monitoring requirements of Article 10 of the SEA Directive and how any identified unforeseen adverse environmental effects will be addressed?

8. Whether, in assessing a NAP's environmental effects on material assets, for the purposes of the SEA Directive, consideration may be given to the value of such assets, the societal impacts of agricultural activities, the impact of the NAP on the agriculture sector and issues such as farmers' income, farm output, the sustainability of the agriculture industry in the Member State concerned, the food supply chain, employment in the sector or is the consideration of such issues precluded by the Directive?
9. Finally, if the answers to any of the preceding questions is negative, does this mean that the European Commission's decision approving Ireland's nitrates derogation is invalid?

Following this referral, additional questions were submitted to the European Court of Justice [23], regarding the consideration of material assets and the weighting to be accorded to this factor under the SEA Directive. The Court was asked to determine whether, where the assessment identifies an option with the least adverse environmental effects, that option must be selected, and whether the process of assessment requires that alternatives be identified, described and evaluated on a comparable basis.

Judgment in this case is awaited, which may be of considerable significance. In the Commission decision to grant Ireland a further derogation under the Nitrates Directive until the end of 2028, the Commission noted that "it may be appropriate for the conditions set out in this Decision to be reviewed following the preliminary ruling of the CJEU in that case."

Floods Directive and WFD

The Floods Directive (FD) applies to all types of floods (river, lake, flash floods, urban and coastal floods) occurring within the territory of the EU. Article 4 of the Directive requires that all Member States undertake a preliminary flood risk assessment by 2011 of all river basins and coastal zones to identify areas at risk of significant flooding. Where a real risk of flooding is identified, then flood hazard maps and flood risk maps of the affected areas were required to be prepared, under Article 6, showing the event likelihood of flooding (1- in-a-100 years) and more extreme events, showing the expected water depth if such an eventuality occurred. By 2015, Article 7 required that catchment-based flood risk management plans (FRMPs) be prepared for these at-risk zones, setting out the measures that would be taken to reduce the probability of flooding and to mitigate the consequences of flooding, should it occur. This timetable harmonises with the six-yearly cycle used by the WFD for river basin management plans, bringing the end of the first FRMP cycle into alignment with the second phase of the RBMP.

The Floods Directive emphasises:

(i) prevention of damage by ensuring that houses and development would not be constructed in flood-prone area or by adapting future developments to meet the risk of flooding;

[23] Case C-895/24, An Taisce II

(ii) protection by reducing the likelihood of flooding or its impact, should it occur, through the restoration of wetlands and floodplains, and,

(iii) preparedness or mitigation, ensuring that the public were informed as to what to do should flooding occur.

In implementing the Directive, Member States were encouraged to make use of the RBMPs and the governance structures adopted in respect of same under the WFD, although Member States were free, under Article 3 of the Floods Directive, to designate different authorities for the purposes of that Directive should they so wish.

While the Floods Directive is generally mindful of the need to coordinate its provisions with WFD, this is done with varying degrees of explicitness. Recital 17 of the Floods Directive states that: "The two processes should therefore use the mutual potential for common synergies and benefits, having regard to the environmental objectives of the WFD, ensuring efficiency and wise use of resources while recognising that the competent authorities and management units might be different under the Floods Directive and WFD." Article 9 of the Floods Directive requires that Member States shall take appropriate steps to coordinate the implementation of the Floods Directive and WFD, concentrating on the information provided under the WFD and the flood maps required under the Floods Directive so as to ensure consistent use of information; the development and review of RBMPs and FRMPs; and the coordination of required stakeholder involvement so as to achieve synergies and benefits with respect to the environmental objectives established by the WFD.

Article 7 of the Floods Directive deals with the flood risk management plans to be prepared. These are generally required to be coordinated at the level of the River Basin District for the at-risk areas, matching the emphasis on the River Basin District in the WFD. Article 7 (2) of the FD requires that, if considered appropriate, objectives for the management of flood risks in at-risk areas should focus on "non-structural initiatives and/or on the reduction of the likelihood of flooding." Article 7(3) provides that:

> [7] 3. Flood risk management plans shall include measures for achieving the objectives established in accordance with paragraph 2 and shall include the components set out in Part A of the Annex.
>
> Flood risk management plans shall take into account relevant aspects such as costs and benefits, flood extent and flood conveyance routes and areas which have the potential to retain flood water, such as natural floodplains, the environmental objectives of Article 4 of Directive 2000/60/EC, soil and water management, spatial planning, land use, nature conservation, navigation and port infrastructure.
>
> Flood risk management plans shall address all aspects of flood risk management focusing on prevention, protection, and preparedness, including flood forecasts and early warning systems and taking into account the characteristics of the particular river basin or sub-basin. Flood risk management plans may also include the promotion of sustainable land use practices, improvement of water retention as well as the controlled flooding of certain areas in the case of a flood event.

The language used in the text of the Floods Directive is largely prescriptive, albeit leaving some residual discretion to authorities in its implementation. It is clear that in drawing up FRMPs, the responsible authorities are required to take into account matters such as "…areas which have the potential to retain flood water, such as natural floodplains", as well as promoting "sustainable land use practices, improvement of water retention as well as the

controlled flooding of certain areas in the event of flood." A failure to give consideration to such matters would seem in breach of the Floods Directive. Having given due consideration to such matters, however, there is no requirement that the attendant measures identified, such as natural floodplains, be implemented in practice. In other words, an authority must consider alternatives to (for example) flood walls but is under no obligation to adopt the alternatives identified.

An exclusive (or over) reliance on traditional 'hard' engineering approaches to flood management appears to be precluded by the firm wording of the Directive, which, at a minimum, requires that authorities take so-called "soft" engineering measures such as "natural floodplains" and "controlled flooding of certain areas in the case of a flood event", into account when preparing flood management plans.

The total absence of such measures from an initial evaluation or assessment of potential options would seem to run *contra* to the Floods Directive, unless it was very clearly and appropriately demonstrated that the scale, nature or urgency of the flooding problem being addressed was such as to exclude "soft" measure from consideration from the outset. Note also that FRMPs are explicitly required to take into account the environmental objectives of Article 4 of the WFD in their framing, thus excluding an over-focus on serving the requirements of the Floods Directive at the expense of the objectives for water bodies established by the WFD.

Further support for a more considered, holistic, approach to potential flood management measures may also be found in the Annex to the Floods Directive which requires that flood risk management plans address a number of components, including the WFD:

> ANNEX A
>
> Flood risk management plans
>
> I. Components of the first flood risk management plans:
>
> [4]… a summary of the measures and their prioritisation aiming to achieve the appropriate objectives of flood risk management, including the measures taken in accordance with Article 7, and flood-related measures taken under other Community acts, including the measures taken in accordance with Article 7, and flood-related measures taken under other Community acts, including ….and Directive 2000/60/EC;
>
> …
>
> Derogations in the case of potential conflict between Floods Directive and WFD and more generally

There is an obvious potential conflict between the requirements of the Floods Directive and the WFD which invoke consideration of Article 4(7) of the WFD and the grounds under which the provisions of the WFD may be derogated from generally, including with respect to flood relief works. For example, take potential measures to alleviate possible flooding in the affected area of a river. It is assumed, in our example, that the use of 'soft' measures such as 'making room' for the river and increasing its natural storage and retention capacity by re-connecting it to its historic floodplain is precluded by practical considerations - the natural floodplain may have been extensively developed, and it would be unfeasible to abandon that development. The flood risk management objective may therefore require new infrastructure – in the form of a new or heightened river embankment or deeper drainage channel- to mitigate the flooding risk.

Article 4(7) of the WFD would allow such an infrastructure measure to be taken, provided the various conditions set out in that article are each fulfilled, namely:

> Member States will not be in breach of this Directive when:
>
> — failure to achieve good groundwater status, good ecological status or, where relevant, good ecological potential or to prevent deterioration in the status of a body of surface water or groundwater is the result of new modifications to the physical characteristics of a surface water body or alterations to the level of bodies of groundwater, or
>
> — failure to prevent deterioration from high status to good status of a body of surface water is the result of new sustainable human development activities
>
> and all the following conditions are met:
>
> (a) all practicable steps are taken to mitigate the adverse impact on the status of the body of water;
> (b) the reasons for those modifications or alterations are specifically set out and explained in the river basin management plan required under Article 13 and the objectives are reviewed every six years;
> (c) the reasons for those modifications or alterations are of overriding public interest and/or the benefits to the environment and to society of achieving the objectives set out in paragraph 1 are outweighed by the benefits of the new modifications or alterations to human health, to the maintenance of human safety or to sustainable development, and
> (d) the beneficial objectives served by those modifications or alterations of the water body cannot for reasons of technical feasibility or disproportionate cost be achieved by other means, which are a significantly better environmental option.

Note that the derogation procedure clearly envisages a careful and thorough assessment of the various interests involved – the attainment of the WFD's objectives compared with the use of the water body concerned that will be served by the proposed modifications to the water body. Here, "new *modifications to the physical characteristics of water bodies*" is interpreted as meaning modifications to their hydromorphological characteristics. No definition is provided of "sustainable human development activities" but such definition is to be guided by reference to relevant EU legislation including the WFD, Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) Directives, Aarhus Convention and the EU Treaty itself[24]. Nor is a definition of "overriding public interest" given, but this expression is used elsewhere in EU legislation, notably the Habitats Directive, where it was interpreted by the CJEU (in Case C-182/10 – Solvay v. Région Wallone) to mean:

> .....
>
> 75. An interest capable of justifying, within the meaning of Article 6(4) of the Habitats Directive, the implementation of a plan or project must be both 'public' and 'overriding', which means that it must be of such an importance that it can be weighed up against that directive's objective of the conservation of natural habitats and wild fauna and flora.
>
> 76. Works intended for the location or expansion of an undertaking satisfy those conditions only in exceptional circumstances

[24] *Common implementation strategy for the Water Framework Directive 2000/60/EC)* - Guidance Document on exemptions to the environmental objectives, Technical Report 2009-027, European Commission, 2009

6.5 Environmental assessments and WFD

Certain environmental assessments may be required in accordance with various EU Directives, including the Birds Directive (79/409/EEC, codified as Directive 2009/147/EC), the Habitats Directive (92/43/EEC), the Strategic Environmental Assessment Directive (2001/42/EC), the Environmental Impact Assessment Directive (2011/92/EU, as amended by Directive 2014/52/EU). While these Directives require reports to cover the expected environmental impact of a proposal, and while water is, in most instances, a relevant consideration for such reports, there is not a specific focus on the objectives of the WFD.

6.5.1 Birds and Habitats Directives

The earliest piece of European legislation relating to the environment came with the introduction of the Birds Directive in 1979 which aims to protect wild birds and their most important habitats throughout Europe. Member States are required to implement Special Protection Areas for certain designated avian species.

The Habitats Directive adopted in 1992 extends protection to certain types of habitats called Special Areas of Conservation designated by Member States in accordance with the Directive. Around 230 different types of habitat are listed, including acid oligotrophic lakes, turloughs, petrifying springs, and various river types, along with certain species of endangered flora and fauna. Together, the two Directives aim to create a network of sites (Natura 2000) benefitting from the strict protection measures of the Directives so that the habitats and species protected reach a favourable conservation status across the EU. For each Natura 2000 site, Member States are required to adopt the necessary conservation measures to promote this objective, which may entail active management and restoration, as well as measures aimed at preventing deterioration or reducing or mitigating harmful effects from proposed projects. The Directives, however, are not confined to protection of species in a designated site: the Directives are also concerned with sites outside Natura 2000 and require a system of strict protection to be maintained in respect of activities such as killing, capture or destruction of protected species of fauna and flora. Certain derogations from this strict protection are permitted under certain specific conditions. Article 6(3) of the Directive specifies that:

> [6(3)] Any plan or project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives. In the light of the conclusions of the assessment of the implications for the site and subject to the provisions of paragraph 4, the competent national authorities shall agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the site concerned and, if appropriate, after having obtained the opinion of the general public.

Article 6(4) of the Directive provides that if the project receives a negative assessment, it may nonetheless still be carried out under strict conditions. These conditions are that the project concerned must have “an overriding public interest”, that all compensatory measures necessary to ensure the coherence of Natura 2000 have been carried out and that the European Commission is informed of the measures adopted.

The requirements of these Directives are implemented by the European Communities (Birds and Natural Habitats) Regulations, 2011 (as amended), replacing earlier implementing instruments. Further complementary measures are taken in the PDA, 2000. Local authorities

and An Board Pleanála are now required to ensure that the requirements of the Birds and Habitats Directives are adhered to in the adoption of development plans and the granting of development consents, echoing the obligation on public authorities under Regulation 3 of the Water Policy Regulations 2003, implementing the WFD, to exercise their "…functions in a manner which is consistent with the provisions of the Directive and which achieves or promotes compliance with the requirements of the Directive."

Part V of the 2011 Birds and Habitats Regulations 2011 sets out the screening to be done in respect of an Appropriate Assessment of a plan or project for which an application for consent is received, or which a public authority wishes to undertake or adopt, and which is not directly connected with or necessary to the management of the site as a European Site. If, following the screening, it is decided that an Appropriate Assessment is required, this must be carried out in accordance with Article 6(3) of the Habitats Directive.

The Habitats Directive has perhaps the mostly easily understood framework for assessment of the various environmental Directives, following the significant ruling in Kelly v An Bord Pleanála [2014] IEHC 400. This was a Judicial Review of a decision by An Bord Pleanála giving permission for the construction of a windfarm at a site in Co. Roscommon. Finlay Geoghegan J determined that the Bord had failed to carry out a proper Appropriate Assessment in accordance with Article 6(3) of the Habitats Directive and section s.177 V(1) of the PDA, 2000, and furthermore, had failed to give reasons for its determination. The court held that, where an Appropriate Assessment was required to be carried out after a prior screening assessment had determined (or implicitly accepted) the development concerned meets the threshold of being considered likely to have significant effects on a European site, then the Appropriate Assessment:

> 40.(i) Must identify, in the light of the best scientific knowledge in the field, all aspects of the development project which can, by itself or in combination with other plans or projects, affect the European site in the light of its conservation objectives. This clearly requires both examination and analysis.
>
> (ii) Must contain complete, precise and definitive findings and conclusions and may not have lacunae or gaps. The requirement for precise and definitive findings and conclusions appears to require analysis, evaluation and decisions. Further, the reference to findings and conclusions in a scientific context requires both findings following analysis and conclusions following an evaluation each in the light of the best scientific knowledge in the field.
>
> (iii) May only include a determination that the proposed development will not adversely affect the integrity of any relevant European site where upon the basis of complete, precise and definitive findings and conclusions made the Board decides that no reasonable scientific doubt remains as to the absence of the identified potential effects.

A particularised prescription like this, if applied to assessments of water bodies, would ensure that these would be carried out with the appropriate degree of rigour, comprehensiveness and degree of scientific certainty mandated by the WFD. The relative complexity of the WFD, dealing as it does with several different types of water body and attendant detailed technical specifications and conditions, however, perhaps masks, or, at the very least, confuses the practical steps to be taken in implementing its requirements.

It seems clear following Weser, however, that the obligation of non-deterioration and the obligation to enhance are susceptible to assessment in accordance with the relevant

provisions of the WFD (see paragraph 16), although the carrying out of that assessment may be complex. Annex V of the WFD gives an objective, scientific basis for the classification of the status of a particular type of water body and a means to gauge whether deterioration or an improvement in the status of a water body has occurred or will eventuate from a proposal.

Moreover, the various provisions of the WFD are complemented by detailed technical guidance documents (38 at the present time) produced under the auspices of the European Commission, guidance that may be formally adopted in accordance with Article 21(2) of the WFD.

While the WFD is not overly prescriptive as to the format of assessment reports or the individual process steps which must be observed, this does not, in any way, absolve the relevant parties from responsibility for devising an appropriate assessment process that ensures that proper assessments are made of the various quality elements in a water body, that the results of these are made available at the required time, with robust conclusions reached on the overall ecological status of a particular water body and how it may be affected by the particular proposal under consideration, using the technical specifications and classification matrices laid out in the Directive and domestic implementing regulations. A failure by the responsible public authorities to implement an appropriately rigorous scientific assessment based on the WFD provisions and parameters would, it is suggested, in a suitable case, likely expose the responsible authorities to successful legal challenge over the adequacy and robustness of assessments carried out for the purposes of the WFD.

6.5.2 Conflicts between the Habitats Directive and WFD

A question arises as to how instances of conflict between the Habitats Directive and the Water Framework Directive should be resolved. Neither Directive is accorded supremacy over the other. How might an objective of the WFD (restoration of a water body) be reconciled with a possibly conflicting objective under the Habitats Directive, in relation to the same water body, which might seek the preservation of the water body in its current form, for reasons of conservation? Thus, a proposal to remove an embankment or dam allowing a river to run its natural course, which would be viewed as laudable from a WFD perspective, might be viewed as a dis-improvement from a Habitats Directive perspective, where this would disrupt a Natura 2000 habitat created or supported by that embankment or dam.

The means by which this conflict may be managed is the assessment prescribed in Articles 6(3) and 6(4) of the Habitats Directive. Article 6(3) provides that any project not directly connected with or necessary to the management of a Natura 2000 site be subjected to an appropriate assessment of the proposed works (in this case, the removal of an embankment or dam) in view of the site's conservation objectives under the Habitats Directive. That assessment, in a particular case, might conclude that the proposed removal would have negative implications for the site, for which alternative solutions could not be found. Nonetheless, the removal of the obstruction in that particular water body might still be approved for "imperative reasons of overriding public interest" – the achievement of the objectives of Article 4 of the WFD in respect of that water body – trumping in that instance the conservation objective for the Natura 2000 site. The Member State would be obliged, however, in accordance with Article 6(4) of the Habitats Directive to take all available compensatory measures to ensure that the overall coherence of Natura 2000 is protected, having advised the European Commission of those measures.

6.5.3 The Strategic Environmental Assessment Directive (SEA)

The Strategic Environmental Assessment Directive (2001/42/EC) applies to a range of public (but not private) programmes and plans in areas such as transport, energy, waste, land use, and agriculture that set the framework for future development consents. Not all public plans and programmes are subject to SEA but only those which are likely to have significant environmental effects, prepared or adopted by a competent authority (local, regional, or national) through a legislative, regulatory, or administrative procedure. This would, for example, cover land use plans, setting out how land is to be developed or the types of future development that would be permissible, waste management plans and the like.

The SEA Directive's primary objective is to ensure a holistic and early appraisal of the effects of certain plans and programmes on the environment. By taking account of environmental effects of a broad range of plans and programmes, while these are being developed, would avoid the pitfall of inadvertently creating a permissioning framework for future development that did not adequately engage with environmental considerations until individual projects arose for assessment. The required strategic environmental assessment must be carried out during the preparation of the particular plan or programme and in advance of its adoption or submission to the applicable legislative procedure.

The SEA was implemented in Ireland by the European Communities (Environmental Assessment of Certain Plans and Programmes) Regulations 2004 (S.I. 435 of 2004) (as amended) which transposed the Directive generally into Irish law, except in respect of land use planning, which was done by further regulations – the *Planning and Development (Strategic Environmental Assessment) Regulations, 2004* (SI. 436 of 2004). The 2004 regulations were modified by the *Planning and Development (Strategic Environmental Assessment (Amendment) Regulations, 2011* which reduced certain of the thresholds triggering its application and clarified aspects of the screening and assessment process.

A SEA[25] is not required in all instances, but only where:

> 3 (1)… the plans or programmes are likely to have significant environmental effects,
>
> or
>
> 3 (2) (a)…which are prepared for agriculture, forestry, fisheries, energy, industry, transport, waste management, water management, telecommunications, tourism, town and country planning or land use and which set the framework for future development consent of projects listed in Annexes I and II to Directive 85/337/EEC, or
>
> (b) which, in view of the likely effect on sites, have been determined to require an assessment pursuant to Article 6 or 7 of Directive 92/43/EEC

Under the Planning and Development (SEA) Regulations, 2004 a strategic environmental assessment is obligatory in respect of the following plans:

i. Regional Planning Guidelines
ii. (Town and Country) Development Plans with a population of 10,000 or greater
iii. Local Area Plans with a population of 5,000 or greater
iv. Planning Schemes for Strategic Development Zones

[25] The Planning and Development Act, 2024 and the SEA Regulations integrate SEA in the development plan-making process.

Screening is required in respect of variations to Development Plans (of any size) or amendments to Local Area Plans (of any size) and for adoption of Development Plans with an affected population of less than 10,000, or a Local Area Plan, with less than 5,000 of population. For other plans and programmes governed by the general Regulations (S.I. 435 of 2004) a case-by-case approach is adopted, with the relevant authority required to assess, using the criteria listed in Schedule 1 to those Regulations, whether a plan or programme or modification to a plan or programme, would or would not be likely to have significant effects on the environment.

Where a programme or plan is subject to SEA, then the required environmental assessment must be carried out prior to the preparation or adoption of the programme or plan concerned, setting out the information specified in Annex 1 to the SEA Directive. That Annex covers the following matters:

(a) an outline of the contents, main objectives of the plan or programme and relationship with other relevant plans and programmes;
(b) the relevant aspects of the current state of the environment and the likely evolution thereof without implementation of the plan or programme;
(c) the environmental characteristics of areas likely to be significantly affected.
(d) any existing environmental problems which are relevant to the plan or programme including, in particular, those relating to any areas of a particular environmental importance, such as areas designated pursuant to Directives 79/409/EEC and 92/43/EEC;
(e) the environmental protection objectives, established at international, Community or Member State level, which are relevant to the plan or programme and the way those objectives and any environmental considerations have been taken into account during its preparation;
(f) the likely significant effects (1) on the environment, including on issues such as biodiversity, population, human health, fauna, flora, soil, water, air, climatic factors, material assets, cultural heritage including architectural and archaeological heritage, landscape and the interrelationship between the above factors;
(g) the measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the plan or programme;
(h) an outline of the reasons for selecting the alternatives dealt with, and a description of how the assessment was undertaken including any difficulties (such as technical deficiencies or lack of know-how) encountered in compiling the required information;
(i) a description of the measures envisaged concerning monitoring in accordance with Article 10; and
(j) a non-technical summary of the information provided under the above headings.

The SEA report, prepared in accordance with these provisions, along with any opinions expressed during the required meaningful public consultation phase must, in accordance with Article 8 of the Directive, be taken into account during the preparation of the plan or programme and before its adoption or submission to the relevant legislative procedure. It is important to note that the latter is a comparatively light requirement – all that is required is to demonstrate an awareness of the SEA report - meaning that consideration must be given to the findings of the report during the preparation of the plan or programme, but the SEA's conclusions do not have to be followed or endorsed in the plan or programme adopted.

When the plan or programme is adopted, under Article 9 of the Directive, statutory consultees and members of the public who have made submissions during the public consultation

process, must be advised that the plan or programme has been adopted and be given a statement describing how environmental considerations were taken account of in the framing of the plan or programme, the reasons for adoption of the plan or programme, in the light of the reasonable alternatives to same, and how account was taken of the consultation process in the decision-making process for the plan or programme adopted.

Finally, following adoption of the plan or programme, Member States are required (under Article 10(1) of the SEA) to monitor the significant environmental effects of implementation of the plan or programme in order to identify, in early course, unforeseen adverse effects so that remedial action may be undertaken.

6.5.4 Environmental Impact Assessment Directive

The Environmental Impact Assessment Directive (85/337/EEC) was adopted in 1985, and, following several amendments, was replaced with a codified Directive (2011/92/EU) in 2011. This Directive was further amended by Directive 2014/52/EU. The EIA Directive is transposed in Ireland by Part X of the Planning and Development Act, 2000 and the *European Union (Planning and Development) (Environmental Impact Assessment) Regulation 2018 (S.I. No. 296 of 2018*), implementing the 2014 Directive. Part 6 of the Planning and Development Act, 2024 introduces a replacement EIA framework. Chapters 1 and 2 of Part 6, covering preliminary matters and the Appropriate Assessment of certain plans[26], were brought into operation on 2 October 2025. The remainder of Part 6 has not yet been commenced. Pending full commencement, Part X of the 2000 Act and the 2018 Regulations continue to apply for EIA requirements for projects and plans not covered by the earlier commencement order.

In brief, the EIA Directive requires that public or private projects that are likely to have a significant effect on the environment must first be subject to an assessment of possible environmental effects at design phase, through the preparation of an Environmental Impact Assessment Report (EIAR) by competent experts. The EIAR is submitted for consideration to the competent authority, which, following the required public consultative process and the gathering of additional information by the authority (the process known as EIA), decides whether to grant development consent.

The findings of the EIA process, unlike those of an Appropriate Assessment under the Habitats Directive, are not determinative and are not binding in and of themselves, unlike the mitigation measures that may be required under the Habitats Directive. Instead, “account” must be taken of the conclusions. The EIA Directive does not automatically require all projects to have an EIAR, but only those that are referenced in Article 4(1) and Annexes 1 and II to that Directive. Member States are given the discretion to specify whether certain projects listed in Annex II of the Directive should also be made subject to an assessment, either on a case-by-case basis, or by prescribing certain ‘trigger’ thresholds in relevant legislation. Note though that projects which do not exceed the thresholds may still require an EIA based on other criteria, such as the size and location of the particular project or the cumulative impact.

In Ireland, Schedule 5 (Part 1) of the Planning and Development Regulations, 2001 sets out the type of development that automatically require an EIAR to be prepared, with Schedule 5

[26] The plans subject to its provisions at the time of writing are those set out in Chapters 1 to 3 of Part 3 of the PDA, 2024 i.e. the National Planning Framework, National Planning Statements and Regional Spatial and Economic Strategies.

(Part 2) setting out the type of developments requiring an EIAR once a relevant threshold has been attained. Examples of the latter type of development relating to water bodies are the requirements to prepare an EIAR where:

Schedule 5 (Part 2)

…

(c) Development consisting of the carrying out of drainage and/or reclamation of wetlands where more than 2 hectares of wetlands would be affected…

….

(f) Seawater fish breeding installations with an output which would exceed 100 tonnes per annum; all fish breeding installations consisting of cage rearing in lakes; all fish breeding installations upstream of drinking water intakes; other freshwater fish breeding installations which would exceed 1 million smolts and with less than 1 cubic metre per second per 1 million smolts low flow diluting water.

Schedule 6 to the 2001 Regulations sets out the matters to be covered in an EIAR which are, of necessity, framed in quite a high-level manner and include such matters as:

> 1. (a) A description of the proposed development comprising information on the site, design, size and other relevant features of the proposed development.
>
> (b) A description of the likely significant effects on the environment of the proposed development.
>
> (c) A description of the features, if any, of the proposed development and the measures, if any, envisaged to avoid, prevent or reduce and, if possible, offset likely significant adverse effects on the environment of the development.
>
> (d) A description of the reasonable alternatives studied by the person or persons who prepared the EIAR, which are relevant to the proposed development and its specific characteristics, and an indication of the main reasons for the option chosen, taking into account the effects of the proposed development on the environment.

with these general requirements being amplified and elaborated in the remainder of Schedule 6.

More information on the contents of an EIAR is set out in detailed 'Guidelines on the information to be contained in Environmental Impact Assessment Reports', EPA (May 2022) prepared by the EPA pursuant to Section 72 of the EPA, Act 1992 (as amended), which make some (but not extensive) reference to hydromorphological matters.

Further obligations to prepare an EIAR arise under the *European Communities (Environmental Impact Assessment) (Agriculture) Regulations, 2011 (as amended)* where certain types of agriculture activity (otherwise exempted) are also made subject to EIA requirements. These activities relate to:

(a) restructuring of rural land holdings;

(b) commencing to use uncultivated land or semi-natural areas for intensive agriculture; or

(c) land drainage works on lands used for agriculture

where certain thresholds set out in Regulation 7 are exceeded. In addition to the exemption of activities under thresholds set in these Regulations, there are general exemptions under the Regulations for other activities, including activities regulated under the Arterial Drainage Acts 1945 to 1995, as amended by the *European Communities (Arterial Drainage) Regulations 2009* or subject to the *Planning and Development (Amendment) (No. 2) Regulations 2011* (dealing, inter alia, with the drainage of wetlands). (See also discussion under 6.3.1, re-development exemptions under the PDR, 2001 for certain drainage/reclamation works).

For those activities for which thresholds are set, these include land where its area or length of field boundary exceeds certain size thresholds set out in Part A of Schedule 1 to the Regulations, or the activity may have a significant effect on the environment or a European site, or the activity may impact adversely on lands subject to a natural heritage order, or where the area of land being drained for agriculture exceeds 15 hectares. In those circumstances, an application must be submitted to the Minister for Agriculture, Food and the Marine for a screening decision. The information to be submitted to the Minister includes:

(a) the name and address of the applicant;
(b) the location of the land, Land Parcel Identification System (LPIS) number assigned by the Minister, townland and county to which the application relates;
(c) the nature and extent of the proposed activity including the anticipated outcomes of the activity and any features or measures to avoid or present significant adverse effects on the environment;
(d) information on the characteristics of the activity and its likely significant effects on the environment, including at a minimum the information specified in Annex IIa to the Directive;
(e) the name and address of the person who will perform the activity; and
(f) such other information as the Minister considers necessary.

Where the Minister considers that the proposed activity is likely to have a significant effect on the environment, the proposed activity may not proceed without consent under the Regulations. (Note that land drainage works on lands used for agriculture above 50 ha automatically require Ministerial consent to be obtained, along with the submission of a mandatory EIAR). In considering whether to grant consent, the Minister has to have regard to the EIAR required to be submitted with the application for consent. The EIAR must cover the following:

….

(c) a description of the main characteristics of the operational phase of the activity (in particular any production process)...;

(d) an estimate, by type and quantity, of expected residues and emissions (such as water, air, soil and subsoil pollution, noise, vibration, light, heat, radiation) and quantities and types of waste produced during the construction and operation phases.

2. A description of the reasonable alternatives…. studied by the applicant, which are relevant to the proposed activity and its specific characteristics, and an indication of the main reasons for selecting the chosen option, including a comparison of the environmental effects.

3. A description of the relevant aspects of the current state of the environment (baseline scenario) and an outline of the likely evolution thereof without implementation of the project as far as natural changes from the baseline scenario can be assessed with

reasonable effort on the basis of the availability of environmental information and scientific knowledge.

4. A description of the factors specified in Regulation 13(8)(b)(ii) likely to be significantly affected by the project:….., water (for example hydromorphological changes, quantity and quality),

5. A description of the likely significant effects of the activity on the environment resulting from, inter alia:

   …

   (b) the use of natural resources, in particular land, soil, water and biodiversity, considering as far as possible the sustainable availability of these resources;

   (c) the emission of pollutants…;

   (d) …

   (e) the cumulation of effects with other existing and approved projects or activities, …;

   (f) …

   (g) the technologies and the substances used. The description of the likely significant effects on the factors specified in Regulation 13(8)(b)(ii) should cover the direct effects and any indirect, secondary, cumulative, transboundary, short-term, medium term and long-term, permanent and temporary, positive and negative effects of the project. This description should take into account the environmental protection objectives established at Union or Member State level which are relevant to the activity.

….

Where, following the screening, it is determined that a project is likely to have a significant effect on a European site (e.g. an SAC, SPA), the application for consent must be accompanied by a Natura Impact Statement (NIS) rather than an EIAR covering the impact of the project individually or in combination with other plans or projects, on the protected site in view of its conservation objectives.

Under Regulation 13, the Minister for Agriculture, Food and the Marine may grant consent, refuse consent or may attach such conditions to a consent as he or she considers necessary.

Earlier (Section 6.3.1), it was noted that the EPA had carried out an exercise which had assigned a status to water bodies then lacking a status under the WFD. Had that not been done, it is doubtful whether a planning authority or *An Bord Pleanála* could lawfully conclude in respect of a relevant application for permission affecting such a water body, that there would be no significant effects on the environment for the purposes of the EIA Directive and/or the exercise mandated by section 172 of the PDA 2000. Permission could only be granted where it could be excluded, on the basis of objective scientific information, that there would not be a deterioration of the status of the water body or the jeopardization of the attainment of good status by that water body.

It seems evident that if a WFD status has not been first determined, such an assessment could not be made and, stemming from this, that any purported EIA determination would be unlawful, and permission could not then be granted. The CJEU in *IL v Land Nord-Rhein Westfallen* Case 535/18. considered, inter alia, a question relating to the timing of information availability to members of the public during the procedure for approval of a 3.7 km length of motorway in

Germany. Certain information relating to the drainage impact of the motorway was made available only by the authorities after approval of the project, when the plaintiffs instituted proceedings. The CJEU found that: ...

> [86] "Therefore, the documents in the file that are made available to the relevant public must make it possible for that public to obtain an accurate impression of the impact that the project at issue will have on the status of the bodies of water concerned in order for it to be able to verify compliance with the obligations arising from, inter alia, Article 4 of Directive 2000/60. In particular, the data provided must be such as to show whether, having regard to the criteria established by that directive, the project at issue is liable to result in a deterioration of a body of water...
>
> [90] In the light of all of the foregoing considerations, the answer to the second question referred must be that:
>
> – Article 4 of Directive 2000/60 must be interpreted as precluding a situation in which it is only after a project has been approved that the competent authority carries out the checks to establish whether the requirements laid down in that framework have been met, including the requirement to prevent deterioration of the status of bodies of water, both surface water and groundwater, which are affected by the project, and
>
> – Article 6 of Directive 2011/92 must be interpreted as meaning that the information to be made available to the public during the procedure for approving a project must include the data that are necessary in order to assess the effects of that project on water, in the light of the criteria and requirements laid down in, inter alia, Article 4(1) of Directive 2000/60."

Clearly, from this ruling, if a WFD status has not been established for a water body subject to classification, and that water body is potentially affected by a project, then an EIAR cannot be conducted as it would not be possible to assess the effect of the project on the water body concerned, there being no baseline against which the effects of a project could be assessed.

Overlap between EIA and WFD

There is potential overlap between the assessments required to be carried out for EIA purposes and those that are carried out in respect of other environmental Directives. This is clearly contemplated by the amended EIA Directive which provides in Article 2(3) for two types of procedure to streamline the environmental assessments respectively required by that Directive and the Birds and Habitats Directives.

The EIA Directive envisages the establishment of either a joint procedure – a single assessment of the environmental impact of a given project - or a coordinated approach, under which a Member State would designate one authority to coordinate the various assessments of a project's environmental impact. While streamlining is mandatory – "where appropriate" - in the case of assessments required by the EIA and Birds and Habitats Directives, it is not obligatory in the case of the WFD. It is up to "…the individual Member States to decide whether to apply it to the EIA Directive and the Water Framework Directive" (Commission guidance document (2016/C 273/01)).

There may be several reasons for this differentiation in approach – not all proposals potentially affecting a water body (and requiring a WFD assessment) need fall with the scope of the projects covered by the EIA's Annex I (automatically requiring an EIA) or Annex II (requiring a determination to be made that an EIA is required based on a case-by-case examination or

exceedance of thresholds). The focus of the WFD assessment is also different – it is primarily concerned with the status of water bodies potentially affected by the relevant proposal, while an assessment from an EIA perspective is broader – it is concerned with the effect of the particular project on a range of factors: (a) population and human health;(b) biodiversity (c) land, soil, water, air and climate; (d) material assets, cultural heritage and the landscape; (e) the interaction between the different factors.

For its part, the WFD provides a very extensive technical and classification methodology required to derive and support the conclusion of impacts or not of a proposal on the status of a water body, a toolkit upon which an EIA assessment must invariably draw in support of its assessment of the impact of a project on, inter alia, water bodies potentially implicated by a EIA relevant project. It seems clear that only an assessment of the relevant parameters using the methodology and classifications set out in the WFD could be used to derive appropriately robust scientific conclusions about the effects of a project on the ecological status or ecological potential of a water body. Thus, where an EIAR incorporates a WFD assessment, then this WFD assessment must adequately address the impacts of a project based on the tests set out at some length in the WFD, alongside an evaluation of the other factors required to be considered by an EIA.

Whatever about their technical content, the WFD assessment and EIA assessments also differ as respects the nature of the outcome of the particular assessment. Following Weser, it is clear that Member States are obliged to refuse authorisation for an individual project where it may cause deterioration in the status of a body of surface water or where it jeopardises the attainment of good surface water status. In contrast, the relevant authority in the case of an EIA must take due account of the particular findings of the EIAR but need not be bound as strictly by the findings.

6.5.5 Assessment of challenges with respect to WFD implementation

This necessarily brief review shows there is much law relating to water but, like its subject matter, its sources and connections are diverse, complex, not always immediately evident and indeed, at times, are ‘subterranean’. The complexity of the law and its various sources is not, however, an excuse or reason to permit the continuance of the status quo, which has had such manifestly unsatisfactory results, as evidenced by the continued deterioration in the status of Irish water bodies measured against the express obligations to prevent deterioration in, and to enhance, water bodies mandated by the WFD, adopted in 2000. A primary focus must be on the consolidation (and simplification) of much of the existing law, which has emerged in a somewhat haphazard and inconsistent manner, some of it driven by domestic requirements, and otherwise by how we have chosen to implement European obligations in a fragmented and piecemeal manner. Ideally, this task should focus on creating as integrated an approach to water bodies and their associated uses as possible, taking account of EU and WFD obligations.

This perhaps might entail a standalone, primary, water regulator, which would authorise certain (or all) water uses affecting surface water bodies and groundwater, perhaps encompassing drinking water, water abstraction, hydropower, flood relief schemes, inland navigation, leisure services, proposed hydromorphological alterations as well as existing arterial drainage schemes.

A unitary water regulator like this could also provide a locus of expertise and guidance to other stakeholders, not least the various planning authorities and other agencies and ensure that the interests of riparian and other water bodies are more effectively coordinated and met.

Whatever the ultimate merits of a unitary water regulator, greater focus and effort should be devoted, in the first instance, to, as far as practicable, consolidating and streamlining the existing corpus of legislation that has emerged at different times, from different sources, in response to different pressures and in a markedly disjointed way.

In approaching this task of consolidation, as a general principle, the number of general exemptions provided from its requirements should be strictly controlled to ensure that the new regime applies as universally as possible, unlike the current hotchpotch of legislation which has various exemptions from its application.

This brief review has identified a number of considerations of importance for the successful incorporation of hydromorphology into practice to meet Ireland's obligations under the WFD. These candidate recommendations are presented below, with supporting text as appropriate.

.

Recommendation 1: Introduce a Water Act, consolidating and updating existing water-related legislation to provide a single source of reference to water matters and single source of law as far as possible:

i. Review and repeal outmoded/outdated/spent/overlapping statutory provisions.

ii. Consolidate as much water-related primary and secondary legislation as far as practicable into a Water Act, organised under the different main water "themes": environment, fisheries, navigation, water services, health, electricity generation, nitrates, pollution control, leisure services, flood defence, hydromorphology, drainage.

iii. Anticipate/ "future-proof" legislation given emerging EU proposals and requirements with respect to WFD and related matters.

iv. Fully resource and keep maintained a readily accessible and up-to-date database of water-related legislation, guidance and caselaw.

Recommendation 2: Review predicted impacts of climate change and implications for the water environment and take appropriate enabling powers:

v. Powers to deal with increased river and coastal flooding, water stress, water quality, water availability, water pricing, land abandonment and the gamut of water-related or water-impacting issues that may arise.

Recommendation 3: Review effectiveness of existing implementation of water law as an input to the proposed Water Act:

vi. Consider whether further statutory enforcement powers or penalties are required, having regard to weaknesses identified and prosecutions taken and outcomes of same in the review period.

vii. Consider whether additional enforcement mechanisms or reallocation of responsibilities for enforcement are required.

A particular challenge faced in implementing the WFD is that the physical geography of the various water bodies used in preparing the RBMP and catchment plans often does not match the exact political geography or boundaries of the planning authorities used in the administration and implementation of the programme of measures flowing from the RBMP.

Even allowing for that difficulty, however, there is a notably poor level of coordination and practical interlinkage between the individual levels of the physical planning framework and the

requirements of the WFD as expressed in the RBMP. A unitary regulator may be more effective in coordinating and driving the changes and investments, at pace, that need to be made if the State is to have any prospect of meeting its obligations under the WFD by the end of the third cycle RBMP or any successor plan

The practical difficulties of ensuring proper coordination between the RBMP and county development plans are exacerbated by the sometimes (and not always obvious) competing aims of various statutory stakeholders as well as some statutory requirements which apparently run counter, or, at the least, act as headwinds, to the requirements of the WFD. Among the statutory bodies, such impacts with respect to water bodies may arise from the commercial activities of state bodies including Coillte. We also find Inland Fisheries Ireland, which is charged with responsibility for fisheries in inland waters alongside a commercial semi-state body responsible for the generation of electricity, which, by virtue of various hydro-electric schemes it operates (the rivers Shannon, Lee, Liffey and Erne) is also responsible for the fisheries in those catchments. This gives rise to potential, if not, actual conflict between the demands of electricity generation and what this might require in terms of the operation of dams, water abstraction and water spate, and measures aimed at conserving fish stocks through the provision of suitable fish passes.

While public bodies are required by Regulation 3 of the 2003 Water Framework Regulations to exercise their statutory functions in a manner consistent with the provisions of the WFD, the practical effect of this imprecise hortatory injunction is unclear. This vaguely expressed duty might be better replaced by more explicit duties tailored to the individual remits of particular statutory bodies, describing in some detail the duty of that entity with respect to the WFD and how that duty is to be discharged alongside its primary duties and responsibilities. Consideration should also be given to how individual remits might be in potential conflict with those of other entities (a simple example being dams compared with fish) and the means by which these clashes might be prevented or resolved.

Recommendation 4: As an input to this updated legislation, review the remit of the various statutory bodies and agencies concerned with water matters, with respect to their general WFD obligations:

viii. Identify all statutory bodies with responsibility or remit in respect of matters relating to the WFD

ix. Review each statutory body's individual responsibilities that touch on or concern the WFD:

x. Identify main areas of conflict (actual or potential) between those responsibilities and the requirements of the WFD.

xi. Amend the aim/purpose of each statutory body/agency statutory charter to include a specific requirement to adhere to WFD as a primary/fundamental objective, with sufficient particularity and guidance as to what that entails.

xii. Amend statutory body/agencies aim/purpose to remove/resolve as far as possible any existing or potential conflicts with WFD requirements, as appropriate.

Other areas requiring to be addressed as a matter of priority include how best to integrate WFD considerations within county development plans and to ensure alignment between river basin management plans and the relevant county development plans. Where development is being permitted close to a body of surface water, guidance is lacking on how should risks from

a proposed development be best assessed and managed. And where the surface water body concerned straddles two or more local authority functional areas, clear direction needs to be given to ensure that both the upstream and downstream effects of any permitted development are adequately considered and mitigated and that responsibilities for actions are clearly assigned. Draft guidelines on Water Services Guidelines for Planning Authorities have been prepared by the Department of Housing, Planning and Local Government (January 2018) to be issued under section 28[27] of the PDA 2000 covering the interface between planning and development functions provided by planning authorities and the delivery of public water services by Irish Water. These are limited in scope to water services, however, and not to WFD requirements generally.

Recommendation 5: As a further input to the legislation, undertake a review of governance and accountability of statutory bodies/agencies with respect to cross-cutting WFD obligations:

xiii. Review individual bodies/agencies set of responsibilities against other bodies' responsibilities and identify areas of overlap, contending or alternative or shared priorities or potential areas of conflict and resolve those issues in the statutory scheme.

xiv. Review options for improved governance of projects with cross-cutting/inter agency impacts with clear articulation of roles and responsibilities, using e.g. the RACI matrix model (or equivalent) to delineate such roles: Responsible, Accountable, Consulted and Informed, underpinned by appropriate legislative provisions. Thus, for example, in a project spanning several agencies' responsibilities, one agency would be designated as the lead agency, with (legal) responsibility for delivery and others required to be consulted or informed, as appropriate.

Recommendation 6: Review hydroelectricity generation:

xv. Existing hydroelectricity projects (Ardnacrusha, Carrigadrohid, Inniscarra Poulaphoucha etc.) should be reviewed from WFD, energy security, climate change and cost-benefit analysis perspectives to see whether the projects can be justified in their current form or should be modified or discontinued.

xvi. Consider appropriateness, in light of WFD obligations, of statutory powers given to the ESB in relation to hydroelectricity and whether these should be reassigned or subject to licensing conditions by an appropriate agency other than the ESB.

A particular challenge is posed by the sometimes-overlapping requirements established by several EU environmental Directives and the assessments required by each of them. The requirements and timings for these differ but there may be potential for some synergies.

In the current River Basin Management Plan for Ireland (2022-2027) (DHLGH, 2024a), Department of Housing, Local Government and Heritage (DHLGH), acknowledges issues relating to WFD guidance and governance and refers (Box 15, page 71) to draft planning guidelines in preparation which will provide *"….guidelines for the incorporation of the Water Framework Directive considerations into the planning system*" alongside the "…*roll out of*

[27] See footnote 17.

training on the new water and planning guidelines to practitioners." It is also planned to give legislative effect to the Water and Planning Guidance to be issued.

These guidelines are long overdue, however, as they were promised in the Second River Basin Management Plan (2018-2021) which stated "The DHPLG will prepare high-level guidance for Planning Authorities on the relationship between physical planning and river basin management planning. This guidance will provide a methodology for Planning Authorities to ensure that relevant plans and planning decisions are consistent with river basin management plans and with the requirements of the WFD."

It is germane to note that since that promise was made, in the intervening period (2018- Q3, 2024) planning permissions for over 253,000 dwelling units were granted without the benefit of that promised guidance.

The EPA has recently updated its detailed guidance on the information to be contained in EIARs. As part of this, it plans also to update the previous (2003) 'Advice Notes on Current Practice in the preparation of EIARs', dealing *inter alia*, with water. Ideally, both the DHPLG's high-level guidance and the EPA's Advice Notes should be coordinated so that planning authorities have the proper RBMP context for planning decisions and that promoters of projects affecting water bodies falling within EIA requirements have the appropriate up-to-date guidance.

Recommendation 7: Detailed guidance should be provided forthwith to local authorities with respect to WFD issues and physical planning.

XVII. The promised guidance from DHLGH to planning authorities on the relationship between physical planning and River Basin Management Planning should be published as a priority. EIA Advice Notes pertaining to water should similarly be prioritised for release.

Recommendation 8: Review effectiveness of existing environmental impact assessments for the purposes of fulfilling the requirements of Article 4 of the Water Framework Directive.

XVIII. Prepare practical best practice guidance for incorporating Article 4 of the WFD within existing environmental assessments, where mandated, with focus on a holistic overview of requirements in terms of assessment coverage, consultations to be held and outcomes to be served. Prepare guidance for standalone WFD assessment in relevant cases where EIA or AA does not apply, and underpinned by legislation, if required.

XIX. Develop a suite of practical case studies and detailed guidance on resolution of conflicts arising from different Directives e.g. how to resolve a conflict between a Habitats Directive objective to protect a particular species in a modified water body and a WFD objective aimed at restoration of waters which will entail removal of that modification.

XX. A review of functional separation arrangements implemented by local authorities where the local authority is also the developer, and the production of detailed guidance on what constitutes best practice should be undertaken.

Other conflicts may arise from the statutory duties that are conferred on the particular entity, which, while appropriate at the time of their conferral, are now fossilised in terms of modern needs, better understanding of ecological issues and the obligations imposed by the WFD and other environmental legislation. The Commissioners of Public Works are responsible for

approximately 11,500 km of arterial drainage in Ireland under the Arterial Drainage Act, 1945 as amended.

Section 37(1) (a) of that Act imposes a duty on the Commissioners of Public Works to:

> …maintain the said drainage works or existing drainage works (as the case may be) in proper repair and effective condition but, in the case of any such existing drainage works, it shall not be obligatory on the Commissioners to maintain such works in a better condition or state of repair than they were in on the date of the maintenance transfer order.

This duty to maintain drainage works "in proper repair and effective condition" is an express one, with no discretion afforded to the Commissioners of Public Works as to what their duty is and how it might be best discharged. It does not permit the Commissioners to consider adopting alternative approaches to the issue of drainage – the existing conditions of arterial drains must be maintained – or, indeed, to even question the rationale for such drainage. It pre-supposes the supremacy of a particular land use for all time, which land use need not be (as) necessary, economically or socially significant or relevant today. Land drainage and land use objectives set decades ago under different economic and social conditions, should not, it is suggested, be the *de facto* guide rail for current and future environmental policies, nor should these uses be the sole, and apparently automatic, driver for the proposed designation of so many rivers, with arterial drainage schemes, as HMWBs.

Local authorities, too, have responsibilities in respect of a further 4,500 km of drainage channels developed in earlier drainage district schemes, responsibilities which should be reconsidered and clarified. It might be preferable if some of these drainage schemes were not maintained and rivers were allowed to resume their natural course, accepting that this might cause some flooding, but counterbalanced by wider environmental benefits, including the restoration of endangered habitats and water bodies.

Similarly, obligations arising from the Floods Directive should be interpreted congruently with the requirements of the WFD and an over (or default) reliance on traditional hard engineering approaches to flood risk management should be avoided as far as practicable, accepting that this may entail some extra expenditure (as mandated by the WFD) and the greater deployment of Nature Based Solutions to manage flood risk.

Recommendation 9: Cease maintenance of current arterial drainage schemes and drainage districts, on a specified date (same to be set out in the proposed legislation), after a suitable lead-in time, unless the drainage schemes can be empirically justified by reference to robust environmental impact, land use and cost benefit analysis:

XXI. Assess the social value/economic benefit of the current agricultural use of the lands subject to drainage versus the wider environmental benefits secured by the cessation of that use and the restoration of the affected rivers to their natural condition, with a view to developing suitable mechanisms for the cessation of such use

XXII. Provide in the proposed Water Act that the Arterial Drainage Acts, 1945-1995 shall cease to have effect on a date to be determined, unless the OPW requests the continuance of such schemes on the basis of detailed and objective environmental and land use considerations for each such scheme it wishes to maintain.

- Develop robust cost-benefit analysis and modelling of upstream and downstream impacts of drainage cessation projects, in line with Art. 4(3) of the WFD, to consider, in particular, existing land-use value and stakeholder considerations.

- Develop appropriate incentive schemes for those affected by such proposed cessation.

XXIII. Provide that each scheme that is to be continued is to be subject to strict licensing requirements, to take account of WFD obligations, same to be reviewed not later than once in every six years to ensure that licensing obligations are being fulfilled and GEP is being achieved where the water body concerned is a HMWB.

XXIV. As a possible precursor to the mandatory "cessation of maintenance" date, in the interregnum period, permit the OPW, in suitable cases, to derogate from its strict duty of maintenance of channels, to allow for trials/pilots of NBS approaches, with clear selection criteria and appropriate stakeholder engagement models to be pioneered.

- Select pilot schemes for implementation and based on evidence from pilot schemes, consider setting a statutory objective (supported by appropriate funding) of restoring a specified percentage of waters each year.

XXV. Implement a similar approach/model in respect of local authority "drainage districts."

Recommendation 10: The process for designation of water bodies as heavily modified should include a rigorous analysis of technical feasibility and disproportionate costs and include explicit consideration of "significantly better environmental" option[s]", as required by Art. 4.3(b) of the WFD.

XXVI. Reconsider proposed designation of river water bodies as HMWBs given recommended change to arterial drainage mandate.

XXVII. Re-evaluate the necessity and desirability of designating 325 river water bodies as HMWBs, as proposed by EPA, in light of proposed change to arterial drainage policy.

Recommendation 11: With respect to proposed Flood Risk Management Plans, presumptively favour NBS approaches:

XXVIII. Introduce a statutory "reverse onus" on the OPW/responsible authority to disprove, or at the very least, oblige them to first fully consider and objectively evaluate whether NBS approaches should be ruled out from consideration as the preferred option in implementing FRMP to give proper effect to Article 4 3 of the WFD. Prepare guidance for standalone WFD assessment in relevant cases where EIA or AA does not apply.

XXIX. In the costing and evaluation of options, explicitly budget for or allow a factor or percentage of additional costs to be incurred in favour of approaches that do not involve modifications to the water bodies concerned, over approaches that involve modifications to those bodies.

XXX. Only after NBS approaches have been definitively ruled out, should any consideration be given to traditional "hard engineering" approaches.

Chapter 7

7 Recommendations

This report covers a large range of issues related to hydromorphology. It includes descriptions of key hydromorphological processes to guide river basin planning and management in Ireland. The state of knowledge that identifies the effects of hydromorphological alterations on the biological elements continues to develop to guide the programmes of measures required for River Basin Management Plans (RBMPs) compliance with the requirements of the Water Framework Directive.

We have included a specific section on the main legal issues and, supported by a stakeholder workshop, the interests and role of citizen participation. This final chapter distils the extensive information that we have reviewed and makes a series of recommendations for a more comprehensive and effective inclusion of hydromorphology into the policies and practice of water management. The recommendations are grouped under a number of specific headings.

7.1 Hydromorphological Assessment

- Following the advice of the European Commission WFD advisory ECOSTAT group, hydromorphological assessment needs to be carried out for each of the 5-class biological classifications and, therefore, requires techniques that are responsive to hydromorphological alterations along the full gradient of status classes. It is recommended that techniques are developed and implemented for the assessment of hydromorphological assessment across all status categories from high to bad status and reported as such across all categories of water bodies.
- Since the water body types and their reference conditions were determined before specific WFD-related reviews on hydromorphology were done, typology and water body delineation should be reconsidered, or reaffirmed as relevant, in each iteration of the RBMP cycle.
- More research is needed to assess the interaction of hydromorphology with other pressures, so as to assess combined and multiple pressures. This should include any modifying effect of climate-driven hydromorphological alterations.
- Overall, there is a need for increased understanding of hydromorphological processes and their relationships with biological communities, as well as the identification of effective approaches to mitigate the effect of hydromorphological pressures to guide effective river basin management.
- As indicators used in WFD assessment generally can often not fully diagnose the cause(s) of ecological degradation, there is further need for: 1) understanding the ecological mechanisms that link hydromorphology to Biological Quality Elements (BQEs), and 2) the development of new BQEs sensitive to hydromorphological alterations, as well as their interactions with other pressures.
- Insofar as possible, there should be reduced reliance on expert judgement in estimating the link between the response of BQEs and hydromorphological alterations. The “Prague Approach”, recommended in Ireland’s third cycle RBMP Water Action Plan largely retains a reliance on expert judgement.
- A better understanding of the ecological mechanisms of BQE response to hydromorphological alteration will support Programmes of Measures (POMs) and should be reported in assessment of POM success after each RBMP cycle.

- Further monitoring, more intense than that specified in the text of the WFD, is needed at relevant temporal and spatial scales to determine the ecological status of water bodies including hydrological regimes, continuity and morphological condition for rivers and streams; hydrological regimes and morphological conditions for lakes; tidal regime and morphological conditions for transitional and coastal water bodies; and effects of alterations of hydrological regime for Groundwater Dependent Ecosystems (GDEs).
- Although there is guidance through the Common Implementation Strategy (CIS) advisory group on hydromorphology and the European Committee for Standardisation (CEN) for general standardised approaches to biological and physical monitoring, and recent adaptation of these for Ireland, there is still a need for improvement and adoption of common monitoring methodologies for hydromorphological elements.
- It is recommended that techniques used to assess hydromorphological alteration in all water bodies are fully described and in the public domain. Where a technique has been adapted from another jurisdiction, or e.g. a European research programme, the full methods and departure from the original should be both fully described. There should be peer reviewed independent validation of the appropriateness of the use of any simplified method and testing across a wide range of situations. These principles would apply to e.g. the River Hydromorphology Assessment Technique (RHAT) and Morphological Quality Index (MQI) for rivers, the Morphological Impact Assessment System (MImAS) for lakes, and Hydromorphological Quality Index (HQI) for transitional and coastal water bodies.
- Assessment of hydromorphological alteration of groundwater dependent ecosystems requires further development and validation for the WFD and the Nature Directives.

7.2 Barriers

- The programme for assessment and planning for removal of small barriers to improve river continuity needs to be accelerated, with clear, consultative and publicly available plans for actions. Removal of barriers needs both ecological assessment and associated measures for ecologically sensitive in-stream and riparian habitat rehabilitation.
- For larger barriers, a case-by-case assessment of the need for and benefits of environmental flows is necessary.
- The management of flows through larger barriers is very wanting, affecting downstream habitats, including Special Areas of Conservation (SACs), and further research is needed to assess environmental flows that support ecological status.
- A re-evaluation of the role of the Electricity Supply Board (ESB) to manage the hydromorphology of water bodies upstream and downstream of major electricity-generating structures is warranted.
- The pilot schemes, as outlined in the third cycle RBMP, for assessing effects of mitigation works on barriers requires full documentation and pre and post evaluations and consultation with key stakeholders

7.3 Water Abstraction/ Climate Change

- The effects and extent of water abstraction, including scenarios of climate change, on water bodies in Ireland requires further research and associated dissemination in the public domain.

- Ireland's legislative provisions for water abstraction have undergone a recent change, with the Water Environment (Abstractions and Associated Impoundments) Act 2022, requiring the registration of any abstraction greater than 25 m^3 in a 24 hour period and the need for a licence for abstractions of 2000 m^3 or more in a 24 hour period. By comparison, in Northern Ireland, England and Wales abstractions over 20 m^3 require a licence, with Northern Ireland and Scotland having 10 m^3 as the threshold for registration. The Abstraction Act has been found not to comply with the WFD following infringement proceedings against Ireland by the European Commission. Consequently, the Government and Environmental Protection Agency (EPA) should, as a priority, review the registration thresholds, the duration of abstraction licences and the evidence base on which it is intended that that the required new thresholds will be based.
- Given increasing uncertainty on the effects of climate change on water bodies, including sustainability of abstraction, it is strongly recommended that much more intensive and policy relevant consideration for adaptive management in the face of climate change is an ongoing necessity for the Irish Government and its agencies, and how that might affect ecological assessment.

7.4 Channelisation, dredging, sand and gravel extraction, and sediment management

- As channelisation, flood control measures and navigation maintenance require periodic dredging that disturbs habitats and sediment dynamics, a POM for assessing the ecological role of sediment and estimating sediment budgets is required. Evaluation of sediment budgets in water body management is notably deficient.
- Introduction of Supplementary Measures for sediment transport management at the river basin scale is required urgently.

7.5 In-stream and riparian vegetation

- The importance of riparian vegetation and in-stream woody debris appears grossly underestimated in river management in many jurisdictions, including Ireland. There is a need for further evaluation of its role in water body hydromorphology and in the routine management of arterial drainage schemes.

7.6 Flood Protection and Nature Based Solutions

- Nature Based Solutions (NBS) are increasingly recognised globally as a cost-effective approach to hydromorphological management. Ireland appears to be only recently paying attention to this as a important in water body management and flood protection. NBS do not always provide an appropriate solution, but proposed Flood Risk Management Plans (FRMPs) should presumptively favour NBS approaches, with a statutory 'reverse onus' on the responsible authority to first fully consider whether NBS approaches should be ruled out from consideration as the preferred option in implementing a FRMP to give proper effect to Article 4 3 of the WFD. This consideration of NBS needs to be evidence-informed and cognisant of the potential benefits to biodiversity, climate mitigation and nutrient loading, and specifically addressed in the consideration of all flood defence schemes.
- While flood management schemes are increasingly subject to environmental assessment and (under the Habitats Directive) Appropriate Assessment, with information provided on the OPW website, further progress involving increased

dialogue and consideration of alternatives is recommended to assist meeting the objectives of both the WFD and Floods Directive and the respective obligations of the Nature Directives.

- Flood Protection Projects that derive from or assist with the implementation of FRMPs should be formally assessed for their compatibility with WFD objectives and evaluated through effective monitoring afterwards.
- It is recommended that greater attention is paid to European examples of NBS, as illustrated in e.g. the Dutch 'Room for the River' programme and from the activities carried out in the Loire. Both followed multidisciplinary approaches that also led to the development of new policies and practices.
- Rehabilitation programmes of urban rivers should be encouraged in Ireland as occurs in other European countries. For established urban areas, an adaptive management and multisectoral approach brings many benefits, with achievements made through both technical innovations and enabling social processes. While the use of NBS is increasingly promoted in urban areas, greater consideration for their use in rural areas, and therefore river basins, is recommended.

7.7 Landuse

- A basic tenet of modern water management, and embedded in the WFD, is that management of water bodies is not separated from that of the catchment. As such, lateral links with land-use should be considered in monitoring and assessment of hydromorphology and the management of impacts to it.
- Extra attention is needed to how land-use policies including agriculture, forestry, urban development, ports and harbours can affect the environmental objectives of the WFD through hydromorphological alterations and their interaction with other pressures.
- Agricultural drainage can have a major hydromorphological impact as it affects hydrological and associated nutrient and sediment loads, riparian habitats and lateral; connectivity between a river and catchment. Further risk assessment of land drainage outside the context of the Arterial Drainage Acts is important to inform RBMPs. This should include drainage of former commercial peat extraction. Where hydromorphological impact is considered reasonably likely, but of overriding economic and social importance, this should be clearly stated for individual water bodies, with an economic analysis as required under Article 5 and Annex III(b) of the WFD and incorporated under the programmes of measures required under Article 11.

7.8 HMWBs and AWBs

- Assessment and designation of Heavily Modified Water Bodies (HMWBs) has generally lagged behind other aspects of ecological status, although there have been a number of guidance documents from the ECOSTAT group that supports the implementation of the WFD, and a review of the designation of HMWBs by the EPA. The latest EPA guidance may not, however, be in line with ECOSTAT guidance. The re-designation of a large number of water bodies to HMWBs, as outlined in the third cycle RBMP Water Action Plan (WAP) is only valid if the physical alterations are shown to have a significant negative effect on the biological communities, and mitigation methods are insufficient to bring the water body to good ecological status. Water bodies potentially affected by arterial drainage should not be designated as HMWBs solely because of historical decisions on land drainage. Similarly, poor water quality in

a water body that has been subject to physical modifications is not *per se* a reason not to reach good ecological status.

- For HMWBs and artificial water bodies (AWBs), it is recommended that there is a clear distinction drawn in the WAP and POMs between a) restoration measures that ensure that hydromorphological conditions of a water body are consistent with good ecological status, and b) those for good ecological potential where mitigation measures cannot restore a water body to good ecological status. Targets for good ecological potential need clear and evidence-informed definition. Assumptions of congruence between high ecological status and high ecological potential need to be clearly described, as each hydromorphologically altered water body may have unique elements that affect its ecological status. Any pseudo-reference estimation for a HMWB or AWB against which to evaluate subsequent changes will involve high uncertainty.
- Careful evidence-informed evaluation in consultation with the European Commission and national competent bodies would be well advised ahead of any increased designations of HMWBs as proposed in the 3rd cycle WAP.
- The process for designation of water bodies as heavily modified should include a rigorous analysis of technical feasibility and disproportionate costs and include explicit consideration of 'significantly better environmental option[s]', as required by Art. 4.3 (b) of the WFD.

7.9 Lakes

- There is a need to link the monitoring of BQEs in Irish lakes to hydromorphological pressure-response relationships.
- A greater use of bathymetry measurements can guide estimates of lake residence times for use in modelling transport of pollutants arising from land-use pressures. This is also important for developing scenarios for the ecological status of lakes in response to seemingly modest temperature increases.

7.10 Groundwater bodies and Groundwater Dependent Ecosystems (GDEs)

- The interrelation of groundwater and surface water, especially in karst regions, needs further study. Moreover, special attention should be drawn to the quantification of their relationship.
- The ecological importance of springs should not be overlooked.
- Despite protection, turloughs remain vulnerable to new drainage schemes, and the legacy of old ones; that which may be further affected as a consequence of climate change. Further safeguarding of turloughs from the effects of drainage, nutrient pollution, or other impacts is required. Better and more widespread quantification of the surface-groundwater interactions is an ongoing need.
- Many other GDEs require further understanding to provide estimates of relevant threshold values of possible impact. Since GDEs vary with local hydrogeology and climate, local and regional studies on their quantitative and chemical interactions are recommended to be done prior to WFD status assessment. Further interaction between the EPA and the Natural Parks and Wildlife Service (NPWS) in assessing the extent and importance of GDEs is needed.
- Although there is an adequate policy framework to deliver turlough conservation, many suggested measures have not been applied. Further efforts involving all relevant stakeholders for the conservation of turloughs should be pursued.

- Improved definition and greater understanding of the impacts of groundwater pressures on Groundwater Dependent Terrestrial Ecosystems (GWDTEs) is needed. Further multi-agency research in this area is recommended, including deriving reference states and the departure from them.

7.11 Transitional and coastal water bodies

- A lack of clear distinction between hydromorphological and biological assessment indicates a need to develop effective pressure-response methods for transitional and coastal waters for both hydromorphological and biological elements.
- The dredged material from ports and harbours is at the borderline of water, soil and waste policies and the European legislation for handling it is complex. This highlights the need for further development of assessment techniques to guide sediment management.

7.12 Legislation relating to hydromorphology in Ireland

- Ireland needs a dedicated Water Act, consolidating and updating existing water-related legislation to provide a single source of reference to water matters and a single source of law as far as possible. A review of the effectiveness of the existing implementation of water law as an input to the proposed Water Act is needed**.**
- Maintaining a readily accessible and up-to-date database of water-related legislation, guidance and caselaw, will support and 'future-proof' legislation that takes account of EU proposals and requirements with respect to WFD, related matters and climate change. A suitable Competent Authority, overseen by the relevant government department should be charged with this task.
- As input to new legislation, there remains a need to review the remit of the various statutory bodies and agencies concerned with water matters, with respect to their general and specific WFD obligations, and their associated governance and accountability in their respective spheres of operation.
- Existing hydroelectricity projects (Ardnacrusha, Carrigadrohid, Inniscarra Poulaphoucha etc.) should be reviewed from WFD, energy security, climate change and cost-benefit analysis perspectives to see whether the projects can be justified in their current form or should be modified or discontinued. In light of WFD obligations, this should include a consideration of the appropriateness of statutory powers given to the ESB in relation to hydroelectricity and whether these should be reassigned or subject to licensing conditions by an appropriate agency other than the ESB.
- Detailed guidance should be provided forthwith to local authorities with respect to WFD issues and physical planning, including where development thresholds fall below those required for EIA. The promised guidance from Department of Housing, Local Government and Heritage (DHLGH) to planning authorities on the relationship between physical planning and River Basin Management Planning should be published as a priority. EIA Advice Notes pertaining to water should similarly be prioritised for release.
- Effectiveness of existing environmental assessments to meet WFD Art. 4 requirements, requires a review of existing EIA and Appropriate Assessment guidelines and a representative sample of Environmental Impact Assessment Reports (EIARs) and Natura Impact Statements. Model templates/detailed WFD guidance for different water body types should be produced. Particular attention should be paid to

projects which do not trigger EIA or AA, but nonetheless require a standalone assessment for WFD purposes, underpinned by legislation, if required.

- More clarity on how the Birds and Habitats Directives apply to the WFD, and vice versa, remains an important need, accentuated by effects of climate change on hydromorphology, opening opportunities for increased establishment of invasive species, often effecting hydromorphological alterations through extensive spread of their population and biomass. Guidance should be further developed, drawing on case studies, that also help resolve potential conflicts between Directives, such as between a Habitats Directive objective to protect a particular species in a modified water body and a WFD objective aimed at restoration of waters which would entail removal of that modification.
- A review of functional separation arrangements implemented by local authorities where the local authority is also the developer, and the production of detailed guidance on what constitutes best practice should be undertaken to ensure that measures taken are fully robust and deal with all actual or potential conflicts, transparently and effectively.
- Where EIAs are undertaken for a relevant project (flood defence schemes, arterial drainage, drainage districts, minor flood relief schemes) by consultants, on behalf of either the OPW or a local authority (such being the proposer of the project concerned) appropriate arrangements, including detailed guidance, must be made to ensure best practice and that the objectivity and rigour of the EIAs produced is preserved.
- An overhaul of the Arterial Drainage Acts (1945, 1995) is long overdue and should include cessation of maintenance of current arterial drainage schemes and drainage districts, on a specified date, unless the drainage schemes can be empirically justified by reference to robust environmental impact, land use and cost-benefit analysis. The proposed review of the Arterial Drainage Act 1945 is welcome, but requires an effective consultation process and alignment with the WFD.
- Any drainage scheme that is to be continued following the above process, should be subject to strict licensing requirements that take account of WFD obligations, with subsequent review not later than once in every six years to ensure that licensing obligations are being fulfilled. A transition period could include pilot schemes of restoring a specified percentage of waters each year and with fair financial compensation and incentives for those adversely affected.

7.13 River Basin Management Plans and Programmes of Measures

- RBMPs are central to achieving the environmental objectives of the WFD. Ensuring consistent policy integration between the River Basin Management Planning process and other national plans remains a priority need. There is a need for an assessment of policy integration for hydromorphology between the third cycle of the River Basin Management Planning process (WAP) and other national plans, policies and programmes, including the Planning Acts.
- Measures laid out in the third cycle RBMP for improved management of water bodies affected by hydromorphological alterations should be incorporated into primary legislation as a critical development for effective management of hydromorphological pressures. A new administrative system reaching across policy and departmental boundaries is crucial in terms of engaging broad and suitable competencies, and for achieving recommendations set out in Chapter 6 of this report.

- In the third cycle RBMP (WAP), a re-focus on how arterial drainage is managed is required, as noted above. This could involve emphasis on multifunctional floodplain management. As the Arterial Drainage Act 1945 represents the thinking of a previous era and clearly results in hydromorphological alteration and the perpetuation of this through the obligation to maintain drainage, the overhaul of the 1945 Act in the context of WFD compliance is clearly needed.
- Similarly, the role of the OPW and Local Authorities in flood defence schemes should be subject to independent review to ensure it meets national and EU obligations, and to assess its likely ability to adapt to and meet more extreme climate events.
- Forging consistent and robust linkages among different policy areas is a significant challenge, including how these are connected with Climate Adaptation Plans, Marine Spatial Planning, Flood Risk Management Plans, and Biodiversity Action Plans. A process of policy (re-)evaluation is recommended. It is further recommended that greater incorporation of the Floods Directive requirements, and associated actions compatible with the WFD, are fully taken into account in the current WAP.
- The role of Inland Fisheries Ireland (IFI) in the management of hydromorphology tends to be unclear. More specific and up to date information can inform stakeholders of actions, which can also help clarify its own role in the third cycle WAP of the RBMP.
- Greater efforts should be made to disseminate outputs of applied research to support water management and proactive strategies of how such outputs can lead to outcomes. This is very evident in a review of state funded research on hydromorphology.
- The statutory mandates, and activities of bodies such as ESB and OPW risk conflict with the objectives of the WFD, with issues of cross-compliance between different policy objectives evident. Where Strategic Action Plans for biodiversity are in place, these require either reporting on specific actions and key performance indicators, in keeping with fulfilling statutory obligations, or the creation of such.
- A re-evaluation of the remits of state bodies and their role in compliance with EU Directives and other policies is long overdue. The roles and responsibilities of the various implementation bodies should be reviewed and clarified. An overarching consolidated Water Act would provide a framework for resolving many of these difficulties.

7.14 Stakeholders' input

- Access to environmental information can be particularly troublesome in Ireland, and greater efforts towards transparency and open-access availability of environmental information, with raw data provided in reasonable time periods, is still needed. WFD monitoring data for water bodies is accessible but could be more 'user-friendly'. A model of good practice is the freely available and easy to access river hydrometric data provided by OPW. Accessing data and transparency from a number of agencies or government departments has often been cumbersome or even not possible.
- It is recommended that the reports and minutes of the various coordinating bodies for the WFD, including the '*National Co-ordination and Management Committee* (NCMC), *Water Policy Advisory Committee'* (WPAC), and the '*National Technical Implementation Group'*, Regional Management Committees and Regional Operational Committees are made available through the internet in a timely manner.
- Compliance with the Aarhus Convention on *Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters* requires checking

its implementation against its purpose. It is recommended that state agencies re-evaluate compliance with legal requirements for access to environmental information, including access to spatial data held by public bodies. An open and democratic society should not be concerned about providing available environmental data in a free and open manner. As data on hydromorphology becomes more relevant, having these data in the public domain in readily accessible formats can improve public confidence in decision-making, and the transparency of WFD compliance.

- Greater involvement of citizens in water management is strongly encouraged. The 3rd cycle WAP has an Action (6.15) that Local Authority Waters Programme **(**LAWPRO) will facilitate public participation in the development of the Catchment Management Work Plans to inform the development and implementation of a national approach to public participation to deliver outcomes for water, climate and nature. Facilitating public participation is required under the WFD. A concerted effort to engage the public twenty-five years after implementation is long overdue, and needs to be accelerated.

8 References

Abam, T.K.S., 1993. Bank erosion and protection in the Niger delta. Hydrol. Sci. J. 38, 231–241.

Acreman, M.C., Adams, B., Birchall, P., Connorton, B., 2000. Does Groundwater Abstraction Cause Degradation of Rivers and Wetlands? Water Environ. J. 14, 200–206.

Adamson, M., O'Sullivan, J., Bedri, Z., 2016. Reflecting Societal Values in Designing Flood Risk Management Strategies. E3S Web Conf. 7, 0–6.

Addy, S., Cooksley, S., Dodd, N., Waylen, K., Stockan, J., Byg, A., Holstead, K., 2016. Nature-Based Solutions for Restoring the Rivers of the UK and Republic of Ireland. CREW reference: CRW2014/10. Aberdeen.

Agences de l'eau Aquascop, 1998. SEQ milieu physique, Système d'évaluation de la qualitè du milieu physique des cours d'eau, version 0, rapport de présentation (projet), rapport Inter-Agences.

Al-Nasrawi, A.K.M., Hamylton, S.M., Jones, B.G., 2018. An assessment of anthropogenic and climatic stressors on estuaries using a spatio-temporal GIS-modelling approach for sustainability: Towamba estuary, southeastern Australia. Environ. Monit. Assess. 190, 375.

Allott, N., McGinnity, P., Hea, B.O., 2005. Factors Influencing the Downstream Transport of Sediment in the Lough Feeagh Catchment, Burrishoole, Co. Mayo, Ireland. Freshw. Forum 23, 126–138.

Alonso, C., Aroviita, J., Baattrup-Pedersen, A., Belletti, B., Brabec, K., Bøgestrand, J., Pérez, M.C., Dudley, B., Ecke, F., Friberg, N., Göthe, E., Greene, S., Gunn, I.D.M., Hajek, O., Hendriks, D.M.D., Jones, J.I., Kairo, K., Kalivodova, M., Komprdova, K., Kohut, L., Kraml, J., Laize, C., Larsen, S.E., Lorenz, A., Lebiedzinski, K., Mader, H., Mayr, P., Murphy, J.F., McDonald, C., Nemethova, S., Noble, R.A., O'Hare, M.T., Rääpysjärvi, J., Segersten, J., Turunen, J., Verdonschot, P., Vink, J., 2013. REstoring rivers FOR effective catchment Management Deliverable D3.1 Impacts of HyMo degradation on ecology. Impacts of hydromorphological degradation and disturbed sediment dynamics on ecological status. EU project report.

Andersen, J.M., 2005. NERI Technical report no. 531. Restoration of Skjern River. Summary of environmental monitoring results 1999-2003. Silkeborg, Denmark.

Andersen, J.M., Jessen, K., Larsen, B., Bundgaard, P., Glüsing, H., Illum, T., Hansen, L., Damgaard, O., Koed, A., Baktoft, H., Jensen, J., Linnemann, M., Ovesen, N., Svendsen, L., Bregnballe, T., Skriver, J., Baattrup-Pedersen, A., Pedersen, M., Madsen, A., Amstrup, O., Bak, M., 2005. Restaurering af Skjern Å. Sammenfatning af overvågningsresultater 1999-2003. [The restoration of Skjern Å. Summarization of the measured results 1999-2003]. Silkeborg, Denmark.

Anderson, E.P., 2013. Hydropower Development and Ecosystem Services in Central America. No. IDB-TN-513 Technical Note. Inter-American Development Bank. https://publications.iadb.org/en/hydropower-development-and-ecosystem-services-central-america.

Anderson, E.P., Jackson, S., Tharme, R.E., Douglas, M., Flotemersch, J.E., Zwarteveen, M., Lokgariwar, C., Montoya, M., Wali, A., Tipa, G.T., Jardine, T.D., Olden, J.D., Cheng, L., Conallin, J., Cosens, B., Dickens, C., Garrick, D., Groenfeldt, D., Kabogo, J., Roux, D.J., Ruhi, A., Arthington, A.H., 2019. Understanding rivers and their social relations: A critical step to advance environmental water management. WIREs Water 6.

Angelopoulos, N. V., Cowx, I.G., Buijse, A.D., 2017. Integrated planning framework for

successful river restoration projects: Upscaling lessons learnt from European case studies. Environ. Sci. Policy 76, 12–22.

Antwi, S.H., Linnane, S., Getty, D., Rolston, A., 2021. River Basin Management Planning in the Republic of Ireland: Past, Present and the Future. Water 13, 2074.

ANZECC/ARMCANZ, 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines (chapters 1-7). Canberra, Australia.

AQUAFACT, 2017. Marine Sediment and Benthic Studies. Galway, Ireland.

Argillier, C., Carriere, A., 2023. Overview of the metrics included in the Lake hydromorphological assessment systems in Europe and progress requested. Report to the ECOSTAT Lake Hydromorphology group, 15th September 2023. Luxembourg, Luxembourg.

Argillier, C., Carriere, A., Poikane, S., van de Bund, W., 2022. Lake Hydromorphological Assessment and Monitoring Methodologies – European survey. Luxembourg, Luxembourg.

Argillier, C., Carriere, A., Wynne, C., Hellsten, S., Vartia, K., Poikane, S., 2023. Lake hydromorphology assessment in Europe: Where are we 20 years after the adoption of the Water Framework Directive? Sci. Total Environ. 855, 158781.

Arntzen, E. V., Geist, D.R., Dresel, P.E., 2006. Effects of fluctuating river flow on groundwater/surface water mixing in the hyporheic zone of a regulated, large cobble bed river. River Res. Appl. 22, 937–946.

Arthington, A.H., Bhaduri, A., Bunn, S.E., Jackson, S.E., Tharme, R.E., Tickner, D., Young, B., Acreman, M., Baker, N., Capon, S., Horne, A.C., Kendy, E., McClain, M.E., Poff, N.L., Richter, B.D., Ward, S., 2018. The Brisbane Declaration and Global Action Agenda on Environmental Flows. Front. Environ. Sci. 6.

Atkinson, S., Bruen, M., O' Sullivan, J.J., Turner, J.N., Ball, B., Carlsson, J., Bullock, C., Casserly, C.M., Kelly-Quinn, M., 2020. An inspection-based assessment of obstacles to salmon, trout, eel and lamprey migration and river channel connectivity in Ireland. Sci. Total Environ. 719, 137215.

Atkinson, S., Bruen, M., Turner, J.N., Ball, B., Bullock, C., O'Sullivan, J.J., Casserly, C., King, J.J., Cullagh, A., Kelly-Quinn, M., 2018. The value of a desk study for building a national river obstacle inventory. River Res. Appl. 34, 1085–1094.

Baattrup-Pedersen, A., Friberg, N., Larsen, S.E.., Riis, T., 2005. The influence of channelisation on riparian plant assemblages. Freshw. Biol. 50, 1248–1261.

Bailey, R.C., Norris, R.H., Reynoldson, T.B., 2004. Bioassessment of Freshwater Ecosystems: Using the Reference Condition Approach. Kluwer Academic Publishers, New York, New York, U.S.A.

Bakker, M.M., Govers, G., van Doorn, A., Quetier, F., Chouvardas, D., Rounsevell, M., 2008. The response of soil erosion and sediment export to land-use change in four areas of Europe: The importance of landscape pattern. Geomorphology 98, 213–226.

Balderacchi, M., Benoit, P., Cambier, P., Eklo, O.M., Gargini, A., Gemitzi, A., Gurel, M., Kløve, B., Nakic, Z., Predaa, E., Ruzicic, S., Wachniew, P., Trevisan, M., 2013. Groundwater Pollution and Quality Monitoring Approaches at the European Level. Crit. Rev. Environ. Sci. Technol. 43, 323–408.

Baron, J.S., Poff, N.L., Angermeier, P.L., Dahm, C.N., Gleick, P.H., Hairston Jr., N.G., Jackson, R.B., Johnston, C.A., Richter, B.D., Steinman, A.D., 2002. Meeting ecological and societal needs for freshwater. Ecol. Appl. 12, 1247–1260.

Bazzanti, M., Mastrantuono, L., Solimini, A.G., 2012. Selecting macroinvertebrate taxa and metrics to assess eutrophication in different depth zones of Mediterranean lakes. Fundam. Appl. Limnol. 180, 133–143.

Beechie, T., Pess, G., Roni, P., Giannico, G., 2008. Setting River Restoration Priorities: A Review of Approaches and a General Protocol for Identifying and Prioritizing Actions. North Am. J. Fish. Manag. 28, 891–905.

Beese, A., 2019. Ground & groundwater conditions at Cork and implications for the Lower Lee Flood Relief Scheme. Report commissioned by Save Cork City. Cork, Ireland.

Belletti, B., Garcia de Leaniz, C., Jones, J., Bizzi, S., Börger, L., Segura, G., Castelletti, A., van de Bund, W., Aarestrup, K., Barry, J., Belka, K., Berkhuysen, A., Birnie-Gauvin, K., Bussettini, M., Carolli, M., Consuegra, S., Dopico, E., Feierfeil, T., Fernández, S., Fernandez Garrido, P., Garcia-Vazquez, E., Garrido, S., Giannico, G., Gough, P., Jepsen, N., Jones, P.E., Kemp, P., Kerr, J., King, J., Łapińska, M., Lázaro, G., Lucas, M.C., Marcello, L., Martin, P., McGinnity, P., O'Hanley, J., Olivo del Amo, R., Parasiewicz, P., Pusch, M., Rincon, G., Rodriguez, C., Royte, J., Schneider, C.T., Tummers, J.S., Vallesi, S., Vowles, A., Verspoor, E., Wanningen, H., Wantzen, K.M., Wildman, L., Zalewski, M., 2020. More than one million barriers fragment Europe's rivers. Nature 588, 436–441.

Belletti, B., Rinaldi, M., Buijse, A.D., Gurnell, A.M., Mosselman, E., 2015. A review of assessment methods for river hydromorphology. Environ. Earth Sci. 73, 2079–2100.

Bernhardt, E.S., Palmer, M.A., Allan, J.D., Alexander, G., Barnas, K., Brooks, S., Carr, J., Clayton, S., Dahm, C., Follstad-Shah, J., Galat, D., Gloss, S., Goodwin, P., Hart, D., Hassett, B., Jenkinson, R., Katz, S., Kondolf, G.M., Lake, P.S., Lave, R., Meyer, J.L., O'Donnell, T.K., Pagano, L., Powell, B., Sudduth, E., 2005. Synthesizing U.S. River Restoration Efforts. Science (80-.). 308, 636–637.

Bhuiyan, F., Hey, R.D., Wormleaton, P.R., 2010. Bank-Attached Vanes for Bank Erosion Control and Restoration of River Meanders. J. Hydraul. Eng. 136, 583–596.

Bickerton, M., Petts, G., Armitage, P., Castella, E., 1993. Assessing the ecological effects of groundwater abstraction on chalk streams: Three examples from Eastern England. Regul. Rivers Res. Manag. 8, 121–134.

Bielenberg, A. (Ed), 2002. The Shannon Scheme and the Electrification of the Irish Free State. An Inspirational milestone. Lilliput Press, Dublin, Ireland.

Biemans, H., Haddeland, I., Kabat, P., Ludwig, F., Hutjes, R.W.A., Heinke, J., Von Bloh, W., Gerten, D., 2011. Impact of reservoirs on river discharge and irrigation water supply during the 20th century. Water Resour. Res. 47, 1–15.

Bijker, W.E., 2007. American and Dutch Coastal Engineering: Differences in Risk Conception and Differences in Technological Culture. Soc. Stud. Sci. 37, 143–151.

Bilotta, G.S., Brazier, R.E., 2008. Understanding the influence of suspended solids on water quality and aquatic biota. Water Res. 42, 2849–2861.

Bilotta, G.S., Brazier, R.E., Haygarth, P.M., 2007. The Impacts of Grazing Animals on the Quality of Soils, Vegetation, and Surface Waters in Intensively Managed Grasslands. Adv. Agron. 237–280.

Binh, D. Van, Kantoush, S.A., Sumi, T., Mai, N.P., Ngoc, T.A., Trung, L.V., An, T.D., 2021. Effects of riverbed incision on the hydrology of the Vietnamese Mekong Delta. Hydrol. Process. 35, 1–21.

Birk, S., Willby, N.J., Kelly, M.G., Bonne, W., Borja, A., Poikane, S., van de Bund, W., 2013. Intercalibrating classifications of ecological status: Europe's quest for common

management objectives for aquatic ecosystems. Sci. Total Environ. 454–455, 490–499.

Blann, K.L., Anderson, J.L., Sands, G.R., Vondracek, B., 2009. Effects of Agricultural Drainage on Aquatic Ecosystems: A Review. Crit. Rev. Environ. Sci. Technol. 39, 909–1001.

Blignaut, J., Aronson, J., de Groot, R., 2014. Restoration of natural capital: A key strategy on the path to sustainability. Ecol. Eng. 65, 54–61.

Blocksom, K.A., Kurtenbach, J.P., Klemm, D.J., Fulk, F.A., Cormier, S.M., 2002. Development and evaluation of the lake macroinvertebrate integrity index (LMII) for New Jersey lakes and resevoirs. Environ. Monit. Assess. 77, 311–333.

BMLFUW, 2009. Nationaler Gewässerbewirtschaftungsplan 2009 – NGP 2009 (BMLFUWUW.4.1.2/0011-I/4/2010); National Water Management Plan 2009, 2010. Vienna, Austria.

BMUB, BfN, 2009. Auenzustandsbericht: Flussauen in Deutschland. BMU, BfN 35.

Boano, F., Caruso, A., Costamagna, E., Ridolfi, L., Fiore, S., Demichelis, F., Galvão, A., Pisoeiro, J., Rizzo, A., Masi, F., 2020. A review of nature-based solutions for greywater treatment: Applications, hydraulic design, and environmental benefits. Sci. Total Environ. 711, 134731.

Boddy, N.C., Fraley, K.M., Warburton, H.J., Jellyman, P.G., Booker, D.J., Kelly, D., McIntosh, A.R., 2020. Big impacts from small abstractions: The effects of surface water abstraction on freshwater fish assemblages. Aquat. Conserv. Mar. Freshw. Ecosyst. 30, 159–172.

Bogen, J., Bösnes, T.E., 2004. The impact of erosion protection work on sediment transport in the River Graelva, Norway. In: Golosov, V., Belyaev, V., Walling, D.E. (Eds.), Sediment Transfer through the Fluvial System. IAHS Press, Wallingford, U.K., pp. 155–164.

Bonacci, O., 2015. Karst hydrogeology/hydrology of dinaric chain and isles. Environ. Earth Sci. 74.

Boon, P., Argillier, C., Boggero, A., Ciampittiello, M., England, J., Peterlin, M., Radulović, S., Rowan, J., Soszka, H., Urbanič, G., 2019. Developing a standard approach for assessing the hydromorphology of lakes in Europe. Aquat. Conserv. Mar. Freshw. Ecosyst. 29, 655–669.

Boon, P.J., Holmes, N.T.H., Maitland, P.S., Fozzard, I.R., 2002. Developing a new version of SERCON (System for Evaluating Rivers for Conservation). Aquat. Conserv. Mar. Freshw. Ecosyst. 12, 439–455.

Borja, A., Basset, A., Bricker, S., Dauvin, J.-C., Elliott, M., Harrison, T., Marques, J.-C., Weisberg, S.B., West, R., 2011. Classifying Ecological Quality and Integrity of Estuaries. In: Wolanski, E., McLusky, D. (Eds.), Treatise on Estuarine and Coastal Science. Waltham: Academic Press.

Borja, A., Josefson, A.B., Miles, A., Muxika, I., Olsgard, F., Phillips, G., Rodríguez, J.G., Rygg, B., 2007. An approach to the intercalibration of benthic ecological status assessment in the North Atlantic ecoregion, according to the European Water Framework Directive. Mar. Pollut. Bull. 55, 42–52.

Borja, A., Ranasinghe, A., Weisberg, S.B., 2009. Assessing ecological integrity in marine waters, using multiple indices and ecosystem components: challenges for the future. Mar. Pollut. Bull. 59, 1–4.

Bouleau, G., Pont, D., 2015. Did you say reference conditions? Ecological and socio-

economic perspectives on the European Water Framework Directive. Environ. Sci. Policy 47, 32–41.

Boulton, A.J., 2009. Recent progress in the conservation of groundwaters and their dependent ecosystems. Aquat. Conserv. Mar. Freshw. Ecosyst. 19, 731–735.

Boulton, A.J., 2020. Editorial: Conservation of groundwaters and their dependent ecosystems: Integrating molecular taxonomy, systematic reserve planning and cultural values. Aquat. Conserv. Mar. Freshw. Ecosyst. 30, 1–7.

Boulton, A.J., Hancock, P.J., 2006. Rivers as groundwater-dependent ecosystems: a review of degrees of dependency, riverine processes and management implications. Aust. J. Bot. 54, 133.

Boyd, J.A., 2003. Hip Deep: A Survey of State Instream Flow Law from the Rocky Mountains to the Pacific Ocean. Nat. Resour. Journal, 44, 1151–1216.

Bracken, F.S.A., Rooney, S.M., Kelly-Quinn, M., King, J.J., Carlsson, J., 2019. Identifying spawning sites and other critical habitat in lotic systems using eDNA “snapshots”: A case study using the sea lamprey Petromyzon marinus L. Ecol. Evol. 9, 553–567.

Branch, G., 1999. Estuarine vulnerability and ecological impacts. Trends Ecol. Evol. 14.

Brandt, S.A., 2000. Classification of geomorphological effects downstream of dams. CATENA 40, 375–401.

Brauns, M., Garcia, X.-F., Walz, N., Pusch, M.., 2007. Effects of human shoreline development on littoral macroinvertebrates in lowland lakes. J. Appl. Ecol. 44, 1138–1144.

Brauns, M., Gücker, B., Wagner, C., Garcia, X.-F., Walz, N., Pusch, M.T., 2011. Human lakeshore development alters the structure and trophic basis of littoral food webs. J. Appl. Ecol. 48, 916–925.

Bregnballe, T., Amstrup, O., Holm, T.E., Clausen, P., Fox, A.D., 2014. Skjern River Valley, Northern Europe’s most expensive wetland restoration project: Benefits to breeding waterbirds. Ornis Fenn. 91, 231–243.

Brennan, C., 2006. River Shannon and Errina and park canals: Final ecology report to the Heritage Council. In: White-Young_Green (Ed.), Waterway Corridor Study. Dublin, Ireland.

Breslow, S.J., Allen, M., Holstein, D., Sojka, B., Barnea, R., Basurto, X., Carothers, C., Charnley, S., Coulthard, S., Dolšak, N., Donatuto, J., García-Quijano, C., Hicks, C.C., Levine, A., Mascia, M.B., Norman, K., Poe, M., Satterfield, T., St. Martin, K., Levin, P.S., 2017. Evaluating indicators of human well-being for ecosystem-based management. Ecosyst. Heal. Sustain. 3, 1–18.

Brew, T., Gilligan, N., 2019. Environmental Guidance: Drainage Maintenance and Construction. Series of Ecological Assessments on Arterial Drainage Maintenance. Environment Section, No. 13. Office Public Works, Trim, Ireland.

Brierley, G.J., Fryirs, K.A., 2005. Geomorphology and River Management. Blackwell Publishing, Malden USA.

Brinker, A., Chucholl, C., Behrmann-Godel, J., Matzinger, M., Basen, T., Baer, J., 2018. River damming drives population fragmentation and habitat loss of the threatened Danube streber (Zingel streber): Implications for conservation. Aquat. Conserv. Mar. Freshw. Ecosyst. 28, 587–599.

Brönmark, C., Hansson, L.-A., 2017. The Biology and Lakes and Ponds, 3rd ed. Oxford University Press, Oxford, U.K.

Brophy, J.T., Perrin, P.M., Penk, M.R., Devaney, F.M., Leyden, K.J., 2019. Saltmarsh Monitoring Project 2017- 2018, National Parks and Wildlife Service. Dublin.

Brummer, C.J., Abbe, T.B., Sampson, J.R., Montgomery, D.R., 2006. Influence of vertical channel change associated with wood accumulations on delineating channel migration zones, Washington, USA. Geomorphology 80, 295–309.

Brunke, M., Gonser, T., 1997. The ecological significance of exchange processes between rivers and groundwater. Freshw. Biol. 37, 1–33.

Bucior, A., Rippey, B., McElarney, Y., Douglas, R., 2021. Evaluating macrophytes as indicators of anthropogenic pressures in rivers in Ireland. Hydrobiologia 848, 1087–1099.

Bunn, S.E., Arthington, A.H., 2002. Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environ. Manage. 30, 492–507.

Burdon, D., Elliot, M., Möller, I., Roast, S., Spencer, T., 2009. Hydromorphological Literature Reviews for Transitional and Coastal Waters.Integrated Catchment Science programme Science report: SC060043/SR2. Cambridge, U.K.

Bureao de Recherches Géologiques et Minières, 2007. Case Study Status Report, Rhine River Basin. France: Aqua Money. https://www.ivm.vu.nl/en/Images/D27_Status_report_international_Rhine_case_study_tcm234-188710.pdf.

Burek, P., Mubareka, S., Rojas, R., De Roo, A., Bianchi, A., Baranzelli, C., Lavalle, C., Vandecasteele, I., 2012. Evaluation of the Effectiveness of Natural Water Retention Measures: Support to the EU Blueprint to Safeguard Europe's Waters. JRC Scientific and Policy Reports. Luxembourg.

Bussettini, M., Schmidt, R., 2022. Sediment mining: development and implementation of policies. In: Tockner, K., Mehner, T. (Eds.), Encyclopedia of Inland Waters. Elservier, Cambridge, U.K.

CAAS Ltd, 2020. Report on Consultation Submissions regarding the River Bride (Blackpool) Drainage Scheme. Cork, Ireland.

Camp, E.F., Suggett, D.J., Gendron, G., Jompa, J., Manfrino, C., Smith, D.J., 2016. Mangrove and seagrass beds provide different biogeochemical services for corals threatened by climate change. Front. Mar. Sci. 3.

Canham, C.A., Froend, R.H., Stock, W.D., 2015. Rapid root elongation by phreatophyte seedlings does not imply tolerance of water table decline. Trees 29, 815–824.

Canham, C.A., Froend, R.H., Stock, W.D., Davies, M., 2012. Dynamics of phreatophyte root growth relative to a seasonally fluctuating water table in a Mediterranean-type environment. Oecologia 170, 909–916.

Carere, M., Dulio, V., Hanke, G., Polesello, S., 2012. Guidance for sediment and biota monitoring under the Common Implementation Strategy for the Water Framework Directive. TrAC Trends Anal. Chem. 36, 15–24.

Carmignani, J.R., Roy, A.H., 2017. Ecological impacts of winter water level drawdowns on lake littoral zones: a review. Aquat. Sci. 79, 803–824.

Carniello, L., Defina, A., D'Alpaos, L., 2009. Morphological evolution of the Venice lagoon: Evidence from the past and trend for the future. J. Geophys. Res. 114.

Carriere, A., Reynaud, N., Gay, A., Baudoin, J.-M., Argillier, C., 2024. LHYMO: A new Water Framework Directive-compliant multimetric index to assess lake hydromorphology and its application to French lakes. Aquat. Conserv. Mar. Freshw. Ecosyst. 34.

Carvalho, L., Mackay, E.B., Cardoso, A.C., Baattrup-Pedersen, A., Birk, S., Blackstock, K.L., Borics, G., Borja, A., Feld, C.K., Ferreira, M.T., Globevnik, L., Grizzetti, B., Hendry, S., Hering, D., Kelly, M.G., Langaas, S., Meissner, K., Panagopoulos, Y., Penning, E., Rouillard, J., Sabater, S., Schmedtje, U., Spears, B.M., Venohr, M., van de Bund, W., Solheim, A.L., 2019. Protecting and restoring Europe's waters: An analysis of the future development needs of the Water Framework Directive. Sci. Total Environ. 658, 1228–1238.

Carvalho, L., Solimini, A.G., Phillips, G., Pietiläinen, O.-P., Moe, J., Cardoso, A.C., Lyche Solheim, A., Ott, I., Søndergaard, M., Tartari, G., Rekolainen, S., 2009. Site-specific chlorophyll reference conditions for lakes in Northern and Western Europe. Hydrobiologia 633, 59–66.

Casado-Arzuaga, I., Onaindia, M., Madariaga, I., Verburg, P.H., 2013. Mapping recreation and aesthetic value of ecosystems in the Bilbao Metropolitan Greenbelt (northern Spain) to support landscape planning. Landsc. Ecol. 29, 1393–1405.

CCME, 2007. A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life. In: Canadian Environmental Quality Guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg. Winnipeg, Canada.

CEN, 2010. Water quality – Guidance standard on determining the degree of modification of river hydromorphology. EN 15843:2010. Brussels, Belgium.

CEN, 2011. Water quality - Guidance standard on assessing the hydromorphological features of lakes. EN 16039:2011. Brussels, Belgium.

CEN, 2014. Water Quality – Guidance Standard on Assessing the Hydromorphological Features of Transitional and Coastal Waters. EN 16503:2014. Brussels, Belgium.

CEN, 2017. Water quality - Guidance standard on determining the degree of modification of lake hydromorphology. EN 16870. Brussels, Belgium.

CEN, 2018. Water quality - Guidance on determining the degree of modification of the hydromorphological features of transitional and coastal waters. EN 17123:2018. Brussels, Belgium.

CEN, 2020. Water quality - Guidance standard for assessing the hydromorphological features of rivers. EN 14614:2020. Brussels, Belgium.

Chainho, P., Chaves, M.L., Costa, J.L., Costa, M.J., Dauer, D.M., 2008. Use of multimetric indices to classify estuaries with different hydromorphological characteristics and different levels of human pressure. Mar. Pollut. Bull. 56, 1128–1137.

Chambers, P.A., Prepas, E.E., Hamilton, H.R., Bothwell, M.L., 1991. Current Velocity and Its Effect on Aquatic Macrophytes in Flowing Waters. Ecol. Appl. 1, 249–257.

Chapman, D. (ed. ., 1996. Water quality assessment—a guide to the use of biota, sediments and water in environmentalmonitoring. E & FN Spon, London.

Chen, Y., 2019. Withdrawal of European Soil Framework Directive: Reasons and Recommendations. J. Sustain. Dev. 13, 1.

Church, M., 1995. Geomorphic response to river flow regulation: Case studies and time-scales. Regul. Rivers Res. Manag. 11, 3–22.

Church, M., 2006. Bed material transport and the morphology of alluvial River Channels. Annu. Rev. Earth Planet. Sci. 34, 325–354.

Ciampittiello, M., Dresti, C., Saidi, H., 2017. A Review of Assessment Approaches for Lake Hydro-Morphology Before and After the European Water Framework Directive (WFD). Curr. World Environ. 12, 491–506.

Clapcott, J.E., Young, R.G., Harding, J.S., Matthei, C.D., Quinn, J.M., Death, R.G., 2011. Sediment Assessment Methods: Protocols and Guidelines for Assessing the Effects of Deposited Fine Sediment on In-Stream Values. Cawthron Institute, Nelson, New Zealand.

Clark, M.J., 2002. Dealing with uncertainty: adaptive approaches to sustainable river management. Aquat. Conserv. Mar. Freshw. Ecosyst. 12, 347–363.

Clarke, J., Kelly-Quinn, M., Blacklocke, S., Bruen, M., 2015. The effect of forest windrowing on physico-chemical water quality in Ireland. Sci. Total Environ. 514, 155–169.

Clarke, R.T., Wright, J.F., Furse, M.T., 2003. RIVPACS models for predicting the expected macroinvertebrate fauna and assessing the ecological quality of rivers. Ecol. Modell. 160, 219–233.

Clemmensen, T.J., 2014. Skjern River Restoration Counterfactual: Exploring a Palimpsestic Nature, Architecture, Design and Conservation - Danish Portal for Artistic and Scientific Research. Cophenhagan, Denmark.

Clifford, N.J., Harmar, O.P., Harvey, G.L., Petts, G.E., 2006. Physical habitat, eco-hydraulics and river design: A review and re-evaluation of some popular concepts and methods. Aquat. Conserv. Mar. Freshw. Ecosyst. 16, 389–408.

Cocchiglia, L., Purcell, P.J., Kelly-Quinn, M., 2012. A Critical Review of the Effects of Motorway River-Crossing Construction on the Aquatic Environment. Freshw. Rev. 5, 141–168.

Coghlan, B., Donovan, R., Keane, S., O'Leary, C., 2024. National Barriers Programme Annual Report 2023. Dublin, Ireland.

Collentine, D., Futter, M.N., 2018. Realising the potential of natural water retention measures in catchment flood management: trade-offs and matching interests. J. Flood Risk Manag. 11, 76–84.

Colleran, B., Lacy, S.N., Retamal, M.R., 2020. Invasive Japanese knotweed (Reynoutria japonica Houtt.) and related knotweeds as catalysts for streambank erosion. River Res. Appl. 36, 1962–1969.

Collier, M.J., Bourke, M., 2020. The case for mainstreaming nature-based solutions into integrated catchment management in ireland. Biol. Environ. 120B, 107–113.

Collins, A.J., Naden, P.S., Sear, D.A., Jones, J.I., Foster, I.D.L., Morrow, K., 2011. Sediment targets for informing river catchment management: international experience and prospects. Hydrol. Process. 25, 2112–2129.

Connolly, N., Cummins, V., 2001. Integrated Coastal Zone Management (ICZM) in Ireland, with particular reference to the use of Geographic Information Systems (GIS) and the EU ICZM Demonstration Programme. The Environmental Institute, UCD, Dublin, 1-902277-589 pp.

Conroy, E., Turner, J.N., Rymszewicz, A., Bruen, M., O'Sullivan, J.J., Lawler, D.M., Lally, H., Kelly-Quinn, M., 2016. Evaluating the relationship between biotic and sediment metrics using mesocosms and field studies. Sci. Total Environ. 568, 1092–1101.

Cooksley, S.L., Brewer, M.J., Donnelly, D., Spezia, L., Tree, A., 2012. Impacts of artificial structures on the freshwater pearl mussel Margaritifera margaritifera in the River Dee, Scotland. Aquat. Conserv. Mar. Freshw. Ecosyst. 22, 318–330.

Cooper, A., 2011. The River Shannon: A Journey Down Ireland's Longest River. Collins Press, Dublin, Ireland.

Cooper, J.A.G., Ramm, A.E.L., Harrison, T.D., 1994. The estuarine health index: A new

approach to scientific information transfer. Ocean Coast. Manag. 25.

Cork City Council, 2013. River Bride Trash Screen Assessment. Report by RPS. Cork, Ireland.

Cork County Council, 2019. Climate Adaptation Strategy. 2019-2024. Cork, Ireland.

Corlett, C., 2019. The Liffey Scheme and the Poulaphuca Reservoir - Part 1 [WWW Document]. URL https://www.christiaancorlett.com/the-liffey-scheme-and-the-poulaphuca-reservoir-part-1

Costa, S., Peters, R., Martins, R., Postmes, L., Keizer, J.J., Roebeling, P., 2021. Effectiveness of Nature-Based Solutions on Pluvial Flood Hazard Mitigation: The Case Study of the City of Eindhoven (The Netherlands). Resources 10 (3).

Cote, D., Kehler, D.G., Bourne, C., Wiersma, Y.F., 2009. A new measure of longitudinal connectivity for stream networks. Landsc. Ecol. 24, 101–113.

Cowx, I.G., Harvey, J.P., Noble, R.A., Nunn, A.D., 2009. Establishing survey and monitoring protocols for the assessment of conservation status of fish populations in river Special Areas of Conservation in the UK. Aquat. Conserv. Mar. Freshw. Ecosyst. 19, 96–103.

Coxon, C., 2011. Agriculture and Karst. In: van Beynen, P. (Ed.), Karst Management. Springer, Dordrecht, The Netherlands.

Coxon, C., Drew, D.P., 2000. Interdependence of groundwater and surface water in lowland karst areas of western Ireland: management issues arising from water and contaminant transfers. Geol. Soc. London, Spec. Publ. 182, 81–88.

Coxon, C.E., 1987. The spatial distribution of turloughs. Irish Geogr. 20, 11–23.

Crain, C.M., Gedan, K.B., Dionne, M., 2009. Anthropogenic Modification of North American Salt Marshes. In: Silliman, B.R., Bertness, M.D., Strong, D. (Eds.), . University of California Press. Berkeley, U.S.A.

Cullen, B., 2002. Some notable features of the design and operational history of Ardnacrusha since 1929. In: Bielenberg, A. (Ed.), The Shannon Scheme and the Electrification of the Irish Free State. The Lilliput press, Dublin, Ireland, pp. 138–154.

Cullen, P., Mccarthy, T.K., 2006. Going with the flow – Can managing flow regimes aid in promoting silver eel spawner escapement from the Irish River Shannon system? Power 1–13.

Cunha Pereira, H., Allott, N., Coxon, C., Naughton, O., Johnston, P., Gill, L., 2011. Phytoplankton of turloughs (seasonal karstic Irish lakes). J. Plankton Res. 33, 385–403.

Curry, R.A., Gehrels, J., Noakes, D.L.G., Swainson, R., 1994. Effects of river flow fluctuations on groundwater discharge through brook trout, Salvelinus fontinalis, spawning and incubation habitats. Hydrobiologia 277, 121–134.

Curtis, T., Downes, S., Ní Chatháin, B., 2009. the Ecological Requirements of Water-Dependent Habitats and Species Designated Under the Habitats Directive. Biol. Environ. Proc. R. Irish Acad. 109, 261–319.

Cyr, H., Downing, J.A., 1988. Empirical Relationships of Phytomacrofaunal Abundance to Plant Biomass and Macrophyte Bed Characteristics. Can. J. Fish. Aquat. Sci. 45, 976–984.

Dadson, S.J., Hall, J.W., Murgatroyd, A., Acreman, M., Bates, P., Beven, K., Heathwaite, L., Holden, J., Holman, I.P., Lane, S.N., O'Connell, E., Penning-Rowsell, E., Reynard, N., Sear, D., Thorne, C., Wilby, R., 2017. A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. Proc. R. Soc. A

Math. Phys. Eng. Sci. 473, 20160706.

DAFM, 2015. Food Wise 2025. A 10-year vision for the Irish agri-food industry. Department of Agriculture, Fisheries and Food. Dublin, Ireland.

DAFM, 2018. DRAFT Plan for Forests & Freshwater Pearl Mussel in Ireland. Department of Agriculture, Fisheries and Food. Dublin, Ireland.

Dahm, V., Hering, D., Nemitz, D., Graf, W., Schmidt-Kloiber, A., Leitner, P., Melcher, A., Feld, C.K., 2013. Effects of physico-chemistry, land use and hydromorphology on three riverine organism groups: A comparative analysis with monitoring data from Germany and Austria. Hydrobiologia 704, 389–415.

Dam Removal Europe, 2017. Sofieholm hydroelectric powerplant, River Nianån, Sweden.

Darwall, W.R.T., Bremerich, V., De Wever, A., Dell, A.I., Freyhof, J., Gessner, M.O., Grossart, H.-P., Harrison, I., Irvine, K., Jähnig, S.C., Jeschke, J., Lee, J.J., Lu, C., Lewandowska, A.M., Monaghan, M.T., Nejstgaard, J.C., Patricio, H., Schmidt-Kloiber, A., Stuart, S.N., Thieme, M., Tockner, K., Turak, E., Weyl, O., 2018. The Alliance for Freshwater Life : A global call to unite efforts for freshwater biodiversity science and conservation. Aquat. Conserv. Mar. Freshw. Ecosyst. 28, 1015–1022.

Davidson, N.C., Dinesen, L., Fennessy, S., Finlayson, C.M., Grillas, P., Grobicki, A., McInnes, R.J., Stroud, D.A., 2020. Trends in the ecological character of the world's wetlands. Mar. Freshw. Res. 71, 127.

Davis, M., Krüger, I., Hinzmann, M., 2015. Coastal Protection and SUDS: Nature-Based Solutions. RECREATE Policy Brief No. 4. Ecologic Institute. Berlin, Germany.

Dawson, F.H., Raven, P.J., Gravelle, M.J., 1999. Distribution of the morphological groups of aquatic plants for rivers in the U.K. Hydrobiologia 415, 123–130.

DCHG, 2022. National Raised Bog Special Areas. Dublin, Ireland.

De Conto, R.M., Pollard, D., 2016. Contribution of Antarctica to past and future sea-level rise. Nature 531, 591–597.

de Groot, R., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol. Complex. 7, 260–272.

de Jonge, V.N., Elliott, M., 2001. Eutrophication. In: Steele, J.H. (Ed.), Encyclopedia of Ocean Sciences. Elservier, pp. 271–288.

de Louw, P.G.B., Griffioen, J., Van den Eertwegh, G.A.P.H., 2000. High nutrient and chloride loads to surface water in polder areas due to groundwater seepage. In: Sililo, O. (Ed.), Past Achievements and Future Challenges. A.A. Balkema, Cape Town, South Africa, pp. 418–486.

de Wit, R., 2011. Biodiversity of Coastal Lagoon Ecosystems and Their Vulnerability to Global Change. Ecosyst. Biodivers.

de Wit, R., Leruste, A., Le Fur, I., Sy, M.M., Bec, B., Ouisse, V., Derolez, V., Rey-Valette, H., 2020. A Multidisciplinary Approach for Restoration Ecology of Shallow Coastal Lagoons, a Case Study in South France. Front. Ecol. Evol. 8.

Deakin, J., Flynn, R., Archbold, M., Daly, D., O'Brien, R., Orr, A., Misstear, B.D., 2016. Understanding pathways transferring nutrients to streams: review of a major Irish study and its implications for determining water quality management strategies. Biol. Environ. Proc. R. Irish Acad. 116B, 233.

DEARA, 2009. River Hydromorphology Assessment Technique (RHAT). Final Report.

Department of Agriculture, Environment and Rural Affairs. Belfast, UK.

DEARA, 2016. An Evaluation of Nutrient Loading to the Freshwater Lakes, Estuarine Waters and Sea Loughs of Northern Ireland (Nutrient Budget and SIMCAT Analysis) AFBI-NIEA SLA Project Code WTE 407. Department of Agriculture, Environment and Rural Affairs, Belfast, U.K.

DEARA, 2017. Surface Waters Alterations Handbook. Department of Agriculture, Environment and Rural Affairs. Belfast, U.K.

Death, R.G., Collier, K.J., 2009. Measuring stream macroinvertebrate responses to gradients of vegetation cover: when is enough enough? Freshw. Biol. 55, 1447–1464.

Dedić, A., Gerhardt, A., Kelly, M.G., Stanić-Koštroman, S., Šiljeg, M., Stroil, B.K., Kamberović, J., Mateljak, Z., Pešić, V., Vučković, I., Snigirova, A., Bogatova, Y., Barinova, S., Radulović, S., Cvijanović, D., Lasić, A., Škobić, D., Sudar, A., Mrđen, D., Herceg, N., 2020. Innovative methods and approaches for WFD: ideas to fill knowledge gaps in science and policy. Water Solut. 3, 30–42.

Dedić, A., Hafner, D., Grizelj, Z., 2012. Diatoms in karstic springs of Trebižat River (Bosnia and Herzegovina). . 8th Cent. Eur. Diatom Meet. Zagreb. Croat.

Degefu, D.M., Weijun, H., Zaiyi, L., Liang, Y., Zhengwei, H., Min, A., 2018. Mapping Monthly Water Scarcity in Global Transboundary Basins at Country-Basin Mesh Based Spatial Resolution. Sci. Rep. 8, 1–10.

Degerman, E., Tamario, C., Watz, J., Nilsson, P.A., Calles, O., 2019. Occurrence and habitat use of European eel (Anguilla anguilla) in running waters: lessons for improved monitoring, habitat restoration and stocking. Aquat. Ecol. 53, 639–650.

DEHLG, 2009. Appropriate Assessment of Plans and Projects in Ireland: Guidance for Planning Authorities. Department of Environment, Housing and Local Government. Dublin, Ireland.

Demars, B.O.L., Potts, J.M., Trémolières, M., Thiébaut, G., Gougelin, N., Nordmann, V., 2012. River macrophyte indices: not the Holy Grail! Freshw. Biol. 57, 1745–1759.

Dewson, Z.S., James, A.B.W., Death, R.G., 2007. Stream Ecosystem Functioning Under Reduced Flow Conditions. Ecol. Appl. 17, 1797–1808.

DHLGH, 2018. EU Water Framework Directive-Department of Housing, Local Government and Heritage. Dublin, Ireland.

DHLGH, 2021. Draft River Basin Management Plan for Ireland 2022-2027. Department of Housing, Local Government and Heritage, Government of Ireland. Dublin, Ireland.

DHLGH, 2024a. Water Action Plan 2024. A River Basin Management Plan for Ireland. Dublin, Ireland.

DHLGH, 2024b. Nature Based Management of Urban Rainwater and Urban. Dublin, Ireland.

DHLGH, 2025. Designation of Ireland’s Heavily Modified Water Bodies arising out of the 2024 Water Action Plan (Consultation Document). Dublin, Ireland.

DHPLG, 2018a. Guidelines for Planning Authorities and An Bord Pleanála on carrying out Environmental Impact Assessment. Department of Housing, Planning and Local Government, Government of Ireland. Dublin, Ireland.

DHPLG, 2018b. River Basin Management Plan for Ireland 2018-2021. Department of Housing, Planning and Local Government, Government of Ireland. Dublin, Ireland.

Díaz-Casallas, D.M., Castro-Fernández, M.F., Bocos, E., Montenegro-Marin, C.E., González

Crespo, R., 2019. 2008–2017 Bogota River Water Quality Assessment based on the Water Quality Index. Sustainability 11, 1668.

Diehl, S., Kornijów, R., 1998. Influence of submerged plants on trophic interactions among fish amd macroinvertebrates. In: Jeppesen, E., Söndergaard, M., Söndergaard, Mo., Christoffersen, K. (Eds.), The Structuring Role of Submerged Macrophytes in Lakes. Springer, New York, pp. 24–46.

Diez, J.R., Elosegi, A., Pozo, J., 2001. Woody Debris in North Iberian Streams: Influence of Geomorphology, Vegetation, and Management. Environ. Manage. 28, 687–698.

Dolédec, S., Philips, N., Townsend, C., 2011. Invertebrate community responses to land use at a broad spatial scale: trait and taxonomic measures compared in New Zealand rivers. Freshw. Biol. 56, 1670–1688.

Donadi, S., Sandin, L., Tamario, C., Degerman, E., 2019. Country-wide analysis of large wood as a driver of fish abundance in Swedish streams: Which species benefit and where? Aquat. Conserv. Mar. Freshw. Ecosyst. 29, 706–716.

Donohue, I., Duck, R.W., Irvine, K., 2003. Land use, sediment loads and dispersal pathways from two catchments at the southern end of Lake Tanganyika, Africa: implications for lake management. Environ. Geol. 44, 448–455.

Donohue, I., Leira, M., Hobbs, W., León-vintró, L., O'Reilly, J., Irvine, K., 2010. Rapid ecosystem recovery from diffuse pollution after the Great Irish Famine. Ecol. Appl. 20, 1733–1743.

Donovan, R., Coghlan, B., O'Briain, R., O'Connell, A., O'Leary, C., 2023. River Boyne WFD III Barrier Assessment Obstacles to Fish Passage and Mitigation Options. Dublin, Ireland.

Drew, D., 1996. Agriculturally induced environmental changes in the Burren Karst, Western Ireland. Environ. Geol. 28, 137–144.

Drew, D.P., 1984. The effects of human activity on a lowland karst aquifer. In: Burger, A., Dubertret, L. (Eds.), Hydrogeology of Karstic Terrains - Case Histories. International Contributions to Hydrogeology 1, pp. 195–199.

Drew, D.P., 2008. Hydrogeology of lowland karst in Ireland. Q. J. Eng. Geol. Hydrogeol. 41, 61–72.

Drew, D.P., 2018. Karst of Ireland: Landscape Hydrogeology Methods. Geological Survey Ireland, Dublin, Ireland.

Drew, D.P., Coxon, C.E., 1988. The effects of land drainage on groundwater resources in karstic areas of Ireland. In: Yuan, D. (Ed.), Proceedings of the International Association of Hydrogeologists 21st Congress of Karst Hydrogeology and Karst Environment Protection, 4. Geological Publishing House, Beijing, China., pp. 204–209.

Drew, D.P., Magee, E., 1994. Environmental Implications of Land Reclamation in the Burren, Co. Clare: a preliminary analysis. Irish Geogr. 27, 81–96.

Dubgaard, A., Kallesøe, M.F., Ladenburg, J., Petersen, M.L., 2003. Cost-benefit analysis of the Skjern river restoration in Denmark. In: Brouwer, R., Pearce, D. (Eds.), Cost-Benefit Analysis and Water Resources Management. Edward Elgar Publishing, Cheltenham, U.K.

Dublin City Council, 2009. Eastern River Basin District Project: Abstractions- National POM/Standards Study Revised Risk Assessment Methodology for Surface Water Abstractions from Lakes. Doc Ref: 39325/AB40/DG51 Final. January 2009. Dublin, Ireland.

Dudgeon, D., 2010. Prospects for sustaining freshwater biodiversity in the 21st century: linking ecosystem structure and function. Curr. Opin. Environ. Sustain. 2, 422–430.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.-I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.-H., Soto, D., Stiassny, M.L.J., Sullivan, C.A., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biol. Rev. 81, 163–182.

Duerdoth, C.P., Arnold, A., Murphy, J.F., Naden, P.S., Scarlett, P., Collins, A.L., Sear, D.A., Jones, J.I., 2015. Assessment of a rapid method for quantitative reach-scale estimates of deposited fine sediment in rivers. Geomorphology 230, 37–50.

Dworak, T., Kampa, E., 2018. Workshop on hydro-morphological measures under the Floods and Water Framework Directives. Finding synergies and addressing challenges. European Commission, Brussels, Belgium.

Eamus, D., Froend, R., 2006. Groundwater-dependent ecosystems: the where, what and why of GDEs. Aust. J. Bot. 54.

Eamus, D., Froend, R., Loomes, R., Hose, G., Murray, B., 2006. A functional methodology for determining the groundwater regime needed to maintain the health of groundwater-dependent vegetation. Aust. J. Bot. 54.

Eaton, B.C., Lapointe, M.F., 2001. Effects of large floods on sediment transport and reach morphology in the cobble-bed Sainte Marguerite River. Geomorphology 40, 291–309.

Echolive.ie, 2019. Cork floods 2009: Remembering one of the city's worst disasters ten years on.

EEA, 2017. Green Infrastructure and Flood Management: Promoting cost-efficient flood risk reduction via green infrastructure solutions, Publications Office of the European Union, Luxembourg. Luxembourg.

EEA, 2018. European waters - Assessment of status and pressures. EEA Report No 7/2018. European Environment Agency, Publications Office of the European Union. Luxembourg, Luxembourg.

EEA, 2019. The European environment-state and outlook 2020. Knowledge for transition to a sustainable Europe. European Environment Agency, Publications Office of the European Union. European Environment Agency, Publications Office of the European Union, Luxembourg, Luxembourg.

EEA, 2020. Floodplains: a natural system to preserve and restore, Report: EEA N024. European Environment Agency, Publications Office of the European Union. Luxembourg, Luxembourg.

Eggleton, J., Thomas, K. V, 2004. A review of factors affecting the release and bioavailability of contaminants during sediment disturbance events. Environ. Int. 30, 973–980.

Elias, J.E., Meyer, M.W., 2003. Comparisons of undeveloped and developed shorelands, northern Wisconsin, and recommendations for restoration. Wetlands 23, 800–816.

Elliott, M., Whitfield, A.K., 2011. Challenging paradigms in estuarine ecology and management. Estuar. Coast. Shelf Sci. 94, 306–314.

Ellis, J., 2006. Uncertainty estimation for monitoring results by the WFD biological classification tools. Science Report to the UK Environment Agency.

England, J., Skinner, K.S., Carter, M.G., 2008. Monitoring, river restoration and the water framework Directive. Water Environ. J. 22, 227–234.

ENV/Arcadis, D.G., Floecksmühle, I., 2011. Hydropower Generation in the context of the EU

WFD Contract N° 070307 / 2010 / 574390 EC DG Environment Project number 11418, version 5, 12-05-2011. Brussels, Belgium.

EPA, 2017. Draft Upper Shannon (Inny) Catchment Assessment (HA 26F). Catchment Science & Management Unit, Volume 1. Environment Protection Agency, Wexford, Ireland.

EPA, 2018a. Liffey Catchment Assessment 2010-2015, Catchment Science & Management Unit. Environment Protection Agency, Wexford, Ireland.

EPA, 2018b. Dunmanus-Bantry-Kenmare Catchment Assessment 2010-2015. Environment Protection Agency, Wexford, Ireland.

EPA, 2019. Ireland's Catchment Flood Risk Assessment and Management (CFRAM) Programme. Environment Protection Agency, Wexford, Ireland.

EPA, 2020. Water quality in 2019, an indicators report. Environment Protection Agency, Wexford, Ireland.

EPA, 2021a. Ireland's National Water Framework Directive Monitoring Programme 2019–2021. Wexford, Ireland.

EPA, 2021b. 3rd Cycle Lower Shannon (Lough Derg) Catchment Report (HA 25C). Environment Protection Agency, Wexford, Ireland.

EPA, 2021c. Appendix B: Review of the National hydrometric monitoring programme. Environment Protection Agency, Wexford, Ireland.

EPA, 2021d. 3rd Cycle Draft Dunmanus-Bantry-Kenmare Catchment Report. Environment Protection Agency, Wexford, Ireland.

EPA, 2022a. Review of Ireland's Heavily Modified Water Body Designations for the Third Cycle River Basin Management Plan. Environment Protection Agency, Wexford, Ireland.

EPA, 2022b. Water Quality in Ireland 2016-2021. Environment Protection Agency, Wexford, Ireland.

EPA, 2024a. Targeting Measures for Water Quality Outcomes. Analysis of the gap to achieving Water Framework Directive Environmental Objectives. Wexford, Ireland.

EPA, 2024b. Water Quality in Ireland. Environmental Protection Agency, Wexfored, Ireland.

Erba, S., Furse, M.T., Balestrini, R., Christodoulides, A., Ofenböck, T., van de Bund, W., Wasson, J.-G., Buffagni, A., 2009. The validation of common European class boundaries for river benthic macroinvertebrates to facilitate the intercalibration process of the Water Framework Directive. Hydrobiologia 633, 17–31.

ESB, 2020. ESB Fisheries Conservation. Non Financial Annual Report. Electricity Supply Board. Dublin, Ireland.

European Commission, 2003a. Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance document No 2. Identification of Water Bodies. Produced by Working Group on Water Bodies. Luxembourg, Luxembourg.

European Commission, 2003b. Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Policy Summary to Guidance Document No. 10. Rivers and Lakes - typology, reference conditions and classification systems. Working Group 2.3 - REFCOND. Brussels, Belgium.

European Commission, 2003c. Common implementation strategy for the Water Framework Directive (2000/60/EC). Guidance Document No 3 - Analysis of Pressures and Impacts.

Brussels, Belgium.

European Commission, 2003d. Toolbox on identification and designation of Artificial and Heavily Modified Water Bodies CIS Working Group 2.2 on Heavily Modified Water Bodies. Brussels, Belgium.

European Commission, 2003e. Common Implementation Strategy for The Water Framework Directive (2000/60/EC). Guidance Document No 12. Horizontal Guidance on the Role of Wetlands in the Water Framework Directive. Brussels, Belgium.

European Commission, 2003f. Common Implementation Strategy for The Water Framework Directive (2000/60/EC). Identification and Designation of Heavily Modified and Artificial Water Bodies. Guidance Document No. 4. Luxembourg, Luxembourg.

European Commission, 2006. WFD and Hydromorphological Pressures. Technical Report. “Good practice in managing the ecological impacts of hydropower schemes; flood protection works; and works designed to facilitate navigation under the Water Framework Directive. Brussels, Belgium.

European Commission, 2007. WFD and Hydro-morphological pressures Policy Paper. Focus on hydropower, navigation and flood defence activities. Recommendations for better policy integration. Brussels, Belgium.

European Commission, 2011. Our life insurance, our natural capital: An EU biodiversity strategy to 2020. Communication from the Commission to the European Parliament, The Council, The Economic and Social Committee and The Committee of the Regions COM(2011) 244.

European Commission, 2012. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Blueprint to Safeguard Europe’s Water Resources, Com (2012).

European Commission, 2013. Green Infrastructure (GI): Enhancing Europe’s Natural Capital. Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions. COM/2013/0249 final. Brussels, EC. eur-l. Brussels, Belgium.

European Commission, 2015a. Assessment of Member States’ progress in the implementation of Programmes of Measures during the first planning cycle of the Water Framework Directive 1–33.

European Commission, 2015b. Ecological flows in the implementation of the Water Frame_work Directive. Guidance Document No. 31. Technical Report - 2015 – 086. Luxembourg, Luxembourg.

European Commission, 2015c. Common Implementation Strategy. Technical Report No. 9 on Groundwater Associated Aquatic Ecosystems. Luxembourg, Luxembourg.

European Commission, 2018a. Commission decision (EU) 2018/229 of 12 February 2018 establishing, pursuant to directive 2000/60/EC of the European Parliament and of the council, the values of the member state monitoring system classifications as a result of the intercalibration. Off. J. Eur. Communities L47, 1–91.

European Commission, 2018b. Guidance on The requirements for hydropower in relation to Natura 2000. European Commission. Brussels, Belgium.

European Commission, 2019a. Common Implementation Strategy. Guidance Document No. 37 Steps for defining and assessing ecological potential for improving comparability of Heavily Modified Water Bodies. Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Luxembourg, Luxembourg.

European Commission, 2019b. Fitness Check of the Water Framework Directive and the Floods Directive. Https://Ec.Europa.Eu/ 1–184.

European Commission, 2021. Biodiversity Strategy 2030 Barrier Removal for River Restoration. Brussels, Belgium.

European Environmental Bureau, 2010. 10 years of the Water Framework Directive : A Toothless Tiger ? A snapshot assessment of EU environmental ambitions. Brussels Belgium.

Evtimova, V. V., Donohue, I., 2014. Quantifying ecological responses to amplified water level fluctuations in standing waters: an experimental approach. J. Appl. Ecol. 51, 1282–1291.

Evtimova, V. V., Donohue, I., 2016. Water-level fluctuations regulate the structure and functioning of natural lakes. Freshw. Biol. 61, 251–264.

Facca, C., Cavraro, F., Franzoi, P., Malavasi, S., 2020. Lagoon Resident Fish Species of Conservation Interest According to the Habitat Directive (92/43/CEE): A Review on Their Potential Use as Ecological Indicator Species. Water 12.

Falkenmark, M., Finlayson, C.M., Gordon, L., 2007. Agriculture, water, and ecosystems: avoiding the costs of going too far. In: Molden, D. (Ed.), Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Earthscan, London, pp. 234–277.

Faller, M., Harvey, G.L., Henshaw, A.J., Bertoldi, W., Bruno, M.C., England, J., 2016. River bank burrowing by invasive crayfish: Spatial distribution, biophysical controls and biogeomorphic significance. Sci. Total Environ. 569–570, 1190–1200.

Fehér, J., Gáspár, J., Veres, K.S., Kiss, A., Kristensen, P., Peterlin, M., Globevnik, L., Kirn, T., Semerádová, S., Künitzer, A., Stein, U., Austnes, K., Spiteri, C., Prins, T., Laukkonen, E., Heiskanen, A.-S., 2012. Hydromorphological alterations and pressures in European rivers, lakes, transitional and coastal waters. ETC/ICM Technical Report 2/2012, ETC/ICM Technical Report. European Topic Centre on Inland, Coastal and Marine Waters, Prague, Czech Republic.

Fekete, A., Sandholz, S., 2021. Here comes the flood, but not failure? Lessons to learn after the heavy rain and pluvial floods in germany 2021. Water (Switzerland) 13, 1–20.

Feld, C.K., 2004. Identification and measure of hydromorphological degradation in Central European lowland streams. Hydrobiologia 516, 69–90.

Feld, C.K., Birk, S., Bradley, D.C., Hering, D., Kail, J., Marzin, A., Melcher, A., Nemitz, D., Pedersen, M.L., Pletterbauer, F., Pont, D., Verdonschot, P.F.M., Friberg, N., 2011. From Natural to Degraded Rivers and Back Again. In: Woodward, G. (Ed.), Advances in Ecological Research, Vol .44. Elsevier Ltd., Amsterdam, pp. 119–209.

Fennessy, M.S., Jacob, A.D., Kentula, M.E., 2004. Review of rapid assessment methods for wetland condition. Washington D.C., U.S.A.

Fernandez, D., Barquin, J., Raven, P.J., 2011. A review of river habitat characterisation methods: indices vs. characterisation protocols. Limnetica 30, 217–234.

Foley, M.M., Bellmore, J.R., O'Connor, J.E., Duda, J.J., East, A.E., Grant, G.E., Anderson, C.W., Bountry, J.A., Collins, M.J., Connolly, P.J., Craig, L.S., Evans, J.E., Greene, S.L., Magilligan, F.J., Magirl, C.S., Major, J.J., Pess, G.R., Randle, T.J., Shafroth, P.B., Torgersen, C.E., Tullos, D., Wilcox, A.C., 2017. Dam removal: Listening in. Water Resour. Res. 53, 5229–5246.

Forest Service, 2008. Forestry and Freshwater Pearl Mussel Requirements Site Assessment

and Mitigation Measures. Dublin, Ireland.

Foster, G.N., Nelson, B.H., Bilton, D.T., Lott, D.A., Merritt, R., Weyl, R.S., Eyre, M.D., 1992. A classification and evaluation of Irish water beetle assemblages. Aquat. Conserv. Mar. Freshw. Ecosyst. 2.

Foulds, S.A., Macklin, M.G., 2006. Holocene land-use change and its impact on river basin dynamics in Great Britain and Ireland. Prog. Phys. Geogr. Earth Environ. 30, 589–604.

FOWG, 2001. Flood Control at Rivers and Streams. Berne, Switzerland.

Fox, G.A., Wilson, G. V., 2010. The Role of Subsurface Flow in Hillslope and Stream Bank Erosion: A Review. Soil Sci. Soc. Am. J. 74, 717–733.

Franca, M.J., Juez, C., Kurniawan, A., Zemann, M., 2022. Case studies of sediment mining activity. In: Tockner, K., Mehner, T. (Eds.), Encyclopedia of Inland Waters. Elsevier.

Francis, T.B., Schindler, D.E., 2009. Shoreline urbanization reduces terrestrial insect subsidies to fishes in North American lakes. Oikos 118, 1872–1882.

Friberg, N., Angelopoulos, N.V., Buijse, A.D., Cowx, I.G., Kail, J., Moe, T.F., Moir, H., O'Hare, M.T., Verdonschot, P.F.M., Wolter, C., 2016. Effective River Restoration in the 21st Century. Adv. Ecol. Res. 55, 535–611.

Friberg, N., Sandin, L., Pedersen, M.L., 2009. Assessing the effects of hydromorphological degradation on macroinvertebrate indicators in rivers: Examples, constraints, and outlook. Integr. Environ. Assess. Manag. 5, 86–96.

Fritioff, Å., Kautsky, L., Greger, M., 2005. Influence of temperature and salinity on heavy metal uptake by submersed plants. Environ. Pollut. 133, 265–274.

Froend, R., Sommer, B., 2010. Phreatophytic vegetation response to climatic and abstraction-induced groundwater drawdown: Examples of long-term spatial and temporal variability in community response. Ecol. Eng. 36.

Fryirs, K.A., 2015. Developing and using geomorphic condition assessments for river rehabilitation planning, implementation and monitoring. WIREs Water 2.

Gabel, F., Lorenz, S., Stoll, S., 2017. Effects of ship-induced waves on aquatic ecosystems. Sci. Total Environ. 601–602, 926–939.

Ganic, E., 2021. Maintenance dredging in full swing at Port of Waterford - Dredging Today. https://www.dredgingtoday.com/2021/04/28/maintenance-dredging-in-full-swing-at-port-of-waterford/.

García de Jalón, D., Alonso, C., González del Tánago, M., Martinez, V., Gurnell, A.M., Lorenz, S., Wolter, C., Rinaldi, M., Belletti, B., Mosselman, E., Hendriks, D., Geerling, G., 2013. Review on pressure effects on hydromorphological variables and ecologically relevant processes. REFORM Deliverable D1.2 Report to the European Union.

García Molinos, J., Donohue, I., 2011. Temporal variability within disturbance events regulates their effects on natural communities. Oecologia 166, 795–806.

García, P., Zapico, E., Colubi, A., 2009. An angiosperm quality index (AQI) for Cantabrian estuaries. Ecol. Indic. 9, 856–865.

Gautier, E., Piégay, H., Bertaina, P., 2000. A methodological approach of fluvial dynamics oriented towards hydrosystem management: case study of the Loire and Allier rivers. Geodin. Acta 13, 29–43.

Gerber, E., Krebs, C., Murrell, C., Moretti, M., Rocklin, R., Schaffner, U., 2008. Exotic invasive knotweeds (Fallopia spp.) negatively affect native plant and invertebrate

assemblages in European riparian habitats. Biol. Conserv. 141, 646–654.

Gerge, S.E., Dixon, M.D., Turner, M.G., 2002. Consequences of human-altered floods: levees, floods, and floodplain forests along the Wisconsin River. Ecol. Appl. 12, 1755–1770.

Germaine, M.A., Lespez, L., 2017. The failure of the largest project to dismantle hydroelectric dams in Europe? (Sélune River, France, 2009-2017). Water Altern. 10, 655–676.

Gieswein, A., Hering, D., Feld, C.K., 2017. Additive effects prevail: The response of biota to multiple stressors in an intensively monitored watershed. Sci. Total Environ. 593–594, 27–35.

Gilligan, N., Quinlan, E., 2020. Ireland Changing the Scale of Heavily Modified Waters Bodies Designated under the Water Framework Directive. Irish Natl. Hydrol. Conf. 2020.

Golosov, V., Walling, D.E., 2019. Erosion and sediment problems: global hotspots. Paris, France.

González del Tánago, M., Martínez-Fernández, V., Aguiar, F.C., Bertoldi, W., Dufour, S., García de Jalón, D., Garófano-Gómez, V., Mandzukovski, D., Rodríguez-González, P.M., 2021. Improving river hydromorphological assessment through better integration of riparian vegetation: Scientific evidence and guidelines. J. Environ. Manage. 292.

González del Tánago, M.G., García de Jalón, D., 2011. Riparian Quality Index (RQI): A methodology for characterising and assessing the environmental conditions of riparian zones. Limnetica 30, 235–254.

Goodwillie, R., Reynolds, J.D., 2003. Turloughs. In: Otte, M.L. (Ed.), Wetlands of Ireland. University College Dublin Press., pp. 130–134.

Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J., Nathan, R.J., 2004. Stream Hydrology: An Introduction for Ecologists, 2nd ed. John Wiley and Sons, Chichester, U.K.

Göthe, E., Degerman, E., Sandin, L., Segersten, J., Tamario, C., Mckie, B.G., 2019. Flow restoration and the impacts of multiple stressors on fish communities in regulated rivers. J. Appl. Ecol. 56, 1687–1702.

Government of Ireland, 2005. The Characterisation and Analysis of Ireland's River Basin Districts in accordance with Section 7(2 and 3) of the European Communities (Water Policy) Regulations 2003 (SI 722 of 2003). Summary report.

Grabowski, R.C., Gurnell, A.M., 2016. Diagnosing problems of fine sediment delivery and transfer in a lowland catchment. Aquat. Sci. 78, 95–106.

Grabowski, R.C., Gurnell, A.M., Burgess-Gamble, L., England, J., Holland, D., Klaar, M.J., Morrissey, I., Uttley, C., Wharton, G., 2019. The current state of the use of large wood in river restoration and management. Water Environ. J. wej.12465.

Grant, G.E., Schmidt, J.C., Lewis, S.L., 2003. The Geomorphic Response of Gravel-Bed Rivers to Dams: Perspectives and Prospects. In: O'Connor, J.E., Grant, G.E. (Eds.), A Peculiar River: Geology, Geomorphology, and Hydrology of the Deschutes River, Oregon. Water Science and Application Series Volume 7. Washington, DC: American Geophysical Union: 209-225. pp. 205–225.

Green, P. a., Vörösmarty, C., Harrison, I., Farrell, T., Sáenz, L., Fekete, B.M., 2015. Freshwater ecosystem services supporting humans: Pivoting from water crisis to water solutions. Glob. Environ. Chang. 34, 108–118.

Green, T.R., Beavis, S.G., Dietrich, C.R., Jakeman, A.J., 1999. Relating stream-bank erosion to in-stream transport of suspended sediment. Hydrol. Process. 13, 777–787.

Greenwood, P., Baumann, P., Pulley, S., Kuhn, N.J., 2018. The invasive alien plant, Impatiens glandulifera (Himalayan Balsam), and increased soil erosion: causation or association? Case studies from a river system in Switzerland and the UK. J. Soils Sediments 18, 3463–3477.

Gregory, K.J., 2006. The human role in changing river channels. Geomorphology 79, 172–191.

Griebler, C., Stein, H., Kellermann, C., Berkhoff, S., Brielmann, H., Schmidt, S., Selesi, D., Steube, C., Fuchs, A., Hahn, H.J., 2010. Ecological assessment of groundwater ecosystems – Vision or illusion? Ecol. Eng. 36.

Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., Babu, S., Borrelli, P., Cheng, L., Crochetiere, H., Ehalt Macedo, H., Filgueiras, R., Goichot, M., Higgins, J., Hogan, Z., Lip, B., McClain, M.E., Meng, J., Mulligan, M., Nilsson, C., Olden, J.D., Opperman, J.J., Petry, P., Reidy Liermann, C., Sáenz, L., Salinas-Rodríguez, S.A., Schelle, P., Schmitt, R.J.P., Snider, J., Tan, F., Tockner, K., Valdujo, P.H., van Soesbergen, A., Zarfl, C., 2019. Mapping the world's free-flowing rivers. Nature 569, 215–221.

Grizzetti, B., Pistocchi, A., Liquete, C., Udias, A., Bouraoui, F., van de Bund, W., 2017. Human pressures and ecological status of European rivers. Sci. Rep. 7, 205.

Grober, U., 2012. Sustainability. A cultural history. Green Books, Totnes, UK.

Guérin, R., Baltassat, J.-M., Boucher, M., Chalikakis, K., Galibert, P.-Y., Girard, J.-F., Plagnes, V., Valois, R., 2009. Geophysical characterisation of karstic networks – Application to the Ouysse system (Poumeyssen, France). Comptes Rendus Geosci. 341.

Gunnell, K., Mulligan, M., Francis, R.A., Hole, D.G., 2019. Evaluating natural infrastructure for flood management within the watersheds of selected global cities. Sci. Total Environ. 670, 411–424.

Gurnell, A.M., Bertoldi, W., Corenblit, D., 2012. Changing river channels: The roles of hydrological processes, plants and pioneer fluvial landforms in humid temperate, mixed load, gravel bed rivers. Earth-Science Rev. 111, 129–141.

Gurnell, A.M., England, J., Burgess-Gamble, L., 2019. Trees and wood: working with natural river processes. Water Environ. J. 33, 342–352.

Gurnell, A.M., González del tánago, M., O'Hare, M.T.T., van Oorschot, M., Belletti, B., Buijse, T., García De Jalón, D., Grabowski, R., Hendriks, D., Mountford, O., Rinaldi, M., Solari, L., Szewczyk, M., Vargas-Luna, A., García De Jalón, D., Grabowski, R., Hendriks, D., Mountford, O., Rinaldi, M., Solari, L., Szewczyk, M., Vargas-Luna, A., García De Jalón, D., Grabowski, R., Hendriks, D., Mountford, O., Rinaldi, M., Solari, L., Szewczyk, M., Vargas-Luna, A., 2014. Influence of Natural Hydromorphological Dynamics on Biota and Ecosystem Function, Part 1 (Chapters 1 to 3 of 6). Deliverable 2.2.1, of REFORM (REstoring rivers FOR effective catchment Management). Brussels, Belgium.

Gurnell, A.M., Gregory, K.J., Petts, G.E., 1995. The role of coarse woody debris in forest aquatic habitats: Implications for management. Aquat. Conserv. Mar. Freshw. Ecosyst. 5, 143–166.

Gurnell, A.M., Lee, M., Souch, C., 2007. Urban Rivers: Hydrology, Geomorphology, Ecology and Opportunities for Change. Geogr. Compass 1, 1118–1137.

Gurnell, A.M., O'Hare, J.M., O'Hare, M.T., Dunbar, M.J., Scarlett, P.M., 2010. An exploration of associations between assemblages of aquatic plant morphotypes and channel geomorphological properties within British rivers. Geomorphology 116, 135–144.

Gurnell, A.M., Rinaldi, M., Belletti, B., Bizzi, S., Blamauer, B., Braca, G., Buijse, A.D., Bussettini, M., Camenen, B., Comiti, F., Demarchi, L., García de Jalón, D. Grabowski, R., Hendriks, D., Mountford, O., Rinaldi, M., Solari, L., Szewczyk, M. Vargas-Luna, A., González del Tánago, M., Grabowski, R.C., Gunn, I.D.M., Habersack, H., Hendriks, D., Henshaw, A.J., Klösch, M., Lastoria, B., Latapie, A., Marcinkowski, P., Martínez-Fernández, V., Mosselman, E., Mountford, J.O., Nardi, L., Okruszko, T., O'Hare, M.T., Palma, M., Percopo, C., Surian, N., van de Bund, W., Weissteiner, C., Ziliani, L., 2016. A multi-scale hierarchical framework for developing understanding of river behaviour to support river management. Aquat. Sci. 78, 1–16.

Gutperlet, R., Capperucci, R.M., Bartholomä, A., Kröncke, I., 2015. Benthic biodiversity changes in response to dredging activities during the construction of a deep-water port. Mar. Biodivers. 45, 819–839.

Guzelj, M., Hauer, C., Egger, G., 2020. The third dimension in river restoration: how anthropogenic disturbance changes boundary conditions for ecological mitigation. Sci. Rep. 10, 1–17.

Haase, P., Hering, D., Jähnig, S.C., Lorenz, A.W., Sundermann, A., 2012. The impact of hydromorphological restoration on river ecological status: a comparison of fish, benthic invertebrates, and macrophytes. Hydrobiologia 704, 475–488.

Habersack, H., Schober, B., 2020. Floodplain evaluation matrix FEM: A multiparameter assessment methodology. J. Flood Risk Manag. 13.

Halpern, B.S., Selkoe, K.A., Micheli, F., Kappel, C. V, 2007. Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats. Conserv. Biol. 21, 1301–1315.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C. V, Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science (80-.). 319, 948–952.

Hancock, P.J., 2002. Human Impacts on the Stream-Groundwater Exchange Zone. Environ. Manage. 29, 763–781.

Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R., Lienkaemper, G.W., Cromack, K., Cummins, K.W., 1986. Ecology of Coarse Woody Debris in Temperate Ecosystems. pp. 133–302.

Harney, A., 2018. CFRAM – Assessing Irelands flood risk with a focus on public and stakeholder engagement. In: Irish National Hydrology Conference.

Harper, D., Smith, C., Kemp, J., Crosa, G., 1998. The use of 'functional habitats' in the conservation, management and rehabilitation of rivers'. In: Bretschko, G., Helesic, J. (Eds.), Advances in River Bottom Ecology. Backhuys Publishers, Chichester, U.K., pp. 315–326.

Harrington, J.R., Harrington, S.T., 2013. Sediment and nutrient behaviour on the River Bandon, Ireland. In: River Basin Management VII. WIT Transactions on Ecology and the Environment, pp. 215–226.

Harrison, E.T., Norris, R.H.H., Wilkinson, S.N.N., 2007. The impact of fine sediment accumulation on benthic macroinvertebrates:Implications for river management. In: 5th Australian Stream Management Conference. Australian Rivers. pp. 139–144.

Harrison, S.S.C., Harris, I.T., 2002. The effects of bankside management on chalk stream invertebrate communities. Freshw. Biol. 47, 2233–2245.

Harvey, G.L., Henshaw, A.J., Brasington, J., England, J., 2019. Burrowing Invasive Species: An Unquantified Erosion Risk at the Aquatic-Terrestrial Interface. Rev. Geophys. 57, 1018–1036.

Harvey, G.L., Henshaw, A.J., Parker, C., Sayer, C.D., 2018. Re-introduction of structurally complex wood jams promotes channel and habitat recovery from overwidening: Implications for river conservation. Aquat. Conserv. Mar. Freshw. Ecosyst. 28, 395–407.

Hassan, M.A., Hogan, D.L., Bird, S.A., May, C.L., Gomi, T., Campbell, D., 2005. Spatial and temporal dynamics of wood in headwater streams in the Pacific Northwest. J. Am. Water Resour. Assoc. 41, 899–919.

Hassan, M.A., Roberge, L., Church, M., More, M., Donner, S.D., Leach, J., Ali, K.F., 2017. What are the contemporary sources of sediment in the Mississippi River? Geophys. Res. Lett. 44, 8919–8924.

Hastie, L.C., Cosgrove, P.J., Ellis, N., Gaywood, M.J., 2003. The Threat of Climate Change to Freshwater Pearl Mussel Populations. Ambio 32, 40–46.

Hatton-Ellis, T., 2008. The Hitchhiker's Guide to the Water Framework Directive. Aquat. Conserv. Mar. Freshw. Ecosyst. 18, 111–116.

Haughey, E., 2021. Climate Change and Land Use in Ireland. Report No 371. Environmetal Protection Agency, Wexford, Ireland.

Haygarth, P.M., Condron, L.M., Heathwaite, A.L., Turner, B.L., Harris, G.P., 2005. The phosphorus transfer continuum: Linking source to impact with an interdisciplinary and multi-scaled approach. Sci. Total Environ. 344, 5–14.

Hedelin, B., 2017. The EU floods directive in Sweden: opportunities for integrated and participatory flood risk planning. J. Flood Risk Manag. 10, 226–237.

Hedrick, L.B., Anderson, J.T., Welsh, S.A., Lin, L.-S., 2013. Sedimentation in Mountain Streams: A Review of Methods of Measurement. Nat. Resour. 04, 92–104.

Heery, S., 1993. The Shannon floodlands: a natural history of the Shannon Callow. Kinvara, Tir Eolas, Ireland.

Hein, T., Schwarz, U., Habersack, H., Nichersu, I., Preiner, S., Willby, N., Weigelhofer, G., 2016. Current status and restoration options for floodplains along the Danube River. Sci. Total Environ. 543, 778–790.

Henriksen, H.J., Rasmussen, P., Brandt, G., von Bülow, D., Jensen, F. V, 2007. Public participation modelling using Bayesian networks in management of groundwater contamination. Environ. Model. Softw. 22.

Henry, C.P., Amoros, C., Roset, N., 2002. Restoration ecology of riverine wetlands: A 5-year post-operation survey on the Rhône River, France. Ecol. Eng. 18, 543–554.

Hensley, K.J., Ayers, P.D., 2018. Estimating Streambank Erosion Rates with a GPS-Based Video Mapping System. JAWRA J. Am. Water Resour. Assoc. 54, 1185–1196.

Hering, D., Borja, A., Carstensen, J., Carvalho, L., Elliott, M., Feld, C.K., Heiskanen, A.-S., Johnson, R.K., Moe, J., Pont, D., Solheim, A.L., de Bund, W. van, 2010. The European Water Framework Directive at the age of 10: A critical review of the achievements with recommendations for the future. Sci. Total Environ. 408, 4007–4019.

Hering, D., Borja, A., Carvalho, L., Feld, C.K., 2013. Assessment and recovery of European

water bodies: key messages from the WISER project. Hydrobiologia 704, 1–9.

Hering, D., Feld, C.K., Moog, O., Ofenböck, T., 2006. Cook book for the development of a Multimetric Index for biological condition of aquatic ecosystems: experiences from the European AQEM and STAR projects and related initiatives. In: The Ecological Status of European Rivers: Evaluation and Intercalibration of Assessment Methods. Springer Netherlands, Dordrecht, pp. 311–324.

Hering, D., Gerhard, M., Kiel, E., Ehlert, T., Pottgiesser, T., 2001. Review study on near-natural conditions of Central European Mountains streams, with particular reference to Debris and Beaver dams: Results of the “REG meeting” 2000. Limnologica 31, 81–92.

Hermoso, V., Filipe, A.F., Segurado, P., Beja, P., 2018. Freshwater conservation in a fragmented world: Dealing with barriers in a systematic planning framework. Aquat. Conserv. Mar. Freshw. Ecosyst. 28, 17–25.

Hes, E.M., van Dam, A.A., 2019. Modelling nitrogen and phosphorus cycling and retention in Cyperus papyrus dominated natural wetlands. Environ. Model. Softw. 122, 104531.

Hilderbrand, R.H., Watts, A.C., Randle, A.M., 2005. The myths of restoration ecology. Ecol. Soc. 10, 19.

Hill, A.J., Neary, V.S., 2012. Annual Water Budgets for a Seasonally Inundated Sinkhole Wetland. Wetlands 32, 963–974.

Hodgen, M.T., 1939. Domesday Water Mills. Antiquity 13, 261–279.

Houston, L., Thompson, E., 2008. EU Water Framework Directive Managing Freshwater Morphology in Ireland. Irish National Hydrology Conference.

Howarth, W., 2006. The progression towards ecological quality standards. J. Environ. Law 18, 3–35.

Hrvatske, V., 2013. Guideline for Hydromorphological Monitoring and Assessment of Rivers in Croatia. Proposal of the Meander project.

Huđek, H., Žganec, K., Pusch, M.T., 2020. A review of hydropower dams in Southeast Europe – distribution, trends and availability of monitoring data using the example of a multinational Danube catchment subarea. Renew. Sustain. Energy Rev. 117, 0–10.

Hume, T.M., Snelder, T., Weatherhead, M., Liefting, R., 2007. A controlling factor approach to estuary classification. Ocean Coast. Manag. 50.

Hunter, H.M., Walton, R.S., 2008. Land-use effects on fluxes of suspended sediment, nitrogen and phosphorus from a river catchment of the Great Barrier Reef, Australia. J. Hydrol. 356, 131–146.

Hynes, H.B.N., 1960. The Biology of Polluted Waters. Liverpool University Press, UK, Liverpool.

Ibisate, A., Díaz, E., Ollero, A., Acín, V., Granado, D., 2013. Channel response to multiple damming in a meandering river, middle and lower Aragón River (Spain). Hydrobiologia 712, 5–23.

IFI, 2009. Tacumshin Lake estuary report. Sampling Fish for the Water Framework Directive-Transitional Waters, Inland fisheries Ireland. Dublin, Ireland.

IFI, 2018. Environmental River Enhancement Programme Annual Report, Inland fisheries Ireland. Dublin, Ireland.

IFI, 2021. IFI Consolidated Fish Counter Summary Report, Inland fisheries Ireland. Dublin, Ireland.

IHA, n.d. Hydropower Sustainability Assessment Protocol.

Imberger, J., Patterson, J.C., 1989. Advances in Applied Mechanics. In: John W. Hutchinson, Theodore Y. Wu (Eds.), Advances in Applied Mechanics. Elsevier, pp. 303–475.

Ioana-Toroimac, G., 2018. Outcomes of the hydromorphology integration in the Water Framework Directive: A review based on science mapping. J. Environ. Manage. 206.

Iordachi, C., Van Assche, K. (Eds.), 2015. The Biopolitics of the Danube DeltaNature, History, Policies. Lexington Books, London.

IPCC, 2022. Mitigation of Climate Change. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Irish Water, 2016. Final Options Appraisal Report (FOAR), 161103WSP1_FOAR 46 6.

Irvine, K., 2004. Classifying ecological status under the European Water Framework Directive: the need for monitoring to account for natural variability. Aquat. Conserv. Mar. Freshw. Ecosyst. 14, 107–112.

Irvine, K., 2009. Editorial: Harmonizing assessment of conservation with that of ecological quality: fitting a square peg into a round hole? Aquat. Conserv. Mar. Freshw. Ecosyst. 19, 365–369.

Irvine, K., 2012. Editorial: The tragedy of the threshold: revising perceptions for aquatic conservation. Aquat. Conserv. Mar. Freshw. Ecosyst. 22, 705–711.

Irvine, K., 2022. Measuring Impact, Overview and Reference Conditions. In: Tockner, K., Mehner, T. (Eds.), Encyclopedia of Inland Waters, 2nd Edition. Elsevier.

Irvine, K., Boelens, R., Fitzsimmons, J., Kemp, A., Johnston, P., 2002. Review of monitoring and Research to meet the needs of the EU Water Framework Directive. Report to the Environmental Protection Agency. Wexford, Ireland.

Irvine, K., Coxon, C., Gill, L., Kimberley, S., Waldren, S., 2018. Turloughs (Ireland). In: Finlayson, C.M., Milton, G.R., Prentice, R.C., Davidson, N.C. (Eds.), The Wetland Book II: Distribution, Description, and Conservation. Springer, Dordrecht, pp. 1067–1077.

Irvine, K., Dickens, C., Castello, L., Bredin, I., Finlayson, C.M., 2021. Vegetated wetlands: from ecology to conservation management. . In: Dalu, T., Wasserman, R.J. (Eds.), Fundamentals of Tropical Freshwater Wetlands: From Ecology to Conservation Management. Elsevier, Cambridge.

Irvine, K., Katsanou, K., 2024. Hydrology-going with the flow. In: DALTON, C., De Eyto, E., Jennings, E. (Eds.), Lakes in Ireland-Mirrors of Change. Marine Institute, Dublin, Ireland.

Irvine, K., Mills, P., Donohue, I., Fuller, J., 2007. Article 17 reporting under the Habitats Directive (92/43/EEC). Report to the National Parks and Wildlife Service. Dublin, Ireland.

Irvine, K., Ní Chuanigh, E., 2012. Management Strategies for the Protection of High Status Water Bodies. A Literature Review. 2010-W-DS-3. EPA STRIVE PROGRAMME 2007-2013. Report to the Environmental Protection Agency, Weford, Ireland.

Irvine, K., O'Brien, S., 2009. Progress on stakeholder participation in the implementation of the Water Framework Directive in the Republic of Ireland. Biol. Environ. Proc. R. Irish Acad. 109, 365–376.

Irvine, K., Weigelhofer, G., Popescu, I., Pfeiffer, E., Păun, A., Drobot, R., Gettel, G., Staska, B., Stanica, A., Hein, T., Habersack, H., 2016. Educating for action: Aligning skills with

policies for sustainable development in the Danube river basin. Sci. Total Environ. 543, 765–777.

Iversen, T.M., Kronvang, B., Madsen, B.L., Markmann, P., Nielsen, M.B., 1993. Re-establishment of Danish streams: restoration and maintenance measures. Aquat. Conserv. Mar. Freshw. Ecosyst. 3, 73–92.

Jacobs, S., Dendoncker, N., Martín-López, B., Barton, D.N., Gomez-Baggethun, E., Boeraeve, F., McGrath, F.L., Vierikko, K., Geneletti, D., Sevecke, K.J., Pipart, N., Primmer, E., Mederly, P., Schmidt, S., Aragão, A., Baral, H., Bark, R.H., Briceno, T., Brogna, D., Cabral, P., De Vreese, R., Liquete, C., Mueller, H., Peh, K.S.H., Phelan, A., Rincón, A.R., Rogers, S.H., Turkelboom, F., Van Reeth, W., van Zanten, B.T., Wam, H.K., Washbourn, C.L., 2016. A new valuation school: Integrating diverse values of nature in resource and land use decisions. Ecosyst. Serv. 22, 213–220.

Jager, N.W., Challies, E., Kochskämper, E., Newig, J., Benson, D., Blackstock, K., Collins, K., Ernst, A., Evers, M., Feichtinger, J., Fritsch, O., Gooch, G., Grund, W., Hedelin, B., Hernández-Mora, N., Hüesker, F., Huitema, D., Irvine, K., Klinke, A., Lange, L., Loupsans, D., Lubell, M., Maganda, C., Matczak, P., Parés, M., Saarikoski, H., Slavíková, L., Van Der Arend, S., Von Korff, Y., 2016. Transforming European water governance? Participation and river basin management under the EU water framework directive in 13 member states. Water (Switzerland) 8.

Jain, C.K., 2004. Metal fractionation study on bed sediments of River Yamuna, India. Water Res. 38, 569–578.

James, A.B.W., Dewson, Z.S., Death, R.G., 2008. Do stream macroinvertebrates use instream refugia in response to severe short-term flow reduction in New Zealand streams? Freshw. Biol. 53, 1316–1334.

Jane, S.F., Hansen, G.J.A., Kraemer, B.M., Leavitt, P.R., Mincer, J.L., North, R.L., Pilla, R.M., Stetler, J.T., Williamson, C.E., Woolway, R.I., Arvola, L., Chandra, S., DeGasperi, C.L., Diemer, L., Dunalska, J., Erina, O., Flaim, G., Grossart, H.-P., Hambright, K.D., Hein, C., Hejzlar, J., Janus, L.L., Jenny, J.-P., Jones, J.R., Knoll, L.B., Leoni, B., Mackay, E., Matsuzaki, S.-I.S., McBride, C., Müller-Navarra, D.C., Paterson, A.M., Pierson, D., Rogora, M., Rusak, J.A., Sadro, S., Saulnier-Talbot, E., Schmid, M., Sommaruga, R., Thiery, W., Verburg, P., Weathers, K.C., Weyhenmeyer, G.A., Yokota, K., Rose, K.C., 2021. Widespread deoxygenation of temperate lakes. Nature 594, 66–70.

Jansson, R., Nilsson, C., Malmqvist, B., 2007. Restoring freshwater ecosystems in riverine landscapes: the roles of connectivity and recovery processes. Freshw. Biol. 52, 589–596.

Janusz, S., Pociask-Karteczka, J., 2017. Springs in South-Central Poland – changes and threats. Episodes 40.

JBA Consulting, 2014. River Fealge (Clonakilty) Drainage Scheme Environmental Impact Statement Vol. 1 - Non Technical Summary. Limerick, Ireland.

Jean Wilson, Catherine Coxon, Carlos Rocha, 2016. A GIS and remote sensing based screening tool for assessing the potential for groundwater discharge to lakes in Ireland. Biol. Environ. Proc. R. Irish Acad. 116B, 265.

Jeppesen, E., Meerhoff, M., Jacobsen, B.A., Hansen, R.S., Søndergaard, M., Jensen, J.P., Lauridsen, T.L., Mazzeo, N., Branco, C.W.C., 2007. Restoration of shallow lakes by nutrient control and biomanipulation—the successful strategy varies with lake size and climate. Hydrobiologia 581, 269–285.

Jepsen, N., Umlauf, G., 2008. Danube Survey 2 - Final Scientific Report. ICPDR JRC49176.

Vienna, Austria.

Jeschke, J., Evans, T., Pattison, Z., Saul, W.-C., Robertson, P.A., 2021. Biological invasions: impact and management. In: Tockner, K., Mehner, T. (Eds.), Encyclopedia of Inland Waters. Elsevier, Cambridge, U.K.

Jeschke, J., Gómez Aparicio, L., Haider, S., Heger, T., Lortie, C., Pyšek, P., Strayer, D., 2012. Support for major hypotheses in invasion biology is uneven and declining. NeoBiota 14, 1–20.

Johansson, L.S., Amsinck, S.L., Bjerring, R., Jeppesenl, E., 2005. Mid- to late-Holocene land-use change and lake development at Dallund Sø, Denmark: trophic structure inferred from cladoceran subfossils. The Holocene 15, 1143–1151.

Jones, J.I., Murphy, J.F., Collins, A.L.J., Sear, D.A., Naden, P.S., Armitage, P.D., 2012. The Impact of Fine Sediment on Macroinverterates. River Res. Appl. 28, 1055–1071.

Juez, C., Franca, M.J., 2022. Physical impacts of sand mining in rivers and floodplains. In: Tockner, K., Mehner, T. (Eds.), Encyclopedia of Inland Waters. Elsevier, Elsevier, Cambridge, U.K.

Jurca, T., Donohue, L., Laketić, D., Radulović, S., Irvine, K., 2012. Importance of the shoreline diversity features for littoral macroinvertebrate assemblages. Fundam. Appl. Limnol. 180, 175–184.

Jurca, T., Donohue, L., McGoff, E., Tunali, S.Y., Irvine, K., 2021. Unravelling the effect of multiple stressors on ecological structure of littoral lake macroinvertebrates. Int. Rev. Hydrobiol. 106, 202–212.

Jurkiewicz-Karnkowska, E., 1989. Accumulation of zinc and copper in molluscs from the Zegrzyński Reservoir and the Narew River. Ekol. Pol. 37, 347–357.

Jusik, S., Szoszkiewicz, K., Kupiec, J.M., Lewin, I., Samecka-Cymerman, A., 2015. Development of comprehensive river typology based on macrophytes in the mountain-lowland gradient of different Central European ecoregions. Hydrobiologia 745, 241–262.

Jyväsjärvi, J., Tolonen, K.T., Hämäläinen, H., 2009. Natural variation of profundal macroinvertebrate communities in boreal lakes is related to lake morphometry: implications for bioassessment. Can. J. Fish. Aquat. Sci. 66, 589–601.

Kampa, E., Bussettini, M., 2018. River Hydromorphological Assessment and Monitoring Methodologies – FINAL REPORT Part 1 – Summary of European country questionnaires 2018. European Commission, Brussels, Belgium.

Kampa, E., Bussettini, M., van de Bund, W., 2019. Resource document on Hydromor-phology in the WFD, 0 . 9. European Commission, Brussels, Belgium.

Kampa, E., Hansen, W., 2004. Identification of Water Bodies, Heavily Modified Water Bodies. European Commission, Brussels, Belgium.

Kampa, E., von der Weppen, J., Dworak, T., 2011. Common Implementation Strategy Workshop. Issue Paper (final version): Water management, Water Framework Directive & Hydropower, 13-14 September 2011. European Commission, Brussels, Belgium.

Kaplan, J.O., Krumhardt, K.M., Zimmermann, N., 2009. The prehistoric and preindustrial deforestation of Europe. Quat. Sci. Rev. 28, 3016–3034.

Karr, J.R., 1981. Assessment of biotic integrity using fish communities. Fisheries 6, 21–27.

Karr, J.R., Chu, E.W., 1997. Biological monitoring and assessment using multimetric indexes effectively. EPA Report 235-R97-001. Washington D.C., U.S.A.

Karr, J.R., Chu, E.W., 1999. Restoring Life in Running Waters: Better Biological Monitoring. Water. Air. Soil Pollut. 116, 666–667.

Katagi, T., 2006. Behavior of pesticides in water-sediment systems. Rev. Environ. Contam. Toxicol. 187, 133–251.

Katz, B.G., Coplen, T.B., Bullen, T.D., Davis, J.H., 1997. Use of Chemical and Isotopic Tracers to Characterize the Interactions Between Ground Water and Surface Water in Mantled Karst. Ground Water 35.

Kaufmann, P.R., Hughes, R.M., Van Sickle, J., Whittier, T.R., Seeliger, C.W., Paulsen, S.G., 2014. Lakeshore and littoral physical habitat structure: A field survey method and its precision. Lake Reserv. Manag. 30, 157–176.

Kaufmann, P.R., Whittier, T.R., 1997. Habitat characterization. In Environmental Monitoring and Assessment Program Surface Waters: Field Operations Manual for Lakes, Baker JR, Peck DV, Sutton DW (eds). EPA/620/R-97/001, US. Washington, DC. U.S.A.

Kavanagh, J., 1964. An insight into arterial drainage. Irish For. 21, 74–85.

Kelly-Quinn, M., Blacklocke, S., Bruen, M., Earle, R., O'Neill, E., O'sullivan, J., Purcell, P., 2014. Dublin Ireland: A city addressing challenging water supply, management, and governance issues. Ecol. Soc. 19.

Kelly-Quinn, M., Bruen, M., Carlsson, J., Gurnell, A., Jarvie, H., Piggott, J., 2019. Managing the small stream network for improved water quality, biodiversity and ecosystem services protection (SSNet). Res. Ideas Outcomes 5.

Kelly-Quinn, M., Bruen, M., Harrison, S., Healy, M., Clarke, J., Drinan, T., Feeley, H.B., Finnegan, J., Graham, C., Regan, J., Blacklocke, S., 2016. HYDROFOR: Assessment of the Impacts of Forest Operations on the Ecological Quality of Water, EPA Research. Dublin, Ireland.

Kelly-Quinn, M., Bruen, M., Turner, J., O'sullivan, J., Carlsson, J., Bullock, C., Atkinson, S., Casserly, C., 2022. Assessment of the Extent and Impact of Barriers on Freshwater Hydromorphology and Connectivity in Ireland (Reconnect) (2015-W-LS-8) EPA Research Report. Wexford, Ireland.

Kelly, S., Barry, J., Kelly, F.L., 2022. Implications of climate change for freshwater fisheries. In: Tockner, K., Mehner, T. (Eds.), Encyclopedia of Inland Waters. Elsevier, Cambridge, U.K.

Kemp, J.L., Harper, D.M., Crosa, G.A., 1999. Use of "functional habitats" to link ecology with morphology and hydrology in river rehabilitation. Aquat. Conserv. Mar. Freshw. Ecosyst. 9, 159–178.

Kemp, J.L., Sandin, L., 2022. Hydromorphology: Overview and assessment methods. In: Tockner, K., Mehner, T. (Eds.), Encyclopedia of Inland Waters. Elsevier, Cambridge, U.K.

Kemp, P., Sear, D., Collins, A., Naden, P., Jones, I., 2011. The impacts of fine sediment on riverine fish. Hydrol. Process. 25, 1800–1821.

Kennedy, R.J., Crozier, W.W., 2010. Evidence of changing migratory patterns of wild Atlantic salmon Salmo salar smolts in the River Bush, Northern Ireland, and possible associations with climate change. J. Fish Biol. 76, 1786–1805.

Kennish, M.J., 2002. Environmental threats and environmental future of estuaries. Environ. Conserv. 29, 78–107.

Keogh, J., Wilkes, R., O'Boyle, S., 2020. A new index for the assessment of hydromorphology in transitional and coastal waters around Ireland. Mar. Pollut. Bull.

151, 110802.

Kessler, A.C., Gupta, S.C., Dolliver, H.A.S., Thoma, D.P., 2012. Lidar Quantification of Bank Erosion in Blue Earth County, Minnesota. J. Environ. Qual. 41, 197–207.

Kilroy, G., Dunne, F., Ryan, J., O'Connor, A., Daly, D., Craig, M., Coxon, C.E., Johnston, P., Henning, M., 2013. A Framework for the Assessment of Groundwater - Dependent Terrestrial Ecosystems under the Water Framework Directive. Irish Environmental Protection Agency, Wexford, Ireland.

Kilroy, G., Dunne, F., Ryan, J., O'Connor, Á., Daly, D., Craig, M., Coxon, C.E., Johnston, P., Moe, H., O'Connor, A., Daly, D., Craig, M., Coxon, C.E., Johnston, P., Henning, M., 2008. A framework for the assessment of groundwater dependent terrestrial ecosystems under the water framework directive (2005-W-FS-5). Irish Environmental Protection Agency, Wexford, Ireland.

King, J.J., Hanna, G., Wightman, G.D., Ireland. Office of Public Works. Environment Section., 2008. Ecological impact assessment (EcIA) of the effects of statutory arterial drainage maintenance activities on three lamprey species (Lampetra planeri Bloch, Lampetra fluviatilis L., and Petromyzon marinus L.), Series of ecological assessments on arterial drainage maintenance. Dublin, Ireland.

King, J.J., Lehane, B.M., Wightman, G.D., Dooley, R., Gilligan, N., 2010. Development and implementation of environmental protocols in river maintenance in Ireland. Water Environ. J. 25, 422–428.

King, J.J., O'Grady, M.F., Curtin, J., 2000. The experimental drainage maintenance (EDM) programme: engineering and fisheries management interactions in drained Irish salmonid channels. SIL Proc. 27, 1532–1535.

Kingsford, R.T., 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. Austral Ecol. 25, 109–127.

Kingsford, R.T., Biggs, H.C., Pollard, S.R., 2011. Strategic Adaptive Management in freshwater protected areas and their rivers. Biol. Conserv. 144, 1194–1203.

Kingsford, R.T., Bino, G., Finlayson, C.M., Falster, D., Fitzsimons, J.A., Gawlik, D.E., Murray, N.J., Grillas, P., Gardner, R.C., Regan, T.J., Roux, D.J., Thomas, R.F., 2021. Ramsar Wetlands of International Importance–Improving Conservation Outcomes. Front. Environ. Sci. 9, 1–6.

Kirk Cochran, J., 2014. Estuaries. In: Reference Module in Earth Systems and Environmental Sciences. Elsevier.

Kleemann, J., Lucca, E., Kofinas, D., Avell, T., Mooren, C.E., Blicharska, M., Teutschbein, C., Sperotto, A., Milliken, S., Fader, M., Dejana, Đ., Da, T., Vasili, V., Taiwo, B., Baubekova, A., Pineda-martos, R., Baganz, F.M., Volkan, H., Spyropoulou, A., Merheb, M., Castelli, G., Pagano, A., Sambo, B., Su, M., Arnold, M., Ra, T., Psomas, A., Masia, S., Jeunesse, I. La, Amorocho-daza, H., Das, S.S., Bresci, E., Munaretto, S., Brouwer, F., Laspidou, C., 2025. Integrating " nature " in the water-energy-food Nexus : Current perspectives and future directions. Sci. Total Environ. 966.

Kleynhans, C.J., 1996. A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River (Limpopo system, South Africa). J. Aquat. Ecosyst. Heal. 5, 41–54.

Klijn, F., de Bruin, D., de Hoog, M.C., Jansen, S., Sijmons, D.F., 2013. Design quality of room-for-the-river measures in the Netherlands: role and assessment of the quality team (Q-team). Int. J. River Basin Manag. 11, 287–299.

Klijn, F., Samuels, P., Van Os, A., 2008. Towards flood risk management in the EU: State of

affairs with examples from various European countries. Int. J. River Basin Manag. 6, 307–321.

Kløve, B., Allan, A., Bertrand, G., Druzynska, E., Ertürk, A., Goldscheider, N., Henry, S., Karakaya, N., Karjalainen, T.P., Koundouri, P., Kupfersberger, H., Kvœrner, J., Lundberg, A., Muotka, T., Preda, E., Pulido-Velazquez, M., Schipper, P., 2011. Groundwater dependent ecosystems. Part II. Ecosystem services and management in Europe under risk of climate change and land use intensification. Environ. Sci. Policy 14, 782–793.

Knighton, D., 1998. Fluvial forms and processes : a new perspective. Arnold, London, U.K.

Koehnken, L., Rintoul, M., 2018. Impacts of Sand Mining on Ecosystem Structure, Process & Biodiversity in Rivers, Rivers, & Potential Geomorphic Transport Sediment Changes in Response to Sand Mining. WWF.

Koehnken, L., Rintoul, M.S., Goichot, M., Tickner, D., Loftus, A., Acreman, M.C., 2020. Impacts of riverine sand mining on freshwater ecosystems: A review of the scientific evidence and guidance for future research. River Res. Appl. 36, 362–370.

Kondolf, G.M., 1997. PROFILE: Hungry Water: Effects of Dams and Gravel Mining on River Channels. Environ. Manage. 21, 533–551.

Kondolf, G.M., 1998. Large scale extraction of alluvial deposits from rivers in California: geomorphic effects and regulatory strategies. In: P.C., K., R.L., B., P.D., K., J.B., B. (Eds.), Gravel Bed Rivers in the Environment. Water Resources Publications, Colorado, U.S.A, pp. 455–470.

Kondolf, G.M., Boulton, A.J., O'Daniel, S., Poole, G.C., Rahel, F.J., Stanley, E.H., Wohl, E., Bång, A., Carlstrom, J., Cristoni, C., Huber, H., Koljonen, S., Louhi, P., Nakamura, K., 2006. Process-based ecological river restoration: Visualizing three-dimensional connectivity and dynamic vectors to recover lost linkages. Ecol. Soc. 11.

Kozerski, H., 2002. Determination of areal sedimentation rates in rivers by using plate sediment trap measurements and flow velocity—settling flux relationship. Water Res. 36, 2983–2990.

Krchnak, K., Richter, B., Thomas, G., 2009. Integrating environmental flows into hydropower dam planning, design, and operations. Water working note no. 22 World Bank Group. Washington, D.C., U.S.A.

Kremer, P., Hamstead, Z., Haase, D., McPhearson, T., Frantzeskaki, N., Andersson, E., Kabisch, N., Larondelle, N., Rall, E.L., Voigt, A., Baró, F., Bertram, C., Gómez-Baggethun, E., Hansen, R., Kaczorowska, A., Kain, J.-H., Kronenberg, J., Langemeyer, J., Pauleit, S., Rehdanz, K., Schewenius, M., van Ham, C., Wurster, D., Elmqvist, T., 2016. Key insights for the future of urban ecosystem services research. Ecol. Soc. 21, art29.

Kristensen, E.A., Kronvang, B., Wiberg-Larsen, P., Thodsen, H., Nielsen, C., Amor, E., Friberg, N., Pedersen, M.L., Baattrup-Pedersen, A., 2014. 10 years after the largest river restoration project in Northern Europe: Hydromorphological changes on multiple scales in River Skjern. Ecol. Eng. 66, 141–149.

Kronvang, B., Svendsen, L.M., Brookes, A., Fisher, K., Møller, B., Ottosen, O., Newson, M., Sear, D., 1998. Restoration of the rivers Brede, Cole and Skerne: A joint Danish and British EU-LIFE demonstration project, III - Channel morphology, hydrodynamics and transport of sediment and nutrients. Aquat. Conserv. Mar. Freshw. Ecosyst. 8, 209–222.

Kuemmerlen, M., Reichert, P., Siber, R., Schuwirth, N., 2019. Ecological assessment of river networks: From reach to catchment scale. Sci. Total Environ. 650, 1613–1627.

Kumar, R., McInnes, R., Finlayson, C.M., Davidson, N.C., Rissik, D., Paul, S., Cui, L., Lei, Y., Capon, S., Fennessy, S., 2020. Wetland ecological character and wise use: towards a new framing. Mar. Freshw. Res. 72, 633–637.

Kunz, M.J., Wüest, A., Wehrli, B., Landert, J., Senn, D.B., 2011. Impact of a large tropical reservoir on riverine transport of sediment, carbon, and nutrients to downstream wetlands. Water Resour. Res. 47, 1–16.

La Jeunesse, I., Elliott, M., 2004. Anthropogenic regulation of the phosphorus balance in the Thau catchment–coastal lagoon system (Mediterraean Sea, France) over 24 years. Mar. Pollut. Bull. 48, 679–87.

Lamberti, G.A., Chaloner, D.T., Hershey, A.E., 2010. Linkages among aquatic ecosystems. J. North Am. Benthol. Soc. 29, 245–263.

Lane, S.N., Reaney, S.M., Heathwaite, A.L., 2009. Representation of landscape hydrological connectivity using a topographically driven surface flow index. Water Resour. Res. 45.

Langendoen, E.J., Simon, A., Klimetz, L., Bankhead, N., Ursic, M.E., 2012. Quantifying Sediment Loadings from Streambank Erosion in Selected Agricultural Watersheds Draining to Lake Champlain. US Dep. Agric. - Agric. Res. Serv. 65.

Langhans, S.D., Domisch, S., Balbi, S., Delacámara, G., Hermoso, V., Kuemmerlen, M., Martin, R., Martínez-López, J., Vermeiren, P., Villa, F., Jähnig, S.C., 2019. Combining eight research areas to foster the uptake of ecosystem-based management in fresh waters. Aquat. Conserv. Mar. Freshw. Ecosyst. 29, 1161–1173.

Larkin, R.G., Sharp, J.M., 1992. On the relationship between river-basin geomorphology, aquifer hydraulics, and ground-water flow direction in alluvial aquifers. Geol. Soc. Am. Bull. 104, 1608–1620.

Lawler, A.D., Rymszewicz, A., Conroy, L., Sullivan, J.O., Bruen, M., Turner, J., 2017. SILTFLUX Literature Review. Report No . 176. EPA Research Programme 2014-2020. Environmental Protection Agency, Wexford, Ireland.

LAWPRO, 2021. Bride (Cork City) Priority Area for Action Desk Study Summary. Local Authority Waters Programme,Cork, Ireland.

Le Dez, M., Delbosc, P., Bouzillé, J.-B., Robin, M., 2021. An expert system for the conservation of Atlantic estuarine wet meadows: application to a Natura 2000 site in France. Biodivers. Conserv. 30, 4337–4357.

Lepage, M., Harrison, T.D., Breine, J., Cabral, H., Coates, S., Galván, C., García, P., Jager, Z., Kelly, F., Mosch, E.C., Pasquaud, S., Scholle, J., Uriarte, A., Borja, A., 2016. An approach to intercalibrate ecological classification tools using fish in transitional water of the North East Atlantic. Ecol. Indic. 67, 318–327.

Lewitus, A.J., Kawaguchi, T., DiTullio, G.R., Keesee, J.D.M., 2004. Iron limitation of phytoplankton in an urbanized vs. forested southeastern U.S. salt marsh estuary. J. Exp. Mar. Bio. Ecol. 298, 233–254.

Liddle, M.J., Scorgie, H.R.A., 1980. The effects of recreation on freshwater plants and animals: A review. Biol. Conserv. 17, 183–206.

Liébault, F., Gomez, B., Page, M., Marden, M., Peacock, D., Richard, D., Trotter, C.M., 2005. Land-use change, sediment production and channel response in upland regions. River Res. Appl. 21, 739–756.

Ligon, F.K., Dietrich, W.E., Trush, W.J., 1995. Downstream Ecological Effects of Dams. Bioscience 45, 183–192.

Liquete, C., Udias, A., Conte, G., Grizzetti, B., Masi, F., 2016. Integrated valuation of a

nature-based solution for water pollution control. Highlighting hidden benefits. Ecosyst. Serv. 22, 392–401.

Liška, I., Wagner, F., Slobodník, J., 2008. Joint Danube Survey 2. Final Scientific Report. Int Comm Prot Danube River.

Liu, D., Liu, H., Wang, X., Kremere, E., 2019. World Small Hydropower Development Report. United Nations Industrial Development Organization; International Center on Small Hydro Power.

Lovell, S.T., Taylor, J.R., 2013. Supplying urban ecosystem services through multifunctional green infrastructure in the United States. Landsc. Ecol. 28, 1447–1463.

Lucena-Moya, P., Duggan, I.C., 2017. Correspondence between zooplankton assemblages and the Estuary Environment Classification system. Estuar. Coast. Shelf Sci. 184, 1–9.

Lucy, F.E., Caffrey, J., Dick, J.T.A., Davis, E., Coughlan, N.E., 2021. Prevention, Control and Eradication of Invasive Alien Species. Environmental Protection Agency, Wexford, Ireland.

Lyche Solheim, A., Rekolainen, S., Moe, S.J., Carvalho, L., Phillips, G., Ptacnik, R., Penning, W.E., Toth, L.G., O'Toole, C., Schartau, A.-K.L., Hesthagen, T., 2008. Ecological threshold responses in European lakes and their applicability for the Water Framework Directive (WFD) implementation: synthesis of lakes results from the REBECCA project. Aquat. Ecol. 42, 317–334.

Ma, Z., Melville, D.S., Liu, J., Chen, Y., Yang, H., Ren, W., Zhang, Z., Piersma, T., Li, B., 2014. Rethinking China's new great wall. Science (80-.). 346, 912–14.

Mack, L., Andersen, H.E., Beklioğlu, M., Bucak, T., Couture, R.M., Cremona, F., Ferreira, M.T., Hutchins, M.G., Mischke, U., Molina-Navarro, E., Rankinen, K., Venohr, M., Birk, S., 2019. The future depends on what we do today – Projecting Europe's surface water quality into three different future scenarios. Sci. Total Environ. 668, 470–484.

Macklin, M.G., Benito, G., Gregory, K.J., Johnstone, E., Lewin, J., Michczyńska, D.J., Soja, R., Starkel, L., Thorndycraft, V.R., 2006. Past hydrological events reflected in the Holocene fluvial record of Europe. CATENA 66, 145–154.

Maddock, I., 1999. The importance of physical habitat assessment for evaluating river health. Freshw. Biol. 41, 373–391.

Magadza, C.H.D., 2006. Kariba Reservoir: Experience and lessons learned. Lakes Reserv. Res. Manag. 11, 271–286.

Magillan, F., Noslow, K.H., 2005. Changes in hydrologic regime by dams. Geomorphology 71, 61–78.

Magilligan, F.J., Nislow, K.H., Fisher, G.B., Wright, J., Mackey, G., Laser, M., 2008. The geomorphic function and characteristics of large woody debris in low gradient rivers, coastal Maine, USA. Geomorphology 97, 467–482.

Magirl, C.S., Hilldale, R.C., Curran, C.A., Duda, J.J., Straub, T.D., Domanski, M., Foreman, J.R., 2015. Large-scale dam removal on the Elwha River, Washington, USA: Fluvial sediment load. Geomorphology 246, 669–686.

Magner, J.A., Vondracek, B., Brooks, K.N., 2008. Grazed riparian management and stream channel response in southeastern Minnesota (USA) streams. Environ. Manage. 42, 377–390.

Maguire, C., Gallagher, K., Maggs, C., Dick, J., Caffrey, J., O'Flynn, C., Fitzpatrick, U., Kelly, J., Harrod, C., 2011. Alien Invasive Species in Irish Water Bodies. STRIVE Synthesis Report (2007-W-MS-2-S1). Environmental Protection Agency, Wexford, Ireland.

Maguire, C., Gibson, C., 2005. Ecological change in Lough Erne: influence of catchment changes 275 and species invasions. Freshw. Forum 24, 38–58.

Maher, C.A., 2013. The River Shannon Callows, Ireland: An examination of how flooding patterns and farming practices affect plant communities and dipteran assemblages on unregulated floodplain meadows. PhD Thesis, National University of Ireland, Galway.

Malta Resources Authority and Malta Environment and Planning, 2011. Technical Document No 1: Characterization and designation of coastal waters. The 1st Water Catchment Management Plan.

Mander, Ü., Tournebize, J., Tonderski, K., Verhoeven, J.T.A., Mitsch, W.J., 2017. Planning and establishment principles for constructed wetlands and riparian buffer zones in agricultural catchments. Ecol. Eng. 103, 296–300.

Marburg, A.E., Turner, M.G., Kratz, T.K., 2006. Natural and Anthropogenic Variation in Coarse Wood among and within Lakes. J. Ecol. 94, 558–568.

Marence, M., Ingabire, J., Taks, B., 2016. Integration of hydropower plant within an existing weir – “A hidden treasure.” Proceedings of the 4th IAHR Europe Congress, Leige, Belgium, 27–29 July 2016. In: Erpicum, S., Dewals, B., Archambeau, P.Pirotton, M. (Eds.), Sustainable Hydraulics in the Era of Global Change. Taylor & Francis, London, pp. 974–978.

Marks, J.C., Haden, G.A., O’Neill, M., Pace, C., 2010. Effects of Flow Restoration and Exotic Species Removal on Recovery of Native Fish: Lessons from a Dam Decommissioning. Restor. Ecol. 18, 934–943.

Masese, F.O., Kitaka, N., Kipkemboi, J., Gettel, G.M., Irvine, K., McClain, M.E., 2014. Macroinvertebrate functional feeding groups in Kenyan highland streams: evidence for a diverse shredder guild. Freshw. Sci. 33, 435–450.

Matthaei, C.D., Piggott, J.J., Townsend, C.R., 2010. Multiple stressors in agricultural streams: Interactions among sediment addition, nutrient enrichment and water abstraction. J. Appl. Ecol. 47, 639–649.

McCarthy, T.K., Frankiewicz, P., Cullen, P., Blaszkowski, M., O’Connor, W., Doherty, D., 2008. Long-term effects of hydropower installations and associated river regulation on River Shannon eel populations: Mitigation and management. Hydrobiologia 609, 109–124.

McEvoy, S., Haasnoot, M., Biesbroek, R., 2021. How are European countries planning for sea level rise? Ocean Coast. Manag. 203, 105512.

McGarrigle, 2014. Assessment of small water bodies in Ireland. Biol. Environ. Proc. R. Irish Acad. 114B, 119–128.

McGinnity, P.M., Mills, P., Roche, W., Müller, M., 2005. A desk study to determine a methodology for the monitoring of the 'morphological conditions’ of Irish Rivers. Final Report. Environmental RTDI Programme 2000-2006. EPA. 237. Galway, Ireland.

McGoff, E., Aroviita, J., Pilotto, F., Miler, O., Solimini, A.G., Porst, G., Jurca, T., Donohue, L., Sandin, L., 2013. Assessing the relationship between the Lake Habitat Survey and littoral macroinvertebrate communities in European lakes. Ecol. Indic. 25, 205–214.

McGoff, E., Irvine, K., 2009. A test of the association between Lake Habitat Quality Assessment and macroinvertebrate community structure. Aquat. Conserv. Mar. Freshw. Ecosyst. 19, 520–533.

McIntyre, P.B., Jones, L.E., Flecker, A.S., Vanni, M.J., 2007. Fish extinctions alter nutrient recycling in tropical freshwaters. Proc. Natl. Acad. Sci. 104, 4461–4466.

McKeogh, E., 2003. Blackpool Developement - Flood Study University College Cork 2003. Cork, Ireland.

McLoughlin, D., 2018. Pilot on-farm projects to test result-based remuneration schemes for the enhancement of biodiversity End of Project Technical Synthesis Report RBAPS Ireland and Spain. End of project technical systhesis report. Sligo, Ireland.

McLusky, D.S. (Ed), 1989. The Estuarine Ecosystem, 2nd ed. Chapman & Hall, London, UK.

McNally, T., 2009. Overview of the EU Water Framework Directive and Its Implementation in Ireland. Biol. Environ. Proc. R. Irish Acad. 109, 131–138.

Mees, H.L.P., Uittenbroek, C.J., Hegger, D.L.T., Driessen, P.P.J., 2019. From citizen participation to government participation: An exploration of the roles of local governments in community initiatives for climate change adaptation in the Netherlands. Environ. Policy Gov. 29, 198–208.

Mellander, P.-E., Jordan, P., Melland, A.R., Murphy, P.N.C., Wall, D.P., Mechan, S., Meehan, R., Kelly, C., Shine, O., Shortle, G., 2013. Quantification of Phosphorus Transport from a Karstic Agricultural Watershed to Emerging Spring Water. Environ. Sci. Technol. 47, 6111–6119.

Mendelow, A.L., 1981. Environmental Scanning - The Impact of the Stakeholder Concept. In: ICIS 1981 Proceedings, 20. Https://Aisel.Aisnet.Org/Icis1981/20.

Meulenbroek, P., Hammerschmied, U., Schmutz, S., Weiss, S., Schabuss, M., Zornig, H., Shumka, S., Schiemer, F., 2020. Conservation requirements of european eel (Anquilla anquilla) in a balkan catchment. Sustain. 12, 1–14.

Mickle, A.M., 1993. Pollution Filtration by Plants in Wetland-Littoral Zones. Proc. Acad. Nat. Sci. Philadelphia 144, 282–290.

Milbrink, G., 1978. Indicator communities of oligochaetes in Scandinavian lakes. SIL Proc. 20, 2406–2411.

Miler, O., 2022. Hydromorphology - Interactions and habitats. In: Tockner, K., Mehner, T. (Eds.), Encyclopedia of Inland Waters. Elsevier, Cambridge, U.K., pp. 1–12.

Miler, O., Brauns, M., 2020. Hierarchical response of littoral macroinvertebrates to altered hydromorphology and eutrophication. Sci. Total Environ. 743, 140582.

Miler, O., Porst, G., Mcgoff, E., Pilotto, F., Donohue, L., Jurca, T., Solimini, A., Sandin, L., Irvine, K., Aroviita, J., Clarke, R., Pusch, M.T., 2015. An index of human alteration of lake shore morphology. Aquat. Conserv. Mar. Freshw. Ecosyst. 25, 353–364.

Miler, O., Porst, G., McGoff, E., Pilotto, F., Donohue, L., Jurca, T., Solimini, A., Sandin, L., Irvine, K., Aroviita, J., Clarke, R., Pusch, M.T., 2013. Morphological alterations of lake shores in Europe: A multimetric ecological assessment approach using benthic macroinvertebrates. Ecol. Indic. 34, 398–410.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington D.C., U.S.A.

Mills, G., 2001. Ireland’s water budget - Model validation and a greenhouse experiment. Irish Geogr. 34, 124–134.

Ministry of the Environment and Rural and Marine Affairs, 2010. River restoration. Basis of the national strategy for river restoration. Spain.

Misstear, B.D., 2021. Hydrogeological Study of Irish Holy wells. PhD thesis. Trinity College Dublin, Ireland.

Mitsch, W.J., 2005. Applying science to conservation and restoration of the world's wetlands. Water Sci. Technol. 51, 13–26.

Mjelde, M., Hellsten, S., Ecke, F., 2013. A water level drawdown index for aquatic macrophytes in Nordic lakes. Hydrobiologia 704, 141–151.

Mockler, E.M., Bruen, M., 2018. Catchment Management Support Tools for Characterisation and Evaluation of Programme of Measures. Environmental Protection Agency, Wexford, Ireland.

Mockler, E.M., Reaney, S., Mellander, P.-E., Wade, A., Collins, A., Arheimer, B., Bruen, M., 2017. Catchment Models and Management Tools for diffuse Contaminants (Sediment, Phosphorus and Pesticides): DiffuseTools Project. Environmental Protection Agency, Environmental Protection Agency, Wexford, Ireland.

Moe, H., Ciurana, O., Barrett, P., Foley, L., Gaston, L., Olsen, R., 2016. Environmental Impacts of Unconventional Gas Exploration and Extraction (UGEE) Final Report 1: Baseline Characterisation of Groundwater, Surface Water and Aquatic Ecosystems, EPA 2014-W-UGEE-1,. Wexford, Ireland.

Moir, H.J., Gibbins, C.N., Soulsby, C., Webb, J., 2004. Linking channel geomorphic characteristics to spatial patterns of spawning activity and discharge use by Atlantic salmon (Salmo salar L.). Geomorphology 60, 21–35.

Molinaroli, E., Guerzoni, S., Sarretta, A., Cucco, A., Umgiesser, G., 2007. Links between hydrology and sedimentology in the Lagoon of Venice, Italy. J. Mar. Syst. 68, 303–317.

Molinos, J.G., Donohue, I., 2010. Interactions among temporal patterns determine the effects of multiple stressors. Ecol. Appl. 20, 1794–1800.

Moorkens, E.A., 2010. Addressing the Conservation and Rehabilitation of Margaritifera margaritifera (L.).populations in the Republic of Ireland within a framework of the Habitats and Species Directive. J. Conchol. 40, 339-350.

Moran, J., Byrne, D., Carlier, J., Dunford, B., Finn, J.A., Huallacháin, D., Sullivan, C.A., 2021. Management of high nature value farmland in the republic of ireland: 25 years evolving toward locally adapted results-orientated solutions and payments. Ecol. Soc. 26.

Moreira, M., Hayes, D.S., Boavida, I., Schletterer, M., Schmutz, S., Pinheiro, A., 2019. Ecologically-based criteria for hydropeaking mitigation: A review. Sci. Total Environ. 657, 1508–1522.

Moss, B., 2008a. The Water Framework Directive: total environment or political compromise? Sci. Total Environ. 400, 32–41.

Moss, B., 2008b. The Kingdom of the Shore: Achievement of Good Ecological Potential in Reservoirs. Freshw. Rev. 1, 29–42.

Moss, B., Hering, D., Green, A.J., Aidoud, A., Becares, E., Beklioglu, M., Bennion, H., Boix, D., Brucet, S., Carvalho, L., Clement, B., Davidson, T., Declerck, S., Dobson, M., van Donk, E., Dudley, B., Feuchtmayr, H., Friberg, N., Grenouillet, G., Hillebrand, H., Hobaek, A., Irvine, K., Jeppesen, E., Johnson, R., Jones, I., Kernan, M., Lauridsen, T.L., Manca, M., Meerhoff, M., Olafsson, J., Ormerod, S.J., Papastergiadou, E., Penning, W.E., Ptacnik, R., Quintana, X., Sandin, L., Seferlis, M., Simpson, G., Triga, C., Verdonschot, P., Verschoor, A.M., Weyhenmeyer, G. a., 2009. Climate Change and the Future of Freshwater Biodiversity in Europe: A Primer for Policy-Makers. Freshw. Rev. 2, 103–130.

Moss, B., Stephen, D., Alvarez, C., Becares, E., Van De Bund, W., Collings, S.E., Van Donk, E., De Eyto, E., Feldmann, T., Fernández-Aláez, C., Fernández-Aláez, M., Franken,

R.J.M.M., García-Criado, F., Gross, E.M., Gyllström, M., Hansson, L.-A.A., Irvine, K., Järvalt, A., Jensen, J.-P.P., Jeppesen, E., Kairesalo, T., Kornijów, R., Krause, T., Künnap, H., Laas, A., Lill, E., Lorens, B., Luup, H., Miracle, M.R., Nõges, P., Nõges, T., Nykänen, M., Ott, I., Peczula, W., Peeters, E.T.H.M.H.M., Phillips, G., Romo, S., Russell, V., Salujõe, J., Scheffer, M., Siewertsen, K., Smal, H., Tesch, C., Timm, H., Tuvikene, L., Tonno, I., Virro, T., Vicente, E., Wilson, D., Bund, W. Van De, Collings, S.E., Donk, E. Van, Eyto, E. De, Feldmann, T., Fernández-Aláez, C., Fernández-Aláez, M., Franken, R.J.M.M., García-Criado, F., Gross, E.M., Gyllström, M., Hansson, L.-A.A., Irvine, K., Järvalt, A., Jensen, J.-P.P., Jeppesen, E., Kairesalo, T., Kornijów, R., Krause, T., Künnap, H., Laas, A., Lill, E., Lorens, B., Luup, H., Rosa Miracle, M., Nõges, P., Nõges, T., Nykänen, M., Ott, I., Peczula, W., Peeters, E.T.H.M.H.M., Phillips, G., Romo, S., Russell, V., Salujõe, J., Scheffer, M., Siewertsen, K., Smal, H., Tesch, C., Timm, H., Tuvikene, L., Tonno, I., Virro, T., Vicente, E., Wilson, D., Van De Bund, W., Collings, S.E., Van Donk, E., De Eyto, E., Feldmann, T., Fernández-Aláez, C., Fernández-Aláez, M., Franken, R.J.M.M., García-Criado, F., Gross, E.M., Gyllström, M., Hansson, L.-A.A., Irvine, K., Järvalt, A., Jensen, J.-P.P., Jeppesen, E., Kairesalo, T., Kornijów, R., Krause, T., Künnap, H., Laas, A., Lill, E., Lorens, B., Luup, H., Miracle, M.R., Nõges, P., Nõges, T., Nykänen, M., Ott, I., Peczula, W., Peeters, E.T.H.M.H.M., Phillips, G., Romo, S., Russell, V., Salujõe, J., Scheffer, M., Siewertsen, K., Smal, H., Tesch, C., Timm, H., Tuvikene, L., Tonno, I., Virro, T., Vicente, E., Wilson, D., 2003. The determination of ecological status in shallow lakes - A tested system (ECOFRAME) for implementation of the European Water Framework Directive. Aquat. Conserv. Mar. Freshw. Ecosyst. 13, 507–549.

Mott MacDonald Ireland, 2009. Appendix 3a Site Synopsis: N11/N25 Oilgate to Rosslare Harbour Road Improvement Scheme Constraints Study Report.

Muller, M., Biswas, A., Martin-hurtado, R., Tortajada, C., 2015. Built infrastructure is essential. Science (80-.). 349, 585–586.

Müller, U., 2013. Implementation of the flood risk management directive in selected European countries. Int. J. Disaster Risk Sci. 4, 115–125.

Mulligan, M., van Soesbergen, A., Sáenz, L., 2020. GOODD, a global dataset of more than 38,000 georeferenced dams. Sci. Data 7, 1–8.

Naiman, R.J., Elliott, S.R., Helfield, J.M., O'Keefe, T.C., 1999. Biophysical interactions and the structure and dynamics of riverine ecosystems: The importance of biotic feedbacks. Hydrobiologia 410, 79–86.

Naiman, R.J., Latterell, J.J., Pettit, N.E., Olden, J.D., 2008. Flow variability and the biophysical vitality of river systems. Comptes Rendus - Geosci. 340, 629–643.

Nakamura, K., Elbaile, E., Salinas, C., Mesquita-Joanes, F., Sousa, R., Guerrero-Campo, J., Ruiz-Zarzuela, I., de Blas, I., 2019. Captive breeding of Margaritifera auricularia (Spengler, 1793) and its conservation importance. Aquat. Conserv. Mar. Freshw. Ecosyst. 29, 1771–1784.

Nakamura, K., Tockner, K., Amano, K., 2006. River and wetland restoration: Lessons from Japan. Bioscience 56, 419–429.

Nanson, G.C., Croke, J.C., 1992. A genetic classification of floodplains. Geomorphology 4, 459–486.

Naughton, O., Johnston, P.M., Gill, L.W., 2012. Groundwater flooding in Irish karst: The hydrological characterisation of ephemeral lakes (turloughs). J. Hydrol. 470–471.

Neilsen, M., 2002. Lowland stream restoration in Denmark: Background and examples. Water Environ. J. 16, 189–193.

Newcastle Gateshead Green Infrastructure, n.d. Strategic Interventions. Newcastle City Council and Gateshead Council., Newcastle, UK.

Newson, M.D., 2002. Geomorphological concepts and tools for sustainable river ecosystem management. Aquat. Conserv. Mar. Freshw. Ecosyst. 12, 365–379.

Newson, M.D., Large, A.R.G., 2006. 'Natural' rivers, 'hydromorphological quality' and river restoration: a challenging new agenda for applied fluvial geomorphology. Earth Surf. Process. Landforms 31, 1606–1624.

NGC, 2004. Knowledge Gaps for Groundwater Reforms. A strategic directions paper for water researchers, based on outcomes of a national workshop held in Canberra 12-13 November 2003 hosted by the National Groundwater Committee. Canberra, Australia.

Ní Chatháin, B., Moorkens, E., Irvine, K., 2013. Management Strategies for the Protection of High Status Water Bodies, Report Series No . 99. Environmental Protection Agency. Wexford, Ireland.

Nickel, D., Schoenfelder, W., Medearis, D., Dolowitz, D.P., Keeley, M., Shuster, W., 2014. German experience in managing stormwater with green infrastructure. J. Environ. Plan. Manag. 57, 403–423.

Nijboer, R.C., Verdonschot, P.F.M., Van der Werf, D.., 2005. The use of indicator taxa as representatives of communities in bioassessment. Freshw. Biol. 50, 1427–1440.

Noda, K., Hamada, J., Kimura, M., Oki, K., 2018. Debates over dam removal in Japan. Water Environ. J. 32, 446–452.

Nones, M., 2015. Implementation of the floods directive in selected EU member states. Water Environ. J. 29, 412–418.

Nones, M., Gerstgraser, C., Wharton, G., 2017. Consideration of hydromorphology and sediment in the implementation of the EU water framework and floods directives: a comparative analysis of selected EU member states. Water Environ. J. 31, 324–329.

Nones, M., Pescaroli, G., 2016. Implications of cascading effects for the EU Floods Directive. Int. J. River Basin Manag. 14, 195–204.

Norgaard, R.B., Kallis, G., Kiparsky, M., 2009. Collectively engaging complex socio-ecological systems: re-envisioning science, governance, and the California Delta. Environ. Sci. Policy 12, 644–652.

NPWS, 2013. The Status of EU Protected Habitats and Species in Ireland: Habitat Assessments. National Parks and Wildlife Service, Dublin, Ireland.

NPWS, 2021. Conservation objectives for Tacumshin Lake SPA [004092]. National Parks and Wildlife Service, Dublin, Ireland.

O'Brien, G., Dickens, C., Baker, C., Stassen, R., van Weert, F., 2020. Sustainable Floodplains: Linking E-Flows to Floodplain Management, Ecosystems, and Livelihoods in the Sahel of North Africa. Sustainability 12, 10578.

O'Brien, G., Studies, S., Irish, A., Review, Q., Dec, N., 1941. Arterial Drainage in Ireland. An Irish Q. Rev. 30, 555–570.

O'Connor, N.A., 1991. The effects of habitat complexity on the macroinvertebrates colonising wood substrates in a lowland stream. Oecologia 85, 504–512.

O'Connor, W., 2003. Biology and Management of European Eel (Anguilla anguilla, L) in the Shannon Estuary, Ireland. PhD thesis, National University of Ireland, Galway, Ireland.

O'Doherty, C., 2020. Millions spent on pipeline plan that may face the axe. Independent.ie,

Dublin, Ireland. https://www.independent.ie/irish-news.

O'Doherty, C., 2021. Investigation under way after hundreds of fish killed near drinking water reservoir - Independent.ie. Dublin, Ireland. https://www.independent.ie/irish-news/investigation-under-way-after-hundreds-of-fish-killed-near-drinking-water-reservoir/40623227.html.

O'Driscoll, M.A., Parizek, R., 2003. The hydrologic catchment area of a chain of karst wetlands in central Pennsylvania, USA. Wetlands 23, 171–179.

O'Driscoll, M.A., Parizek, R.R., 2008. Geological controls on seasonal-pool hydroperiod in a karst setting. Wetlands 28, 1004–1017.

O'Higgins, T., Lago, M., Reilly, K., Culhane, F., Robinson, L., 2018. Aquacross D9.2 Case Study 4 Report Management and impact of Invasive Alien Species (IAS) in Lough Erne in Ireland. University College Cork, Cork, Ireland.

O'Rourke, F., Bryne, C., Smith, G., 2023. Land Use Evidence Review Phase 1 Synthesis Report. Dublin, Ireland.

Ock, G., Sumi, T., Takemon, Y., 2013. Sediment replenishment to downstream reaches below dams: implementation perspectives. Hydrol. Res. Lett. 7, 54–59.

Ockenden, M.C., Deasy, C., Quinton, J.N., Bailey, A.P., Surridge, B., Stoate, C., 2012. Evaluation of field wetlands for mitigation of diffuse pollution from agriculture: Sediment retention, cost and effectiveness. Environ. Sci. Policy 24, 110–119.

OECD, 1982. Eutrophication of water. Monitoring, assessment and control. Organisation for Economic Co-operation and Development, Paris, France.

Okun, N., Mehner, T., 2005. Distribution and feeding of juvenile fish on invertebrates in littoral reed (Phragmites) stands. Ecol. Freshw. Fish 14, 139–149.

Old, G.H., Leeks, G.J.L., Packman, J.C., Smith, B.P.G., Lewis, S., Hewitt, E.J., 2006. River flow and associated transport of sediments and solutes through a highly urbanised catchment, Bradford, West Yorkshire. Sci. Total Environ. 360, 98–108.

Opperman, J.J., Kendy, E., Tharme, R.E., Warner, A.T., Barrios, E., Richter, B.D., 2018. A Three-Level Framework for Assessing and Implementing Environmental Flows. Front. Environ. Sci. 6.

OPW, 2007. Series of Ecological Assessment of Arterial Drainage Maintenance-No 1. Screening of Natura 2000 Sites for Impacts of Arterial Drainage Maintenance Operations. Office of Public Works, Dublin, Ireland.

OPW, 2012. Eastern CFRAM Study. Office of Public Works, Dublin, Ireland.

OPW, 2015. Clonakilty Flood Relief Scheme. Office of Public Works, Dublin, Ireland.

OPW, 2016a. River Bride (Blackpool) Certified Drainage Scheme Blackpool Hydraulic Modelling Report. Commissioned to ARUP and JBA Consulting. Office of Public Works, Cork, Ireland.

OPW, 2016b. Office of Public Works River Bride (Blackpool) Certified Drainage Scheme Flood Risk Management Options Report 230436/REP/1 Issue 1 | 22 January 2016. Commissioned to ARUP and JPA consulting. Office of Public Works, Dublin, Ireland.

OPW, 2018. Flood Risk Management Plan, Flood Risk Management Plan. Shannon Upper & Lower. Dublin, Ireland.

OPW, 2019. King's Island Flood Relief Scheme Environmental Impact Assessment Report Volume 2- EIAR Report. Office of Public Works, Dublin, Ireland.

OPW, 2021a. Scoping Report for the Arterial Drainage Maintenance Activities 2022- JBA Consulting Engineers and Scientists Ltd. Office of Public Works, Dublin, Ireland.

OPW, 2021b. The Review of the Flood Risk Management Plans Report – December 2021. Dublin, Ireland.

OPW, 2022. Biodiversity Action Strategy 2022-2026. Office of Public Works, Navan, Ireland.

Orford, J.D., Carter, R.W.G., Forbes, D.L., Taylor, R.B., 1988. Overwash occurrence consequent on morphodynamic changes following lagoon outlet closure on a coarse clastic barrier. Earth Surf. Process. Landforms 13, 27–35.

Orlando-Bonaca, M., Mavrič, B., Urbanič, G., 2012. Development of a new index for the assessment of hydromorphological alterations of the Mediterranean rocky shore. Ecol. Indic. 12, 26–36.

Ormerod, S.J., 2004. A golden age of river restoration science? Aquat. Conserv. Mar. Freshw. Ecosyst. 14, 543–549.

Orr, H.G., Large, A.R.G., Newson, M.D., Walsh, C.L., 2008. A predictive typology for characterising hydromorphology. Geomorphology 100, 32–40.

Osborne, S.P., 2006. The New Public Governance? 1. Public Manag. Rev. 8, 377–387.

OSPAR Commission, 2009. Assessment of the impact of coastal defence structures Biodiversity Series, Assessment.

Ostendorp, W., Hofmann, H., Teufel, L., Miler, O., 2020. Effects of a retaining wall and an artificial embankment on nearshore littoral habitats and biota in a large Alpine lake. Hydrobiologia 847, 365–389.

Owens, P.N., 2009. Adaptive management frameworks for natural resource management at the landscape scale: implications and applications for sediment resources. J. Soils Sediments 9, 578–593.

Owens, P.N., Batalla, R.J., Collins, A.J., Gomez, B., Hicks, D.M., Horowitz, A.J., Kondolf, G.M., Marden, M., Page, M.J., Peacock, D.H., Petticrew, E.L., Salomons, W., Trustrum, N.A., 2005. Fine-grained sediment in river systems: environmental significance and management issues. River Res. Appl. 21, 693–717.

Padmalal, D., Maya, K., 2014. Sand Mining. Environmental Impacts and Selected Case Studies. Springer, Dordrecht, Netherlands.

Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Glob. Environ. Chang. 19, 354–365.

Palliwoda, J., Kowarik, I., von der Lippe, M., 2017. Human-biodiversity interactions in urban parks: The species level matters. Landsc. Urban Plan. 157, 394–406.

Palmer, M., Allan, J.D., Meyer, J., Bernhardt, E.S., 2007. River Restoration in the Twenty-First Century: Data and Experiential Knowledge to Inform Future Efforts. Restor. Ecol. 15, 472–481.

Palmer, M.A., Menninger, H., Bernhardt, E.S., 2010. River restoration, habitat heterogeneity and biodiversity: A failure of theory or practice? Freshw. Biol. 55, 205–222.

Parasiewicz, P., Ryan, K., Vezza, P., Comoglio, C., Ballestero, T., Rogers, J.N., 2013. Use of quantitative habitat models for establishing performance metrics in river restoration planning. Ecohydrology 6, 668–678.

Pardo, I., Gómez-Rodríguez, C., Wasson, J.-G., Owen, R., van de Bund, W., Kelly, M.G.,

Bennett, C., Birk, S., Buffagni, A., Erba, S., Mengin, N., Murray-Bligh, J., Ofenböeck, G., 2012. The European reference condition concept: A scientific and technical approach to identify minimally-impacted river ecosystems. Sci. Total Environ. 420, 33–42.

Parker, D.J., 1995. Floodplain development policy in England and Wales. Appl. Geogr. 15, 341–363.

Patt, H., Juerging, P., Kraus, W., 2004. Engineering, Near-natural hydraulic Rivers, Development and design of Rivers. In: Naturnaher Wasserbau. Springer-Verlag, Berlin/Heidelberg, pp. 145–164.

Pätzig, M., Grüneberg, B., Brauns, M., 2015. Water depth but not season mediates the effects of human lakeshore modification on littoral macroinvertebrates in a large lowland lake. Fundam. Appl. Limnol. 186, 311–321.

Peacock, C., 2003. Rivers, Floodplains and Wetlands: Connectivity and Dynamics. Water 1–64.

Pedersen, M.L., Andersen, J.M., Nielsen, K., Linnemann, M., 2007. Restoration of Skjern River and its valley: Project description and general ecological changes in the project area. Ecol. Eng. 30, 131–144.

Pejchar, L., Mooney, H.A., 2009. Invasive species, ecosystem services and human well-being. Trends Ecol. Evol. 24, 497–504.

Pérez-Bielsa, C., Lambán, L.J., Plata, J.L., Rubio, F.M., Soto, R., 2012. Characterization of a karstic aquifer using magnetic resonance sounding and electrical resistivity tomography: a case-study of Estaña Lakes (northern Spain). Hydrogeol. J. 20, 1045–1059.

Perrin, P.M., Waldren, S., Penk, M.R., O'Neill, F.H., 2020. Saltmarsh Function and Human Impacts in Relation to Ecological Status (SAMFHIRES), EPA Report 313. Wexford, Ireland.

Pešić, V., Dmitrović, D., Savić, A., Milošević, Đ., Zawal, A., Vukašinović-Pešić, V., Von Fumetti, S., 2019. Application of macroinvertebrate multimetrics as a measure of the impact of anthropogenic modification of spring habitats. Aquat. Conserv. Mar. Freshw. Ecosyst. 29, 341–352.

Petts, G.E., 1980. Long-term Consequences of Upstream Impoundment. Environ. Conserv. 7, 325–332.

Petts, G.E., 1984. Impounded Rivers. John Wiley & Sons, Ltd., Chichester, UK.

Petts, G.E., 1988. Accumulation of fine sediment within substrate gravels along two regulated rivers, UK. Regul. Rivers Res. Manag. 2, 141–153.

Phellan, N., Rumley, J., Salas Herreo, F., 2021. Hydromorphological assessment and monitoring methodologies in coastal and transitional report. Luxembourg, Luxembourg.

Piégay, H., Gurnell, A.M., 1997. Large woody debris and river geomorphological pattern: examples from S.E. France and S. England. Geomorphology 19, 99–116.

Piégay, H., Walling, D.E., Landon, N., He, Q., Liébault, F., Petiot, R., 2004. Contemporary changes in sediment yield in an alpine mountain basin due to afforestation (the upper Drôme in France). Catena 55, 183–212.

Pilotto, F., Bazzanti, M., Di Vito, V., Frosali, D., Livretti, F., Mastrantuono, L., Pusch, M.T., Sena, F., Solimini, A.G., 2015. Relative impacts of morphological alteration to shorelines and eutrophication on littoral macroinvertebrates in Mediterranean lakes. Freshw. Sci. 34, 410–422.

Pilotto, F., Free, G., Cardoso, A.C., Wolfram, G., Solimini, A.G., 2012. Spatial variance of profundal and sublittoral invertebrate benthic communities in response to eutrophication and morphological pressures. Fundam. Appl. Limnol. 180, 101–110.

Pinter, N., van der Ploeg, R.R., Schweigert, P., Hoefer, G., 2006. Flood magnification on the River Rhine. Hydrol. Process. 20, 147–164.

Pitacco, V., Mistri, M., Munari, C., 2018. Long-term variability of macrobenthic community in a shallow coastal lagoon (Valli di Comacchio, northern Adriatic): Is community resistant to climate changes? Mar. Environ. Res. 137, 73–87.

Planty-Tabacchi, A.-M., Tabacchi, E., Naiman, R.J., Deferrari, C., Decamps, H., 1996. Invasibility of Species-Rich Communities in Riparian Zones. Conserv. Biol. 10, 598–607.

Poff, N.L., Olden, J.D., Merritt, D.M., Pepin, D.M., 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. Proc. Natl. Acad. Sci. 104, 5732–5737.

Poff, N.L., Richter, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C.D., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G., Merritt, D.M., O'□Keeffe, J.H., Oldon, Julian D.ogers, K., Tharme, R.E., Warner, A., 2010. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshw. Biol. 55, 147–170.

Poff, N.L., Zimmerman, J.K.H., 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshw. Biol. 55, 194–205.

Poikane, S., Birk, S., Böhmer, J., Carvalho, L., De Hoyos, C., Gassner, H., Hellsten, S., Kelly, M.G., Lyche Solheim, A., Olin, M., Pall, K., Phillips, G., Portielje, R., Ritterbusch, D., Sandin, L., Schartau, A.-K.K., Solimini, A.G., van den Berg, M., Wolfram, G., Van De Bund, W., 2015. A hitchhiker's guide to European lake ecological assessment and intercalibration. Ecol. Indic. 52, 533–544.

Poikane, S., Johnson, R.K., Sandin, L., Schartau, A.K., Solimini, A.G., Urbanič, G., Arbačiauskas, K., Aroviita, J., Gabriels, W., Miler, O., Pusch, M.T., Timm, H., Böhmer, J., 2016. Benthic macroinvertebrates in lake ecological assessment: A review of methods, intercalibration and practical recommendations. Sci. Total Environ. 543, 123–134.

Poikane, S., Salas Herrero, F., Kelly, M.G., Borja, A., Birk, S., van de Bund, W., 2020a. European aquatic ecological assessment methods: A critical review of their sensitivity to key pressures. Sci. Total Environ. 740, 140075.

Poikane, S., Zampoukas, N., Borja, A., Davies, S.P., van de Bund, W., Birk, S., 2014. Intercalibration of aquatic ecological assessment methods in the European Union: Lessons learned and way forward. Environ. Sci. Policy 44, 237–246.

Poikane, S., Zohary, T., Cantonati, M., 2020b. Assessing the ecological effects of hydromorphological pressures on European lakes. Inl. Waters 10, 241–255.

Poole, G.C., Stanford, J.A., Running, S.W., Frissell, C.A., 2006. Multiscale Geomorphic Drivers of Groundwater Flow Paths: Subsurface Hydrologic Dynamics and Hyporheic Habitat Diversity. J. North Am. Benthol. Soc. 25, 288–303.

Porst, G., Brauns, M., Irvine, K., Solimini, A., Sandin, L., Pusch, M., Miler, O., 2019. Effects of shoreline alteration and habitat heterogeneity on macroinvertebrate community composition across European lakes. Ecol. Indic. 98, 285–296.

Premke, K., Karlsson, J., Steger, K., Gudasz, C., von Wachenfeldt, E., Tranvik, L.J., 2010.

Stable isotope analysis of benthic fauna and their food sources in boreal lakes. J. North Am. Benthol. Soc. 29, 1339–1348.

Purseglove, J., 1989. Taming the flood. A history and natural history of rivers and wetlands. Oxford University Press, Oxford, U.K.

Pusch, M., Behrendt, H., Gancarczyk, A., Kronvang, B., Sandin, L., Stendera, S., Wolter, C., Andersen, H.E., Fischer, H., Hoffmann, C.C., Nowacki, F., Schöll, F., Svendsen, L.M., Bäthe, J., Friberg, N., Hachoł, J., Pedersen, M.L., Scholten, M., Wnuk-Gławdel, E., 2009. Rivers of the Central European Highlands and Plains. In: Tockner, K., Uehlinger, U., Robinson, C.T. (Eds.), Rivers of Europe. Elsevier, Dordrecht, The Netherlands, pp. 525–576.

Pyšek, P., Hulme, P.E., Simberloff, D., Bacher, S., Blackburn, T.M., Carlton, J.T., Dawson, W., Essl, F., Foxcroft, L.C., Genovesi, P., Jeschke, J., Kühn, I., Liebhold, A.M., Mandrak, N.E., Meyerson, L.A., Pauchard, A., Pergl, J., Roy, H.E., Seebens, H., van Kleunen, M., Vilà, M., Wingfield, M.J., Richardson, D.M., 2020. Scientists' warning on invasive alien species. Biol. Rev. 95, 1511–1534.

Rasmussen, J.B., 1988. Littoral Zoobenthic Biomass in Lakes, and Its Relationship to Physical, Chemical, and Trophic Factors. Can. J. Fish. Aquat. Sci. 45, 1436–1447.

Raven, P.J., Holmes, N.T.H., Charrier, P., Dawson, F.H., Naura, M., Boon, P.J., 2002. Towards a harmonized approach for hydromorphological assessment of rivers in Europe: A qualitative comparison of three survey methods. Aquat. Conserv. Mar. Freshw. Ecosyst. 12, 405–424.

Raymond, C.M., Berry, P., Breil, M., Nita, M.R., Kabisch, N., De Bel, M., Enzi, V., Frantzeskaki, N., Geneletti, D., Cardinaletti, M., Lovinger, L., Basnou, C., Monteiro, A., Robrecht, H., Sgrigna, G., Muhari, L., Calfapietra, C. 2017.Geneletti, D., Cardinaletti, M., Lovinger, L., Basnou, C., Monteiro, A., Robrecht, H., Sgrigna, G., Muhari, L. and Calfapietra, C. 2017., 2017. An Impact Evaluation Framework to Support Planning and Evaluation of Nature-Based Solutions Projects. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. www.eklipse-mechanism.eu/apps. Wallingford, U.K.

Reale, A., 2011. The Shannon scheme and its effect on the Shannon fisheriesUnpublished work. Retrieved from https://www.limerick.ie/sites/default/files/atoms/files/the_shannon_scheme_and_its_effect_on_the_shannon_fisher.pdf.

Recio, M., Ondiviela, B., Puente, A., Galván, C., Gómez, A.G., Juanes, J.A., 2013. The Influence of Hydromorphological Stressors on Estuarine Vegetation Indicators. Estuaries and Coasts 36, 997–1005.

Renöfält, B.M., Jansson, R., Nilsson, C., 2010. Effects of hydropower generation and opportunities for environmental flow management in Swedish riverine ecosystems. Freshw. Biol. 55, 49–67.

RESTORE, 2013. River restoration in Europe : the art of the possible. Report to the European Union, RESTORE Layman's Report.

Revez, A., 2014. Flood risk management in Ireland: the role of public participation. PhD thesis. National University Galway, Galway, Ireland.

Richardson, D.M., Holmes, P.M., Esler, K.J., Galatowitsch, S.M., Stromberg, J.C., Kirkman, S.P., Pyšek, P., Hobbs, R.J., 2007. Riparian vegetation: degradation, alien plant invasions, and restoration prospects. Divers. Distrib. 13, 126–139.

Richter, B.D., Braun, D.P., Mendelson, M.A., Master, L.L., 1997. Threats to Imperiled Freshwater Fauna. Conserv. Biol. 11, 1081–1093.

Riley, W.D., Potter, E.C.E.E., Biggs, J., Collins, A.L., Jarvie, H.P., Jones, J.I., Kelly-Quinn, M., Ormerod, S.J., Sear, D.A., Wilby, R.L., Broadmeadow, S., Brown, C.D., Chanin, P., Copp, G.H., Cowx, I.G., Grogan, A., Hornby, D.D., Huggett, D., Kelly, M.G., Naura, M., Newman, J.R., Siriwardena, G.M., 2018. Small Water Bodies in Great Britain and Ireland: Ecosystem function, human-generated degradation, and options for restorative action. Sci. Total Environ. 645, 1598–1616.

Rinaldi, M., Belletti, B., Bund, W., Bertoldi, W., Gurnell, A.M., Buijse, A.D., Mosselman, E., 2013. Review on eco-hydromorphological methods. REFORM (REstoring rivers FOR effective catchment Management), Project funded by the European Commission within the 7th Framework Programme (2007 – 2013).

Rinaldi, M., Belletti, B., Comiti, F., Nardi, L., 2015a. The Geomorphic Units survey and classification System (GUS), Deliverable 6.2, Part 4 . REFORM (REstoring rivers FOR effective catchment Management).

Rinaldi, M., Gurnell, A.M., del Tánago, M.G., Bussettini, M., Hendriks, D., 2016. Classification of river morphology and hydrology to support management and restoration. Aquat. Sci. 78, 17–33.

Rinaldi, M., Surian, N., Comiti, F., Bussettini, M., 2015b. A methodological framework for hydromorphological assessment, analysis and monitoring (IDRAIM) aimed at promoting integrated river management. Geomorphology 251, 122–136.

Rippey, B., Campbell, J., McElarney, Y., Thompson, J., Gallagher, M., 2021. Timescale of reduction of long-term phosphorus release from sediment in lakes. Water Res. 200.

Rodgers, M., O'Connor, M., Robinson, M., Muller, M., Poole, R., Xiao, L., 2011. Suspended solid yield from forest harvesting on upland blanket peat. Hydrol. Process. 25, 207–216.

Rodríguez-Amaya, C., Durán-Ariza, A., Duarte-Méndez, S., 2020. Submerged vane technology in Colombia: Five representative projects. Water (Switzerland) 12.

Rodríguez-Rodríguez, M., Martos-Rosillo, S., Pedrera, A., Benavente-Herrera, J., 2015. Ratosa playa lake in southern Spain. Karst pan or compound sink? Environ. Monit. Assess. 187, 175.

Rogger, M., Agnoletti, M., Alaoui, A., Bathurst, J.C., Bodner, G., Borga, M., Chaplot, V., Gallart, F., Glatzel, G., Hall, J., Holden, J., Holko, L., Horn, R., Kiss, A., Kohnová, S., Leitinger, G., Lennartz, B., Parajka, J., Perdigão, R., Peth, S., Plavcová, L., Quinton, J.N., Robinson, M., Salinas, J.L., Santoro, A., Szolgay, J., Tron, S., van den Akker, J.J.H., Viglione, A., Blöschl, G., 2017. Land use change impacts on floods at the catchment scale: Challenges and opportunities for future research. Water Resour. Res. 53.

Rohde, M.M., Froend, R., Howard, J., 2017. A Global Synthesis of Managing Groundwater Dependent Ecosystems Under Sustainable Groundwater Policy. Groundwater 55, 293–301.

Rohde, M.M., Matsumoto, S., Howard, J., Liu, S., Riege, L., Remson, E.J., 2018. Groundwater Dependent Ecosystems under the Sustainable Groundwater Management Act: Guidance for Preparing Groundwater Sustainability Plans. San Francisco, U.S.A.

Rolston, A.A., Jennings, E., Linnane, S., Getty, D., 2017. Developing the Concept of Catchment Services for Progress Towards Integrated Water Management (Extra TIMe) - Report No.229 to the EPA. Environmental Protection Agency,Wexford, Ireland.

Roni, P., Beechie, T., 2012. Stream and Watershed Restoration. John Wiley & Sons, Ltd, Chichester, U.K.

Rooney, S.M., Wightman, G., Ó'Conchúir, R., King, J.J., 2015. Behaviour of sea lamprey

(Petromyzon marinus L.) at man-made obstacles during upriver spawning migration: Use of telemetry to assess efficacy of weir modifications for improved passage. Biol. Environ. 115B, 1–12.

Rosenberg, D.M., Resh, V.H. (Eds), 1993. Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman and Hall, London, U.K.

Rounds, C.I., Vitense, K., Hansen, G.J.A., 2023. Digitizing lake bathymetric data using ImageJ. Limnol. Oceanogr. Methods 21, 615–624.

Roux, D.J., Kleynhans, C.J., Thirion, C., Hill, L., Engelbrecht, J.S., Deacon, A.R., Kemper, N.P., 1999. Adaptive assessment and management of riverine ecosystems: The Crocodile/Elands River case study. Water SA 25, 501–511.

Rowan, J.S., Carwardine, J., Duck, R.W., Bragg, O.M., Black, A.R., Cutler, M.E.J., Soutar, I., Boon, P.J., 2006. Development of a technique for Lake Habitat Survey (LHS) with applications for the European Union Water Framework Directive. Aquat. Conserv. Mar. Freshw. Ecosyst. 16, 637–657.

Rowan, J.S., Greig, S.J., Armstrong, C.T., Smith, D.C., Tierney, D., 2012. Development of a classification and decision-support tool for assessing lake hydromorphology. Environ. Model. Softw. 36, 86–98.

RPS Group, 2021. Natura Impact Statement Draft 3rd Cycle River Basin Management Plan Report.

RTE, 2016. Preferred route for Shannon pipeline published. Dublin, Ireland. https://www.rte.ie/news/2016/1108/829936-pipeline/.

Ruddiman, W.F., 2005. Plows, Plagues, and Petroleum: How Humans Took Control of the Climate. Princeton University Press, Princeton, U.S.A.

Russell, K.L., Vietz, G.J., Fletcher, T.D., 2017. Global sediment yields from urban and urbanizing watersheds. Earth-Science Rev. 168, 73–80.

Russi, D., ten Brink, P., Farmer, A., Bandura, T., Coates, D., Dorster, J., Kumar, R., Davidson, N.C., Badura, T., Coates, D., Förster, J., Kumar, R., Davidson, N.C., 2013. The Economics of Ecosystems and Biodiversity for Water and Wetlands, IEEP, London and Brussels; Ramsar Secretaria. IIEP, London, Brussels.

Ryan Hanley/MKO, 2020. River Deel (Crossmolina) Drainage Scheme. Environmental Impact Assessment Report (EIAR) Non- technical summary.

Ryan, T.D., 1986. Agricultural drainage practices in Ireland. Environ. Geol. Water Sci. 9, 31–40.

Rydell, L.E., 1956. River Shannon Flood Problem. Final Report, Corp of Engineers U.S. Army. Dublin, Ireland.

Ryder, E., de Eyto, E., Dillane, M., Poole, R., Jennings, E., 2014. Identifying the role of environmental drivers in organic carbon export from a forested peat catchment. Sci. Total Environ. 490, 28–36.

Rymszewicz, A., Mockler, E., O'Sullivan, J., Bruen, M., Turner, J., Conroy, E., Kelly-Quinn, M., Harrington, J., Lawler, D., 2015. Assessing the applicability of the Revised Universal Soil Loss Equation (RUSLE) to Irish Catchments. Proc. Int. Assoc. Hydrol. Sci. 367, 99–105.

Saether, O.A., 1979. Chironomid communities as water quality indicators. Holarctic. Ecology 2, 65–74.

Sahlberg, P., Oldroyd, D., 2010. Pedagogy for economic competitiveness and sustainable

development. Eur. J. Educ. 45, 280–299.

Salas Herrero, F., 2018. Hydromorphological assessment and monitoring methodologies in coastal and transitional report. Summary of European country questionnaires, EUR 29597 EN, .

Salter, M., Singleton-White, S., 2019. Chalk Streams in Crisis: A call for drought action now. https://docslib.org/doc/10848081/chalk-streams-in-crisis-a-call-for-drought-action-now.

Sandin, L., Johnson, R.K., 2004. Local, landscape and regional factors structuring benthic macroinvertebrate assemblages in Swedish streams. Landsc. Ecol. 19, 501–515.

SANDRP, 2020. Ireland Supreme Court holds dam operator responsible for 2009 floods. https://sandrp.in/2020/07/14/ireland-supreme-court-holds-dam-operator-responsible-for-2009-floods/.

Sarretta, A., Pillon, S., Molinaroli, E., Guerzoni, S., Fontolan, G., 2010. Sediment budget in the Lagoon of Venice, Italy. Cont. Shelf Res. 30, 934–949.

Sayers, P., Galloway, G., Penning-Rowsell, E., Yuanyuan, L., Fuxin, S., Yiwei, C., Kang, W., Le Quesne, T., Wang, L., Guan, Y., 2015. Strategic flood management: ten 'golden rules' to guide a sound approach. Int. J. River Basin Manag. 13, 137–151.

Scanlon, B.R., Jolly, I., Sophocleous, M., Zhang, L., 2007. Global impacts of conversions from natural to agricultural ecosystems on water resources: Quantity versus quality. Water Resour. Res. 43.

Schanze, J., Olfert, A., Tourbier, J.T., Gersdorf, I., Schwager, H., 2012. Existing Urban River Rehabilitation Schemes. Repos. PUJ 28, 60.

Scheurer, K., Alewell, C., Bänninger, D., Burkhardt-Holm, P., 2009. Climate and land-use changes affecting river sediment and brown trout in alpine countries—a review. Environ. Sci. Pollut. Res. 16, 232–242.

Schindler, S., O'Neill, F.H., Biró, M., Damm, C., Gasso, V., Kanka, R., van der Sluis, T., Krug, A., Lauwaars, S.G., Sebesvari, Z., Pusch, M., Baranovsky, B., Ehlert, T., Neukirchen, B., Martin, J.R., Euller, K., Mauerhofer, V., Wrbka, T., 2016. Multifunctional floodplain management and biodiversity effects: a knowledge synthesis for six European countries. Biodivers. Conserv. 25, 1349–1382.

Schmidt, J.C., Wilcock, P.R., 2008. Metrics for assessing the downstream effects of dams. Water Resour. Res. 44.

Schmieder, K., 2004. European lake shores in danger — concepts for a sustainable development. Limnologica 34, 3–14.

Schneider, K.N., Winemiller, K.O., 2008. Structural complexity of woody debris patches influences fish and macroinvertebrate species richness in a temperate floodplain-river system. Hydrobiologia 610, 235–244.

Schramm, M.P., Bevelhimer, M.S., DeRolph, C.R., 2016. A synthesis of environmental and recreational mitigation requirements at hydropower projects in the United States. Environ. Sci. Policy 61, 87–96.

Schwarz, U., 2007. Pilot Study: Hydromorphological survey and mapping of the Drava and Mura Rivers. Prepared for International Association for Danube Research (IAD) General Secretariat, Vienna, Austria.

Schwarz, U., 2021. The potential of barrier removal to reconnect Europe's rivers. Vienna, Austria.

Sear, D., 1995. Morphological and sedimentological changes in a gravel-bed river following

12 years of flow regulation for hydropower. Regul. Rivers Res. Manag. 10, 247–264.

Segura, C., Booth, D.B., 2010. Effects of Geomorphic Setting and Urbanization on Wood, Pools, Sediment Storage, and Bank Erosion in Puget Sound Streams1. JAWRA J. Am. Water Resour. Assoc. 46, 972–986.

SEPA, 2012a. Guide to hydropower construction best practice. Scottish Environment Agency, Scottish Environment Protection Agency, Edinburgh, U.K.

SEPA, 2012b. Supporting Guidance (WAT-SG-78) Sediment Management Authorisation. Scottish Environment Protection Agency, Edinburgh, U.K.

SER, n.d. Restoration Resource Center Denmark: Skjern River Restoration.

Shafai-Bejestan, M., Mahmoodi, S., Soozepour, A., 2016. Floating vanes for bend scour control. In: River Flow 2016. CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742, pp. 1280–1284.

Sharp, L., 2017. Reconnecting people and water: Public engagement and sustainable urban water management. Routledge, London, U.K.

Sheehy Skeffington, M., Moran, J., O Connor, Á., Regan, E., Coxon, C.E., Scott, N.E., Gormally, M., 2006. Turloughs – Ireland's unique wetland habitat. Biol. Conserv. 133, 265–290.

Shen, S.-L., Ma, L., Xu, Y.-S., Yin, Z.-Y., 2013. Interpretation of increased deformation rate in aquifer IV due to groundwater pumping in Shanghai. Can. Geotech. J. 50, 1129–1142.

Sherriff, S.C., Rowan, J.S., Melland, A.R., Jordan, P., Fenton, O., Ó hUallacháin, D., 2015. Investigating suspended sediment dynamics in contrasting agricultural catchments using ex situ turbidity-based suspended sediment monitoring. Hydrol. Earth Syst. Sci. 19, 3349–3363.

Shields, F.D., Copeland, R.R., Klingeman, P.C., Doyle, M.W., Simon, A., 2003. Design for Stream Restoration. J. Hydraul. Eng. 129, 575–584.

Shields, F.D., Morin, N., Cooper, C.M., 2004. Large Woody Debris Structures for Sand-Bed Channels. J. Hydraul. Eng. 130, 208–217.

Shine, C., Kettunen, M., Genovesi, P., Essl, F., Gollasch, S., Rabitsch, W., Scalera, R., Starfinger, U., ten Brink, P., 2010. Assessment to support continued development of the EU Strategy to combat invasive alien species. Final Report for the European Commission. Brussels, Belgium.

Shwartz, A., Turbé, A., Julliard, R., Simon, L., Prévot, A.C., 2014. Outstanding challenges for urban conservation research and action. Glob. Environ. Chang. 28, 39–49.

Simon, A., 1989. A model of channel response in disturbed alluvial channels. Earth Surf. Process. Landforms 14, 11–26.

Skinner, K.S., Bruce-Burgess, L., 2005. Strategic and project level river restoration protocols? Key components for meeting the requirements of the Water Framework Directive (WFD). Water Environ. J. 19, 135–142.

Smeets, E., Weterings, R., 1999. Environmental indicators: Typology and overview. Technical report No 25. European Environment Agency, Copenhagen, Denmark.

Smith, B.D., Maitland, P.S., Pennock, S.M., 1987. A comparative study of water level regimes and littoral benthic communities in Scottish lochs. Biol. Conserv. 39, 291–316.

Smith, V.H., Joye, S.B., Howarth, R.W., 2006. Eutrophication of freshwater and marine

ecosystems. Limnol. Oceanogr. 51, 351–355.

Smol, J.P., 2008. Pollution of lakes and rivers: A paleoenvironmental perspective, 2nd ed. Wiley-Blackwell, Oxford, U.K.

Soga, M., Yamaura, Y., Aikoh, T., Shoji, Y., Kubo, T., Gaston, K.J., 2015. Reducing the extinction of experience: Association between urban form and recreational use of public greenspace. Landsc. Urban Plan. 143, 69–75.

Sollie, S., Verhoeven, J.T.A., 2008. Nutrient Cycling and Retention Along a Littoral Gradient in a Dutch Shallow Lake in Relation to Water Level Regime. Water. Air. Soil Pollut. 193, 107–121.

Sommer, B., Froend, R., 2014. Phreatophytic vegetation responses to groundwater depth in a drying mediterranean-type landscape. J. Veg. Sci. 25, 1045–1055.

Sophocleous, M., 2000. From safe yield to sustainable development of water resources—the Kansas experience. J. Hydrol. 235, 27–43.

Sophocleous, M., 2002. Interactions between groundwater and surface water: the state of the science. Hydrogeol. J. 10, 52–67.

Sophronides, P., Steenbruggen, J., Scholten, H.J., Giaoutzi, M., 2016. Geodesign the multilayered water safety. Res. Urban. Ser. 4, 113–138.

Stähly, S., Franca, M.J., Robinson, C.T., Schleiss, A.J., 2019. Sediment replenishment combined with an artificial flood improves river habitats downstream of a dam. Sci. Rep. 9, 1–8.

Statham, P.J., 2012. Nutrients in estuaries — An overview and the potential impacts of climate change. Sci. Total Environ. 434, 213–227.

Statzner, B., Hildrew, A.G., Resh, V.H., 2001. Species Traits and Environmental Constraints: Entomological Research and the History of Ecological Theory. Annu. Rev. Entomol. 46, 291–316.

Stefanidis, K., Latsiou, A., Kouvarda, T., Lampou, A., Kalaitzakis, N., Gritzalis, K., Dimitriou, E., 2020. Disentangling the Main Components of Hydromorphological Modifications at Reach Scale in Rivers of Greece. Hydrology 7, 22.

Stoddard, J.L., Larsen, D.P., Hawkins, C.P., Johnson, R.K., Norris, R.H., 2006. Setting expectations for the ecological conidition of streams: The concept of reference condition. Ecol. Appl. 16, 1267–1276.

Strayer, D.L., Findlay, S.E.G., 2010. Ecology of freshwater shore zones. Aquat. Sci. 72, 127–163.

Strona, G., Fattorini, S., Fiasca, B., Di Lorenzo, T., Di Cicco, M., Lorenzetti, W., Boccacci, F., Galassi, D.M.P., 2019. AQUALIFE Software: A New Tool for a Standardized Ecological Assessment of Groundwater Dependent Ecosystems. Water 11, 2574.

Su, J., Ji, D., Lin, M., Chen, Y., Sun, Y., Huo, S., Zhu, J., Xi, B., 2017. Developing surface water quality standards in China. Resour. Conserv. Recycl. 117, 294–303.

Sutherland, A.B., Culp, J.M., Benoy, G.A., 2010. Characterizing deposited sediment for stream habitat assessment. Limnol. Oceanogr. Methods 8, 30–44.

Swedish Environmental Protection Agency, 2000. Environmental Quality Criteria. Lakes and Watercourses. SEPA, Stockholm, Sweden.

Talbot, C.J., Bennett, E.M., Cassell, K., Hanes, D.M., Minor, E.C., Paerl, H., Raymond, P.A., Vargas, R., Vidon, P.G., Wollheim, W., Xenopoulos, M.A., 2018. The impact of flooding

on aquatic ecosystem services. Biogeochemistry 141, 439–461.

Taylor, B.R., Roff, J.C., 1986. Long-term effects of highway construction on the ecology of a Southern Ontario stream. Environ. Pollut. Ser. A, Ecol. Biol. 40, 317–344.

Taylor, R.G., Scanlon, B., Döll, P., Rodell, M., van Beek, R., Wada, Y., Longuevergne, L., Leblanc, M., Famiglietti, J.S., Edmunds, M., Konikow, L., Green, T.R., Chen, J., Taniguchi, M., Bierkens, M.F.P., MacDonald, A., Fan, Y., Maxwell, R.M., Yechieli, Y., Gurdak, J.J., Allen, D.M., Shamsudduha, M., Hiscock, K., Yeh, P.J.-F., Holman, I., Treidel, H., 2013. Ground water and climate change. Nat. Clim. Chang. 3, 322–329.

Tezer, A., Sen, O.L., Aksehirli, like, Cetin, N.I., Onur, A.C.T., 2012. Integrated planning for the resilience of urban riverine ecosystems: the Istanbul-Omerli Watershed case. Ecohydrol. Hydrobiol. 12, 153–163.

Tharme, R.E., King, J.M., 1988. Development of the Building Block Methodology for instream flow assessments, and supporting research on the effects of different magnitude flows on riverine ecosystems. Water Research Commission Report No. 576/1/98., Pretoria, S.Africa.

The City of New York, 2008. PlanNYC: Sustainable Stormwater Management Plan 2008. A Greener, Greater New York. New York, U.S.A.

The Journal, 2020. Building barriers: How plans for the largest flood scheme in Irish history became so divisive. Dublin, Ireland. https://www.thejournal.ie/cork-flood-scheme-investigation-5124293-Jun2020/.

Tickner, D., Opperman, J.J., Abell, R., Acreman, M., Arthington, A.H., Bunn, S.E., Cooke, S.J., Dalton, J., Darwall, W.R.T., Edwards, G., Harrison, I.A.N., Hughes, K., Jones, T.I.M., Leclère, D., Lynch, A.J., Leonard, P., Mcclain, M.E., Muruven, D., Olden, J.D., Ormerod, S.J., Robinson, J., Tharme, R.E., Thieme, M., Tockner, K., Wright, M., Young, L., 2020. Bending the Curve of Global Freshwater Biodiversity Loss: An Emergency Recovery Plan. Bioscience 70, 330–342.

Timms, R.M., Moss, B., 1984. Prevention of growth of potentially dense phytoplankton populations by zooplankton grazing, in the presence of zooplanktivorous fish, in a shallow wetland ecosystem. Limnol. Oceanogr. 29, 472–486.

Tockner, K., Stanford, J.A., 2002. Riverine flood plains: present state and future trends. Environ. Conserv. 29, 308–330.

Tockner, K., Uehlinger, U., Robinson, C.T., 2009. Rivers of Europe. Elsevier, Dordrecht, The Netherlands.

Toland, M., Murphy, M., 2013. River Hydromorphology Assessment Technique (RHAT) Training Manual - Version 2.

Tolonen, K.T., Hämäläinen, H., Holopainen, I.J., Karjalainen, J., 2001. Influences of habitat type and environmental variables on littoral macroinvertebrate communities in a large lake system. Fundam. Appl. Limnol. 152, 39–67.

Tomlinson, M., 2011. Ecological water requirements of groundwater systems: a knowledge and policy review. Waterlines report No 68 - December 2011.

Tonkin, J.D., Jähnig, S.C., Haase, P., 2014. The Rise of Riverine Flow-ecology and Environmental Flow Research. Environ. Process. 1, 323–330.

Townsend, C.R., Uhlmann, S.S., Matthaei, C.D., 2008. Individual and combined responses of stream ecosystems to multiple stressors. J. Appl. Ecol. 45, 1810–1819.

Townsend, S.A., 1999. The seasonal pattern of dissolved oxygen, and hypolimnetic deoxygenation, in two tropical Australian reservoirs. Lakes Reserv. Res. Manag. 4, 41–

53.

Turley, M.D., Bilotta, G.S., Chadd, R.P., Extence, C.A., Brazier, R.E., Burnside, N.G., Pickwell, A.G.G., 2016. A sediment-specific family-level biomonitoring tool to identify the impacts of fine sediment in temperate rivers and streams. Ecol. Indic. 70, 151–165.

U.K. Government, 2016. National Flood Resilience Review. London, U.K.

Uisce Éireann, 2024. Annual Environmental Report.

UKTAG, 2012. Technical report on groundwater dependent terrestrial ecosystem (GWDTE) threshold values. https://www.wfduk.org/sites/default/files/Media/Environmental%20standards/GWDTE%20chemical%20values_Final_230312.pdf.

UKTAG, 2013. TraC-MImAS Technical Report e Version A (4) (Development and Review of a TraC Hydromorphology Decision Support Tool for (A) Screening Proposed New or Altered Activities/Structures for Compliance with WFD Water Body Status and (B) Classifying TraC Waters.

Ulibarri, N., McClain, M., Miroslav, M., 2022. Hydropower: Case Studies in Sustainability. In: Tockner, K., Mehner, T. (Eds.), Encyclopedia of Inland Waters. Elsevier, Cambridge, U.K.

UN-Water WWAP (United Nations World Water Assessment), 2018. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. Paris, France.

UNECE, 1998. Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters done at Aarhus, Denmark, on 25 June 1998.

UNEP, 2020. UNEP-Nairobi Convention/WIOMSA. Guidelines for the Assessment of Environmental Flows in the Western Indian Ocean Region. Nairobi, Kenya.

Urban, M.A., Rhoads, B.L., 2003. Catastrophic Human-Induced Change in Stream-Channel Planform and Geometry in an Agricultural Watershed, Illinois, USA. Ann. Assoc. Am. Geogr. 93, 783–796.

Urbanič, G., 2014. A Littoral Fauna Index for assessing the impact of lakeshore alterations in Alpine lakes. Ecohydrology 7, 703–716.

USEPA, 2002. Methods for evaluating wetland condition: developing metrics and indexes of biological integrity. EPA-822-R-02-016. Washington, D.C., U.S.A.

Vadeboncoeur, Y., Jeppesen, E., Vander Zanden, M.J., Schierup, H.H., K., C., Lodge, D.M., 2003. From Greenland to green lakes: Cultural eutrophication and the loss of benthic pathways in lakes. Limnol. . Oceanogr. 48, 1408–1418.

Vadeboncoeur, Y., Vander Zanden, M.J., Lodge, D.M., 2002. Putting the Lake Back Together: Reintegrating Benthic Pathways into Lake Food Web Models. Bioscience 52, 44–54.

Vahedifard, F., Madani, K., AghaKouchak, A., Thota, S.K., 2021. Are we ready for more dam removals in the United States? Environ. Res. Infrastruct. Sustain. 1, 013001.

van Alphen, S., 2020. Room for the River: Innovation, or Tradition? The Case of the Noordwaard. In: Adaptive Strategies for Water Heritage. Springer International Publishing, Cham, pp. 308–323.

van den Berg, M.S., Coops, H., Noordhuis, R., van Schie, J., Simons, J., 1997. Macroinvertebrate communities in relation to submerged vegetation in two Chara-

dominated lakes. Hydrobiologia 342, 143–150.

van den Honert, R.C., McAneney, J., 2011. The 2011 Brisbane Floods: Causes, Impacts and Implications. Water 3, 1149–1173.

van Eps, M.A., Formica, S.J., Morris, T.L., Beck, J.M., Cotter, A.S., 2004. Using a bank erosion hazard index (BEHI) to estimate annual sediment loads from streambank erosion in the west Fork White River Watershed. In: Self-Sustaining Solutions for Streams, Wetlands, and Watersheds, 12-15, September 2004. St. Joseph, MI, U.S.A.

Van Puijenbroek, P.J.T.M., Buijse, A.D., Kraak, M.H.S., Verdonschot, P.F.M., 2019. Species and river specific effects of river fragmentation on European anadromous fish species. River Res. Appl. 35, 68–77.

Vanmaercke, M., Poesen, J., Verstraeten, G., de Vente, J., Ocakoglu, F., 2011. Sediment yield in Europe: Spatial patterns and scale dependency. Geomorphology 130, 142–161.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., Cushing, C.E., 1980. The River Continuum Concept. Can. J. Fish. Aquat. Sci. 37, 130–137.

Vartia, K., Beekman, J., Alves, M., van de Bund, W., Bussettini, M., Döbbelt-Grüne, S., Halleraker, J.H., Karottki, I., Kling, J., Wallentin, J., 2018. WG ECOSTAT report on common understanding of using mitigation measures for reaching Good Ecological Potential for Heavily Modified Water Bodies – Part 3: Impacted by drainage schemes, EUR 29132 EN. Luxembourg, Luxembourg.

Vaughan, I.P., Diamond, M., Gurnell, A.M., Hall, K.A., Jenkins, A., Milner, N.J., Naylor, L.A., Sear, D.A., Woodward, G., Ormerod, S.J., 2009. Integrating ecology with hydromorphology: a priority for river science and management. Aquat. Conserv. Mar. Freshw. Ecosyst. 19, 113–125.

Vaughan, I.P., Ormerod, S.J., 2010. Linking ecological and hydromorphological data: Approaches, challenges and future prospects for riverine science. Aquat. Conserv. Mar. Freshw. Ecosyst. 20, 125–130.

Verdonschot, P.F.M., Verdonschot, R.C.M., 2021. Ecologische systeembenadering en ecologische systeemanalyse. Rapport Kennisimpuls waterkwaliteit (KIWK) 134.

Verheem, R., Laeven, M., 2009. SEA for flood protection in The Netherlands – A Case Study. Views and Experiences from the Netherlands Commission for Environmental Assessment. Utrecht, The Netherlands.

Vezza, P., Goltara, A., Spairani, M., Zolezzi, G., Siviglia, A., Carolli, M., Cristina Bruno, M., Boz, B., Stellin, D., Comoglio, C., Parasiewicz, P., 2015. Habitat Indices for Rivers: Quantifying the Impact of Hydro-Morphological Alterations on the Fish Community. In: Engineering Geology for Society and Territory - Volume 3. Springer International Publishing, Cham, pp. 357–360.

Vollenweider, R.A., Kerekes, J., 1980. The loadingconcept as basis for controlling eutrophication philosophy and preliminary results of the OECD programme on eutrophication. Prog. Water Technol. 12, 5–38.

Vörösmarty, C., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., Davies, P.M., 2010. Global threats to human water security and river biodiversity. Nature 467, 555–561.

Vörösmarty, C., Meybeck, M., Fekete, B., Sharma, K., Green, P., Syvitski, J.P.., 2003. Anthropogenic sediment retention: major global impact from registered river impoundments. Glob. Planet. Change 39, 169–190.

Vörösmarty, C., Sharma, K.P., Fekete, B.M., Copeland, A.H., Holden, J., Marble, J., Lough,

J.A., 1997. The storage and aging of continental runoff in large reservoir systems of the world. Ambio 26, 210–2019.

Vörösmarty, C., Stewart-Koster, B., Green, P.A., Boone, E.L., Flörke, M., Fischer, G., Wiberg, D.A., Bunn, S.E., Bhaduri, A., McIntyre, P.B., Sadoff, C., Liu, H., Stifel, D., 2021. A green-gray path to global water security and sustainable infrastructure. Glob. Environ. Chang. 70, 102344.

Voulvoulis, N., Arpon, K.D., Giakoumis, T., 2017. The EU Water Framework Directive: From great expectations to problems with implementation. Sci. Total Environ. 575, 358–366.

Vymazal, J., Dvořáková Březinová, T., 2018. Treatment of a small stream impacted by agricultural drainage in a semi-constructed wetland. Sci. Total Environ. 643, 52–62.

Wagenhoff, A., Townsend, C.R., Phillips, N., Matthaei, C.D., 2011. Subsidy-stress and multiple-stressor effects along gradients of deposited fine sediment and dissolved nutrients in a regional set of streams and rivers. Freshw. Biol. 56, 1916–1936.

Wagner, D.L., Grames, E.M., Forister, M.L., Berenbaum, M.R., Stopak, D., 2021. Insect decline in the Anthropocene: Death by a thousand cuts. Proc. Natl. Acad. Sci. 118, e2023989118.

Waldren, S., 2015. Turlough Hydrology, Ecology and Conservation.Unpublished Report to the National Parks & Wildlife Services. Trinity College Dublin, Ireland.

Walker, J., Diamond, M., Naura, M., 2002. The development of Physical Quality Objectives for rivers in England and Wales. Aquat. Conserv. Mar. Freshw. Ecosyst. 12, 381–390.

Walther, C.A., García, C., Dwyer, N., Gault, J., 2021. Climate Status Report for Ireland 2020. Dublin,Ireland. https://www.epa.ie/publications/research/climate-change/Research_Report_386.pdf.

Ward, J.V., Tockner, K., Uehlinger, U., Malard, F., 2001. Understanding natural patterns and processes in river corridors as the basis for effective river restoration. Regul. Rivers Res. Manag. 17, 709–709.

Ward, P.J., de Ruiter, M.C., Mård, J., Schröter, K., Van Loon, A., Veldkamp, T., von Uexkull, N., Wanders, N., AghaKouchak, A., Arnbjerg-Nielsen, K., Capewell, L., Carmen Llasat, M., Day, R., Dewals, B., Di Baldassarre, G., Huning, L.S., Kreibich, H., Mazzoleni, M., Savelli, E., Teutschbein, C., van den Berg, H., van der Heijden, A., Vincken, J.M.R.R., Waterloo, M.J., Wens, M., 2020. The need to integrate flood and drought disaster risk reduction strategies. Water Secur. 11, 100070.

Ward, P.J., van Balen, R.T., Verstraeten, G., Renssen, H., Vandenberghe, J., 2009. The impact of land use and climate change on late Holocene and future suspended sediment yield of the Meuse catchment. Geomorphology 103, 389–400.

Ward, R.S., Fitzsimons, V., 2008. A European Framework for quantitative status. EU Groundwater Policy Developements Conference.

Warner, J., Wester, P., Bolding, A., 2008. Going with the flow: river basins as the natural units for water management? Water Policy 10, 121–138.

Warner, J.F., van Buuren, A., Edelenbos, J., 2012. Making Space for the River: Governance Experiences with Multifunctional River Flood Management in the US and Europe. IWA Publishing.

Wasson, J.-G., Chandesris, A., Garcia-Bautista, A., Pella, H., Villeneuve, B., 2006. Relationships between ecological and chemical status of surface waters - REBECCA. Geographical 1–7.

Webster, K.E., Tedd, K., Coxon, C., Donohue, I., 2017. Environmental Flow Assessment for

Irish Rivers. Environmental Protection Agency, Wexford, Ireland.

Wehn, U., Almomani, A., 2019. Incentives and barriers for participation in community-based environmental monitoring and information systems: A critical analysis and integration of the literature. Environ. Sci. Policy 101, 341–357.

Weiß, A., Matouskova, M., Matschullat, J., 2008. Hydromorphological assessment within the EU-Water Framework Directive—trans-boundary cooperation and application to different water basins. Hydrobiologia 603, 53–72.

Werth, W., 1992. Ökologische Gewässerzustandsbewertung in Oberösterreich. In: Friedrich, G., J., L. (Eds.), Ökologische Bewertung von Fließgewässern. Limnologie Aktuell, Band 3. Gustav Fischer Verlag, Stuttgart, pp. 67–77.

Wetsteyn, L.P.M.J., Bakker, C., 1991. Abiotic characteristics and phytoplankton primary production in relation to a large-scale coastal engineering project in the Oosterschelde (The Netherlands): a preliminary evaluation, Estuaries and Coasts : Spatial and Temporal Intercomparisons. ECSA 19 Symposium 4-8 September 1989, University of Caen, France.

Wetzel, R.G., 2001. Limnology. Lake and River Ecosystems. Academic Press.

WFD, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Off. J. Eur. Parliam. L327, 1–82.

Wharton, G., Gilvear, D.J., 2007. River restoration in the UK: Meeting the dual needs of the European union water framework directive and flood defence? Int. J. River Basin Manag. 5, 143–154.

Wheater, H., Evans, E., 2009. Land use, water management and future flood risk. Land use policy 26, 251–264.

Wheater, H.S., Peach, D., Binley, A., 2007. Characterising groundwater-dominated lowland catchments: the UK Lowland Catchment Research Programme (LOCAR). Hydrol. Earth Syst. Sci. 11.

White (née Ní Chatháin), Moorkens, Irvine, K., Glasgow, Chuanigh, 2014. Management strategies for the protection of high status water bodies under the Water Framework Directive. Biol. Environ. Proc. R. Irish Acad. 114B, 129.

White, J., Irvine, K., 2003. The use of littoral mesohabitats and their macroinvertebrate assemblages in the ecological assessment of lakes. Aquat. Conserv. Mar. Freshw. Ecosyst. 13, 331–351.

White, J.C., Hill, M.J., Bickerton, M.A., Wood, P.J., 2017. Macroinvertebrate Taxonomic and Functional Trait Compositions within Lotic Habitats Affected By River Restoration Practices. Environ. Manage. 60, 513–525.

Whittier, T.R., Paulsen, S.G., Larsen, D.P., Peterson, S.A., Herlihy, A.T., Kaufmann, P.R., 2002. Indicators of ecological stress and their extent in the population of Northeastern lakes: A regional-scale assessment. Bioscience 52, 235–247.

Wiederholm, T., 1980. Use of Benthos in Lake Monitoring. J. Water Pollut. Control Fed. 52, 537–547.

Wilcox, D.A., Meeker, J.E., 1991. Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. Can. J. Bot. 69, 1542–1551.

Willems, J.J., Molenveld, A., Voorberg, W., Brinkman, G., 2020. Diverging ambitions and instruments for citizen participation across different stages in green infrastructure projects. Urban Plan. 5, 22–32.

Williams, L., Harrison, S., O'Hagan, A.M., 2012. The use of wetlands for flood attenuation. Report for An Taisce by Aquatic Services Unit. Cork, Ireland.

Williams, P.W., 1993. Karst Terrains, environmental changes, human impact. In: Williams, P.W. (Ed. . (Ed.), Catena Supplement. pp. 1–19.

Wilson, S.D., Tilman, D., 1993. Plant Competition and Resource Availability in Response to Disturbance and Fertilization. Ecology 74, 599–611.

Winter, T.C., 1995. Recent advances in understanding the interaction of groundwater and surface water. Rev. Geophys. 33, 985–994.

Winter, T.C., 1999. Relation of streams, lakes, and wetlands to groundwater flow systems. Hydrogeol. J. 7, 28–45.

Withers, P.J.A., Jarvie, H.P., 2008. Delivery and cycling of phosphorus in rivers: A review. Sci. Total Environ. 400, 379–395.

Withrington, D., 2005. Water Framework Directive (2000/60/EC): Interpreting the provision applying to protected areas for habitats and species directly depending on water. Water Law 16, 197–200.

WMO, 2006. Social Aspects and Stakeholder Involvement in Integrated Flood Management. WMO/Global Water Partnership (GWP) Associated Programme on Flood Management (APFM) Technical Document No. 4, WMO No. 1008. World Meteorological Organization, Geneva, Switzerland.

WMO, 2007. Economic Aspects of Integrated Flood Management, WMO/Global Water Partnership (GWP) Associated Programme on Flood Management (APFM) Technical Document No. 5, WMO No. 1010. World Meteorological Organization, Geneva, Switzerland.

Wohl, E., 2020. Large Wood in Rivers, Oxford Bibliographies in Environmental Science. Oxford University Press, Oxford, U.K.

Wohl, E., Bledsoe, B.P., Jacobson, R.B., Poff, N.L., Rathburn, S.L., Walters, D.M., Wilcox, A.C., 2015. The natural sediment regime in rivers: Broadening the foundation for ecosystem management. Bioscience 65, 358–371.

Wohl, E., Kramer, N., Ruiz-Villanueva, V., Scott, D.N., Comiti, F., Gurnell, A.M., Piegay, H., Lininger, K.B., Jaeger, K.L., Walters, D.M., Fausch, K.D., 2019. The Natural Wood Regime in Rivers. Bioscience 69, 259–273.

Wolfe, D.A., Long, E.R., Thursby, G.B., 1996. Sediment Toxicity in the Hudson-Raritan Estuary: Distribution and Correlations with Chemical Contamination. Estuaries 19.

Wood, P.J., Armitage, P.D., 1999. Sediment deposition in a small lowland stream—management implications. Regul. Rivers Res. Manag. 15, 199–210.

Woodward, G., Gray, C., Baird, D.J., 2013. A critique of biomonitoring in an age of globalisation and emerging environmental threats. Limnetica 32, 159–174.

Woolway, R.I., Kraemer, B.M., Lenters, J.D., Merchant, C.J., O'Reilly, C.M., Sharma, S., 2020. Global lake responses to climate change. Nat. Rev. Earth Environ. 1, 388–403.

World Bank Group, 2018. Environmental Flows for Hydropower Projects, Good practice Handbook. Guidance for the Private Sector in Emerging Markets. www.ifc.org/hydroadvisory.

WWDR, 2018. The United Nations World Water Development Report: Nature-Based Solutions for Water. UNESCO, Paris, France.

Xu, H., Horn, O., 2017. China's Sponge City concept: Restoring the Urban Water Cycle through Nature-Based Solutions. ICLEI Briefing Sheet. Bonn, Germany, ICLEI.

Yang, D., Kanae, S., Oki, T., Koike, T., Musiake, K., 2003. Global potential soil erosion with reference to land use and climate changes. Hydrol. Process. 17, 2913–2928.

Young, P., J. Czech, ., Thompson, L., 2011. Hydropower related pulsed flow impacts on stream fishes: a brief conceptual model knowledge gaps and research needs. Rev. Fish Biol. Fish. 21, 713–731.

Zarfl, C., Lumsdon, A.E., Berlekamp, J., Tydecks, L., Tockner, K., 2015. A global boom in hydropower dam construction. Aquat. Sci. 77, 161–170.

Ziv, G., Baran, E., Nam, S., Rodriguez-Iturbe, I., Levin, S.A., 2012. Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin. Proc. Natl. Acad. Sci. 109, 5609–5614.

Zuber, A., Malecki, J., Dulinski, M., 2008. Ground water ages and altitudes of recharge areas in the Polish Tatra Mts. As determined from 3H, 18O and 2H data. Geol. Q. 52, 71–80.

ANNEX I: Results from the stakeholder questionnaire

1. How would you define your organisation?

Table II.1 presents the responses regarding the respondent's affiliation with organisations. It has been recorded that out of the total 10 respondents, 5 are affiliated with governmental bodies, 3 with water resources management bodies at subnational level and 1 each with civil society and Science, academia and research centres (Figure II.1).

Table II.1. Organisation.

Category	Frequency
Governmental bodies	
National (Ministry, Public Agency, etc.)	4
Local	1
Water resources management body at subnational level	
State water resource management authority	1
Civil society	
Member-based organisation	1
Non-governmental organisation	1
Other organization	1
Science, academia and research centres	
Other research body	1

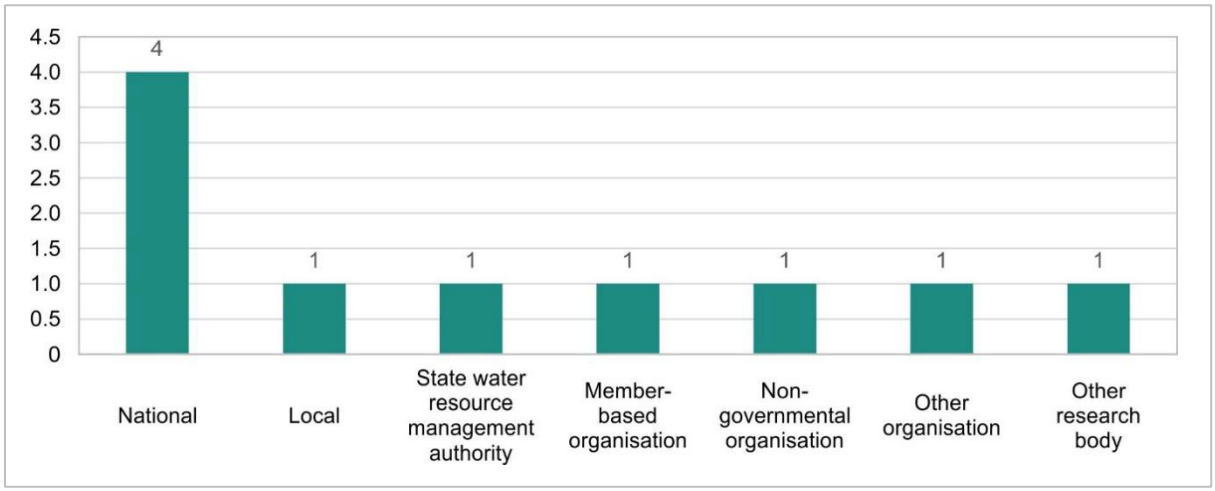


Figure II.1. Categories of respondents who were part of an identified organisation.

2.a. What is your organisation's primary area of interest related to water?

Figure II.2 presents the respondents' responses regarding stakeholders' organisation primary area of interest related to water. Out of the total of 10 respondents 7 ranked surface water of which 6 ranked rivers first as the primary area and 1 lake, followed by groundwater which was ranked first by 2 respondents, while no respondent ranked transitional and marine water first.

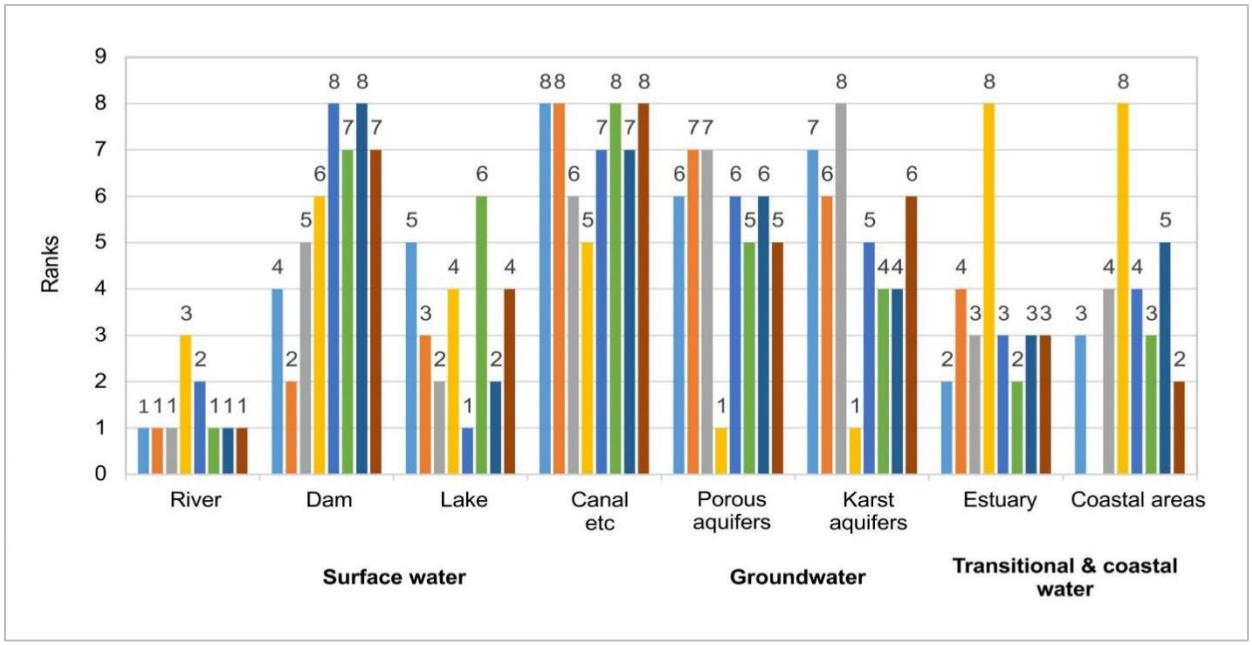


Figure II.2. Organisation's primary area of interest related to water, on rank from 1 to 8, starting with the most important area of interest.

2.b. What is the most important aspect for you?

Figure II.3 presents the respondents' responses regarding the most important aspect for the stakeholders. It has been recorded that the most important aspect is water quality and resources followed by protection against flood, quality of water resources and habitat protection.

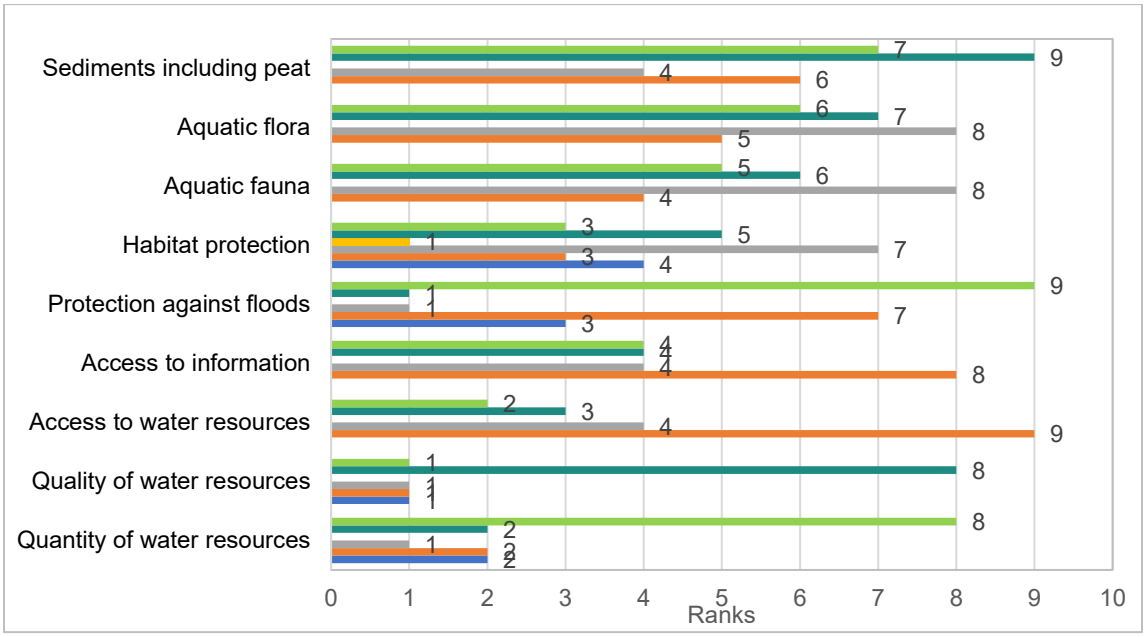


Figure II.3. Most important aspects, for stakeholder based on a response to a questionnaire, and ranking from 1 to 9, starting with the most important area of interest (1) to the least important one (9). N.B some respondents uses an (incorrect) nine-scale ranking)

3. At which scale does your organisation primarily operate?

Table II.2 shows the responses regarding the organisation's primary operation scale. Out of the total of 10 respondents 9 are working at national, 8 are working at international, 6 are working at basin scale and 6 at regional/ provincial/ state level. Moreover, 5 are working at sub-basin scale and community level, 4 working at municipal level while 3 were working at institutional scale and 3 selected the option other (Figure II.4 and Figure II.5).

Table II.2. Scale of operation.

Scale	Frequency	Percentage
International level	8	80
Water resource management level (basin scale)	6	60
Water resource management level (sub-basin scale)	5	50
Water resource management level (institutional scale)	3	30
National level	9	90
Regional/provincial / state level	6	60
Municipal level	4	40
Community level	5	50
Other, specify	3	30

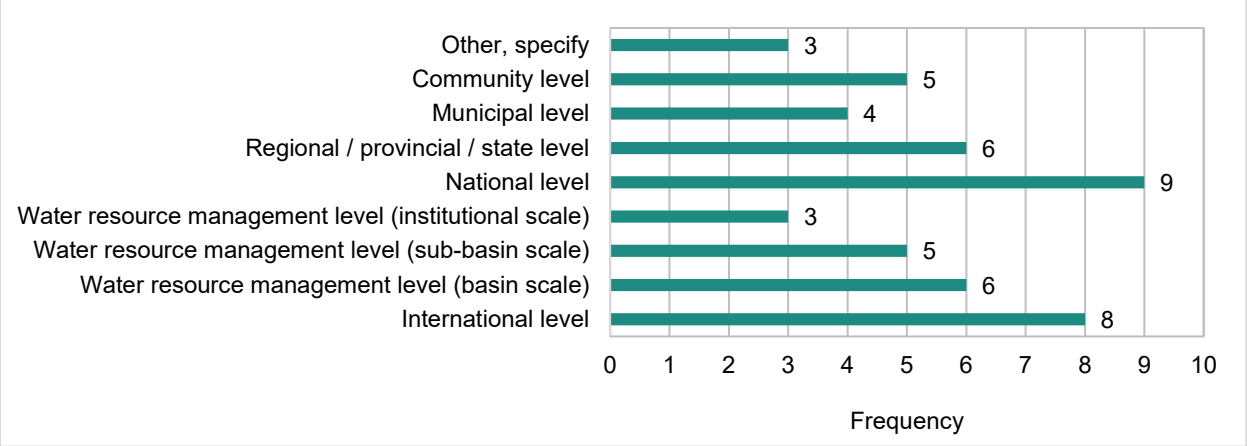


Figure II.4. Primary scale of operation.

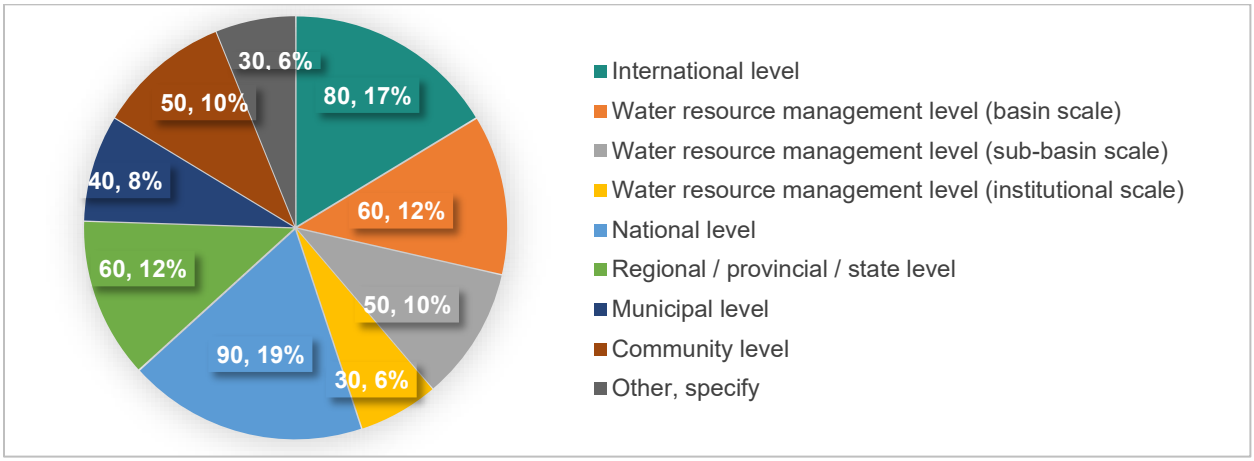


Figure II.5. Primary scale of operation for your organisation.

4. What are the type(s) of stakeholders your organisation mostly interacts with?

Table II.3 presents the responses regarding the organisation's interaction with stakeholders. It has been recorded that all are interacting with governmental (national, regional, local) while 9 interact with local authorities, NGOs and Science, academia and research centres (Figure II.6).

Table II.3. Types of organisations that the stakeholders mostly interact with.

Category of stakeholder	Frequency	Percentage
Inter-governmental / supranational organisations	7	70
Governmental (national, regional, local)	10	100
Local authorities	9	90
Service providers	2	20
Water institutions at sub-national level (river basin organisations, regional water authorities or boards)	7	70
Forestry	8	80
River management and drainage	6	60
Regulators (economic, environmental)	8	80
Business	3	30
Agricultural actors	7	70
Civil society	6	60
Agencies	7	70
NGOs	9	90
Financial actors (donors, international financial institutions,investors)	1	10
Science, academia and research centres	9	90
Consumer associations	0	0
Trade unions and workers	0	0
Advisors (engineering, consulting firms)	5	50
Media	7	70
Parliamentarians	5	50

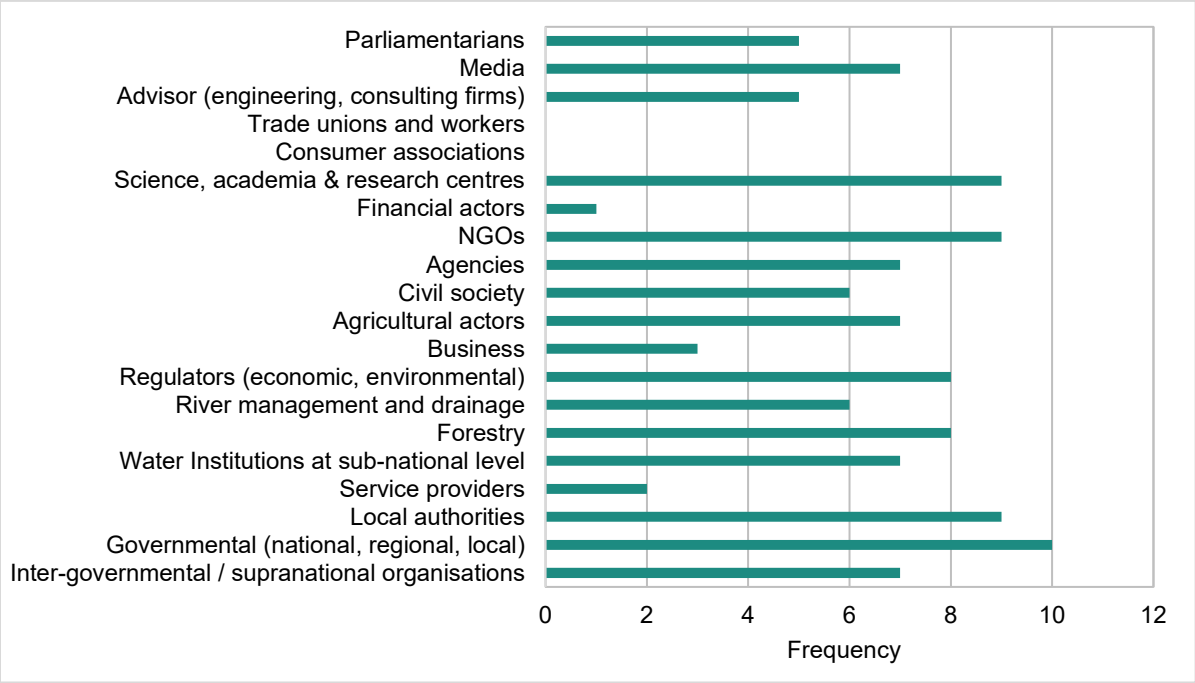


Figure II.6. Types of organisations that the stakeholders mostly interact with.

6. What are the types of stakeholders that your organisation finds most challenging to engage with and why?

The answers that we received are the following:

- Our members face challenges dealing with the complexities of the Irish Planning System and with Judicial Reviews.
- Some state agencies (not named) can be reluctant to collaborate and share data – possibly because they have research agendas of their own.
- Depends on the situation
- You would likely get a different answer for every individual working with NPWS! From my perspective, I consider that the frequent interactions with farming organisations at national level have blocked positive progress on nature with farmers on a local level. This is being surmounted in some regions via LIFE projects and EIPs (e.g. Burren Programme, KerryLIFE, Pearl Mussel Project, Hen Harrier EIP, Wild Atlantic Nature), however, the national-level interactions still exert a strong influence on NPWS senior management and national policy – including responses to EU policy (e.g. CAP, EU Biodiversity Strategy)
- Other Government Departments, Regulators and Agencies can also be challenging stakeholders, and many are still struggling to understand and accept their legal responsibilities with respect to nature. In my experience, the most challenging have been those responsible for drainage (OPW), forestry (Forest Service) and the WFD (the water section of the same department NPWS recently transferred back to and the EPA catchments unit). For a long time, those involved in the WFD quite rightly challenged other bodies to see beyond their own 'silos'. There is some irony then that, at national level, the WFD has become ever more focussed on the macroinvertebrate metric/indicator and phosphorus in rivers so that it is difficult to see what real outcomes it can deliver, not just for nature and biodiversity, but also for human health, recreation and well-being. By contrast, my experience of working with WFD catchment science teams in LAWPRO has been very positive. So, a summary might be that national-level policy and plans are frequently an impediment to real progress at:
    - Farming representatives, e.g. the IFA, as they don't want to accept the science or change their practices.
    - The OPW, as they'are very set in their ways and don't see anything wrong with what they're doing.
    - Department of Agriculture- they're unwilling to accept the scale of the challenge and changes which are necessary for environmental compliance/protection.
- Over many years of flood risk management implementation, extensive and proactive structures have been developed around stakeholder engagement and communications, which are continuously expanding. Significant resources and project focus are allocated to maximise stakeholder engagement, intertwined with an ethos of collaboration between relevant statutory authorities.

- Farming bodies. There has been good progress but there is still a lot of scepticism about the new integrated catchment management approach and how it might affect their farms and businesses.
- NPWS.
- Government.
- Specific communication and strategic barriers to undertake research.

6. To what extent is your organisation involved with the Water Framework Directive?

Table II.4 shows the responses regarding the organisation's involvement with the Water Framework Directive (WFD). Out of the total 10 responses, 7 interact at awareness and 7 at involvement level followed by 3 that interact at compliance and 3 at other levels while only 2 interact at mandatory level (Figure II.7 and Figure II.8).

Table II.4. Organisation involvement with the Water Framework Directive (WFD).

Level	Frequency	Percentage
Awareness	7	70
Involvement	7	70
Mandatory	2	20
Compliance	3	30
Other	3	30

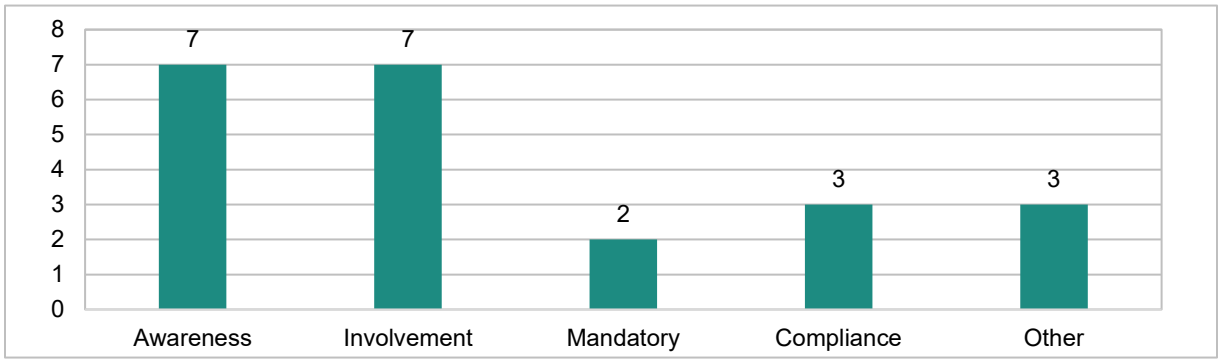


Figure II.7. Organisation involvement with the Water Framework Directive (WFD).

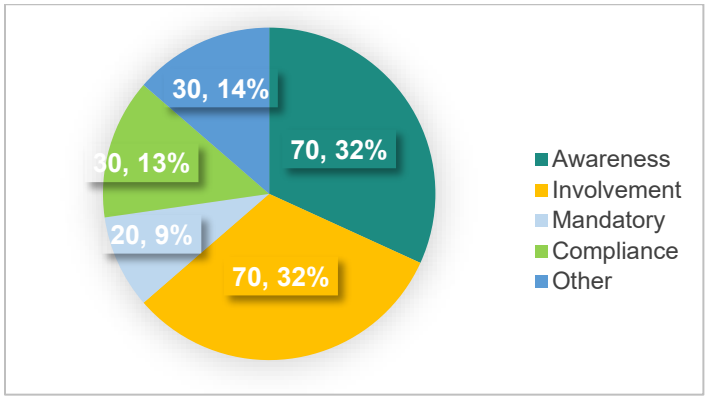


Figure II.8. Organisation involvement with the Water Framework Directive (WFD).

7. To what extent and how was your organisation involved in the design of the River Basin Management Plans?

Table II.5 shows the responses regarding the involvement of organisations in the design of River Basin Management Plans. Out of the total of 10 responses 4 (40%) mentioned that are involved indirectly and 4 directly while 1 (10%) mentioned not very much involved and 1 heavily involved (Figure II.9).

Table II.5. Involvement of organisation in the design of River Basin Management Plans.

Categories	Frequency	Percentage
Indirectly Involved	4	40
directly Involved	4	40
Not very much	1	10
Heavily involved	1	10
Total	10	100

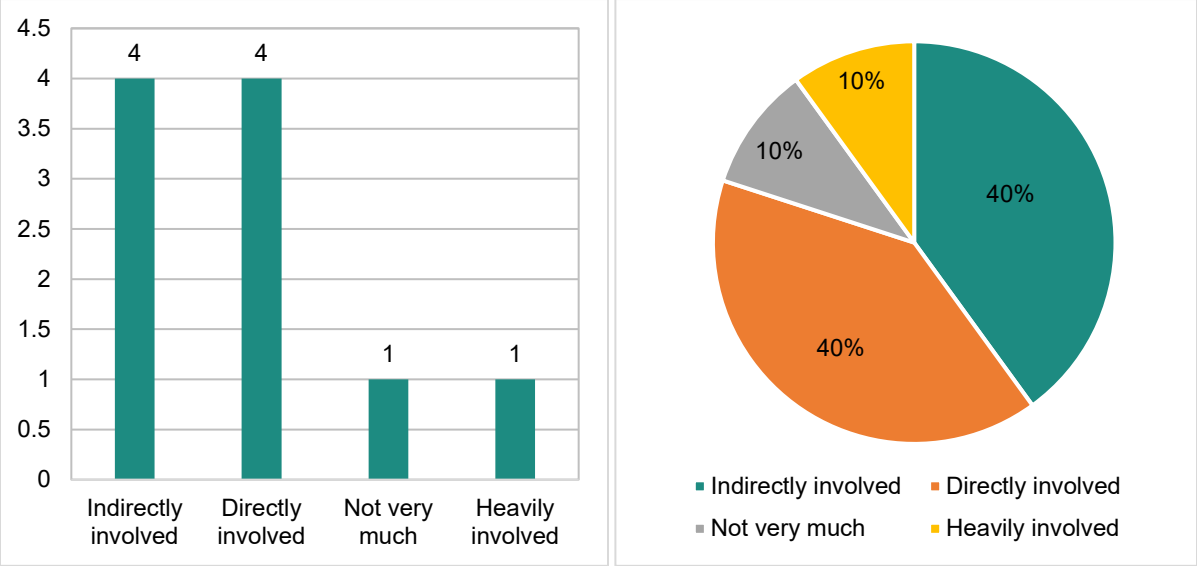


Figure II.9. Involvement of organisation in the design of River Basin Management Plans.

8. To what extent and how is your organisation involved with the topic of hydromorphological alternations?

Table II.6 shows the responses regarding the organisation's involvement with the hydromorphological alternations. It has been recorded that out of the total 10 respondents, 8 are involved at awareness level followed by 6 at involvement level, 3 involved at compliance and 3 at compulsory level, while 1 respondent selected the other option (Figure II.10 and Figure II.11).

Table II.6. Organisation involvement with the hydromorphological alternations.

Nature of involvement	Frequency	Percentage
Awareness	8	80
Involvement	6	60
Compulsory	3	30
Compliance	3	30
Other	1	10

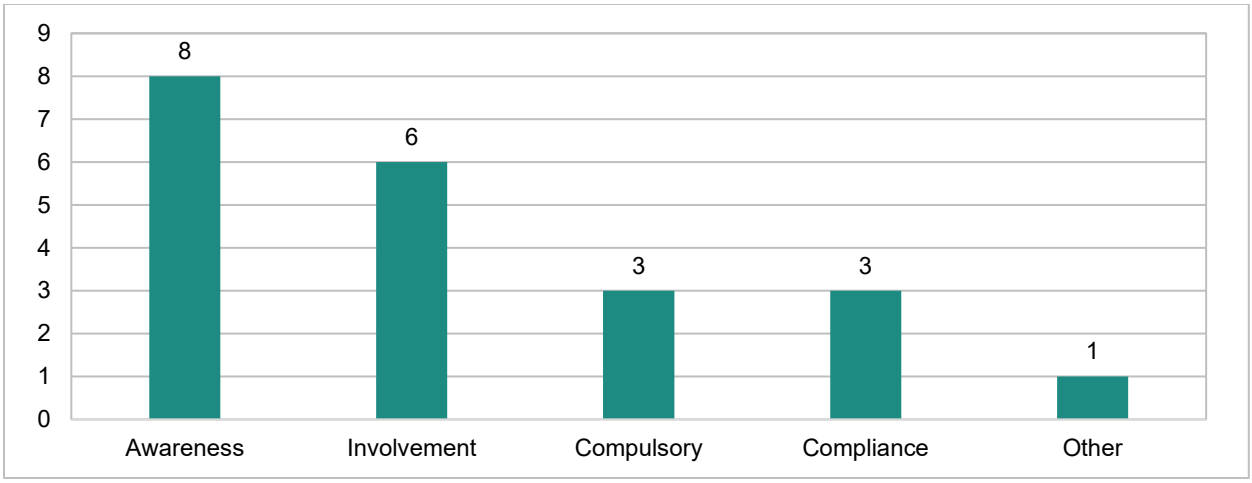


Figure II.10. Organisation involvement with the hydromorphological alternations.

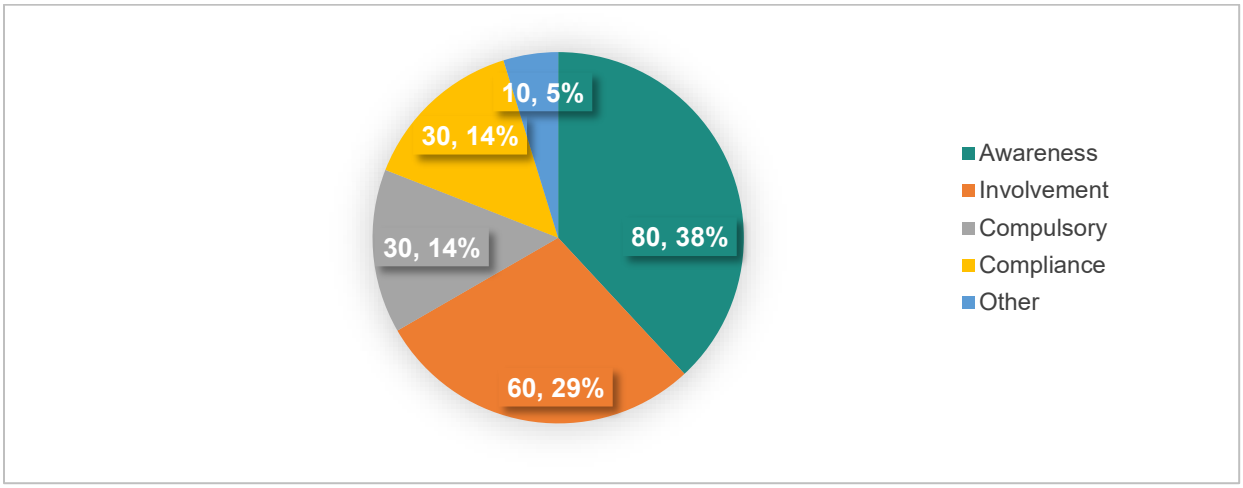


Figure II.11. Organisation involvement with the hydromorphological alternations.

9. Please describe any activities related to hydromorphological alterations that your organisation is/ has been involved in.

Table II.7 summarises the responses regarding the involvement of organisations in the design of River Basin Management Plans. It has been recorded that out of the total 10 responses, 2 were indirectly involved (20%), another two were not involved and 6 (60%) were directly involved (Figure II.12).

Table II.7. Involvement of organisation related to hydromorphological alterations.

Categories	Frequency	Percentage
Indirectly involved	2	20
Directly involved	6	60
Not involved	2	20
Total	10	100

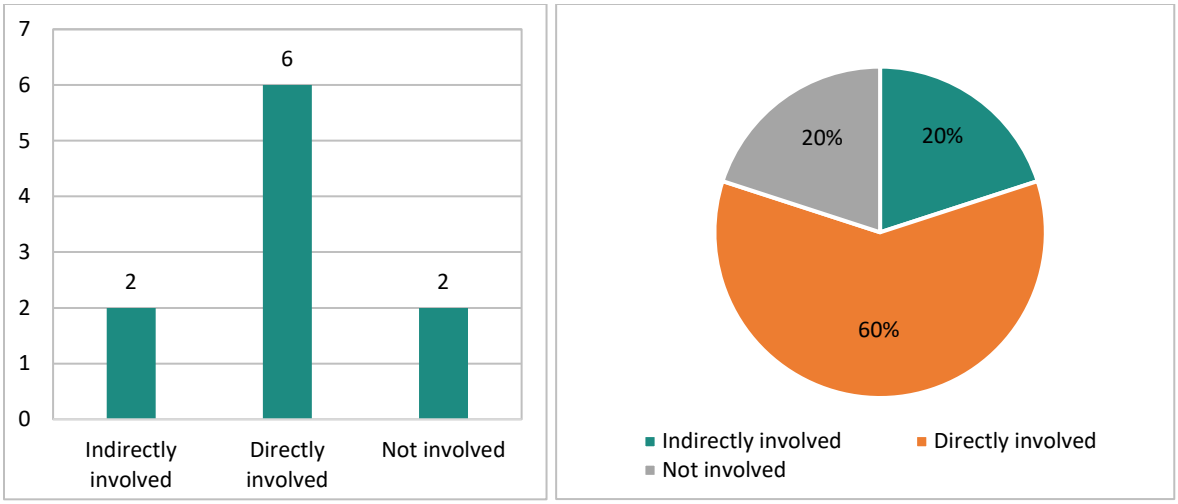


Figure II.12. Involvement of organisation related to hydromorphological alterations.

10. What regulation does your organisation consider important for hydromorphological alterations at the international level?

Table II.8 shows data regarding the regulation that is important for hydromorphological alterations at international level. It has been recorded that out of the total of 10 responses 1 (10%) mentioned protection of marine habitats, 1 (10%) WFD, habitats directive and implementation of the Water Framework Directive and 2 (20%) mentioned FD, WFD while 5 (50%) did not answer this question (Figure II.13).

Table II.8. Regulation important for hydromorphological alterations at the international level.

Categories	Frequency	Percentage
Protection of marine habitats	1	10
Floods Directive (FD); Water Framework Directive (WFD)	2	20
Water Framework Directive (WFD); Habitats Directive (HD)	1	10
Implementation of the Water Framework Directive (WFD)	1	10
NA	5	50
Total	10	100

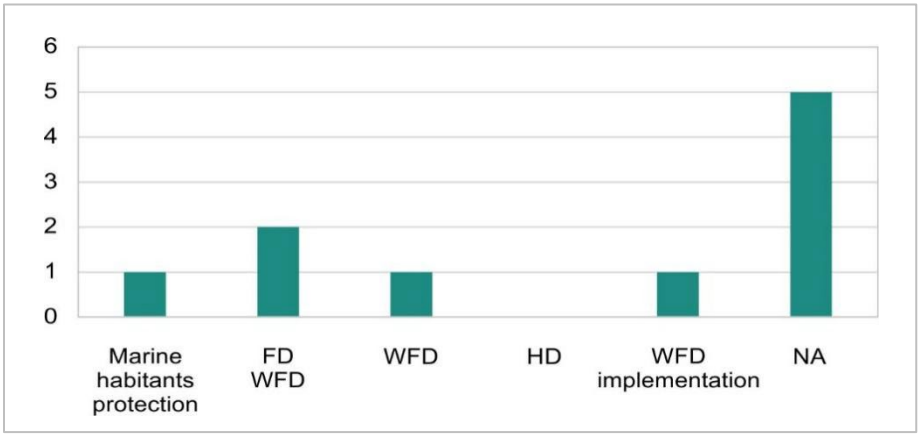


Figure II.13. Any regulation that is important for hydromorphological alterations at international level.

11. Except for WFD what other regulations does your organisation consider important for hydromorphological alterations at the national level?

Table II.9 presents the answers on what other regulations are considered important for hydromorphological alterations at national level. It has been recorded that out of the total of 10 responses 1 (10%) mentioned OSPAR etc – marine protection Natura Directives, 1 mentioned FD, Arterial Drainage network, European Green Deal (River Restoration) and 1 Regulation of public and private drainage schemes, 3 (30%) mentioned Planning and Development legislation while 2 each with a percentage of 20 mentioned Habitats and Birds Directives, EIA Directive, Wildlife Act, Nitrates Regulations and NA (Figure II.14).

Table II.9. Other regulations are considered important for hydromorphological alterations at national level except for WFD.

Categories	Frequency	Percentage
OSPAR etc – marine protection	1	10
Natura Directives		
Floods Directive (FD)	1	10
Arterial Drainage network		
European Green Deal (River Restoration)		
Planning and Development legislation	3	30
Habitats (HB) and Birds Directives, EIA Directive, Wildlife Act, Nitrates Regulations	2	20
Regulation of public and private drainage schemes	1	10
NA	2	20
Total	10	100

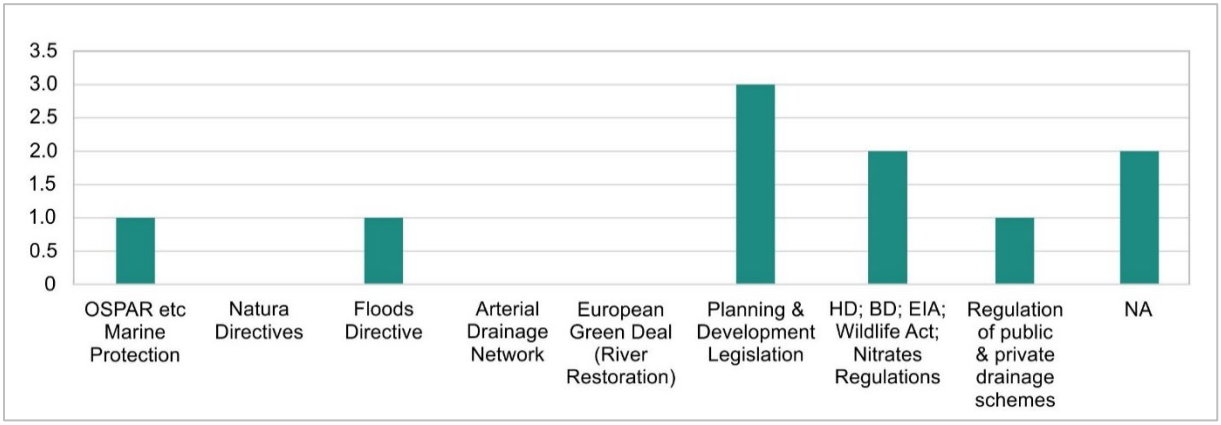


Figure II.14. Important regulations for hydromorphological alterations at the national level other than the WFD.

12. Which policy/regulations does your organisation refer to/consult for advising/complying in relation to hydromorphological alterations and/or their mitigation?

Table II.10 describes the responses regarding Policy/regulations which refer to/consult for advising/complying in relation to hydromorphological alterations and/or their mitigation. Out of the total of 10 responses 1 (10%) mentioned Planning and Development Regulations and Acts, WFD, Habitats Directive (HD), EIA, Wildlife Act and concomitant case law, both national and CJEU and

National and EU guidance on AA, while 6 with a percentage of 60 mentioned NA and 2 with a percentage of 20 mentioned FD, WFD, IFI (Figure II.15).

Table II.10. Policy/regulations that the stakeholders' organisation refers to/consults for advising/complying in relation to hydromorphological alterations and/or their mitigation.

Categories	Frequency	Percentage
NA	6	60
FD, WFD, IFI	2	20
Planning and Development Regulations and Acts, WFD, Habitats Directive (HB), EIA, Wildlife Act and concomitant case law, both national and CJEU	1	10
National and EU guidance on AA	1	10
Total	10	100

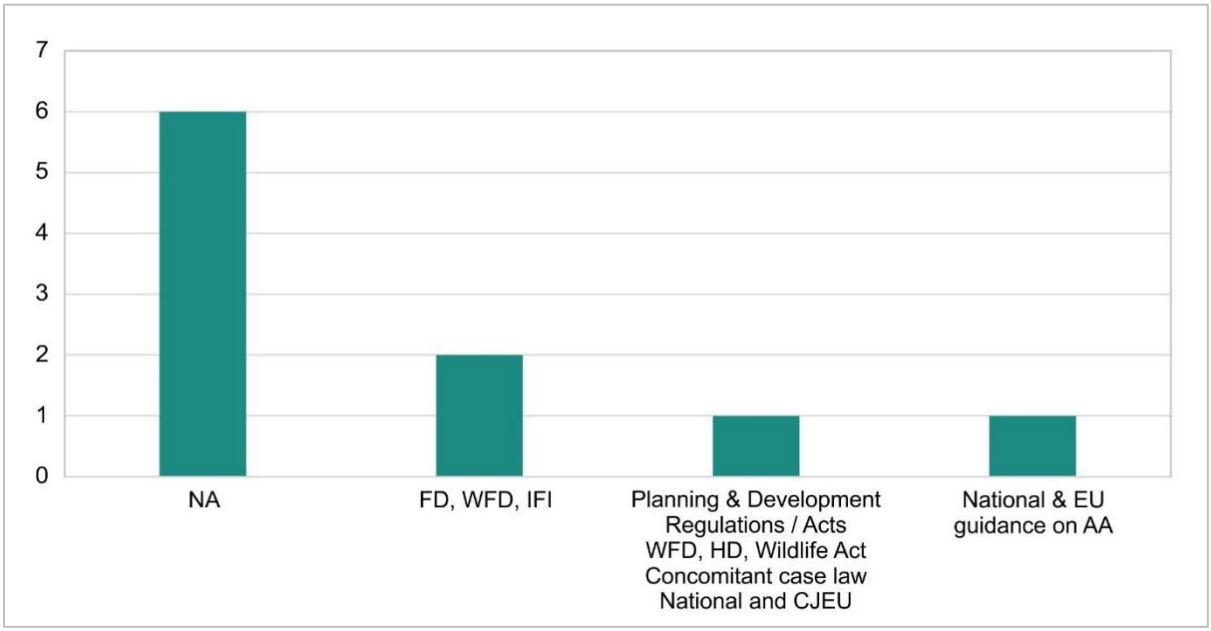


Figure II.15. Policy/regulations that the stakeholders' organisations refer to/consult for advising/complying in relation to hydromorphological alterations and/or their mitigation.

13. Which of the following drivers usually triggers further engagement from your organisation in water-related decision-making?

Figure II.16 presents the responses regarding drivers that usually trigger further engagement from the stakeholder's organisation in water-related decision-making. It has been recorded that, the most important drivers for respondents are crisis management (droughts, floods, etc.) and Policy reform or project under discussion (dam construction, privatisation, law etc.) followed by Regulatory frameworks for public participation (WFD, Law etc.) and Adaptive governance, call for flexible and resilient (co)management mechanisms to cope with future challenges (climate change etc.) (Figure II.16).

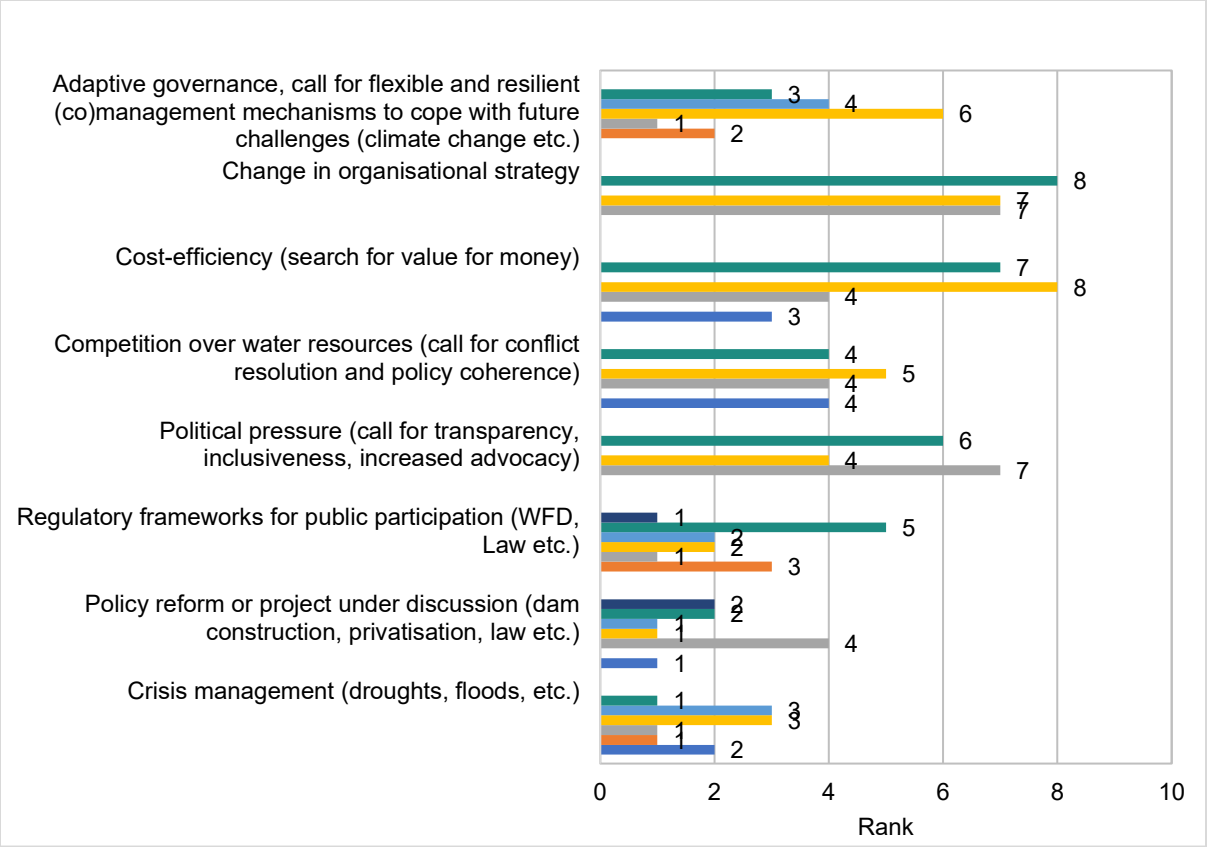


Figure II.16. The main drivers that usually trigger further engagement from an organisation in water related decision-making. Answers based on the ranking from 1 to 8 starting with the most critical factor (1) to the least important one (8).

14. How does your organisation engage with the issue of hydromorphological alterations?

Table II.11 shows the responses regarding the way that the stakeholder's organisation engages with the issue of hydromorphological alterations. It has been recorded that from a total of 9 responses, 8 are engaged with supporting an effective implementation of a policy and 8 raising awareness on the topic followed by 7 engaged with supporting capacity building, qualifications, and training while a minimum of 1 engaged with contributing to the financial sustainability of ecosystems management (Figure II.17).

Table II.11. Organisation engagement with the issue of hydromorphological alternations.

Objective	Yes	No	Total
Supporting effective implementation of a policy, reform or project	8	1	9
Ensuring proper enforcement of regulations and norms	3	6	9
Raising awareness on the topic	8	1	9
Building/Operating/Maintaining infrastructure	4	5	9
Contributing to the financial sustainability of ecosystem management	1	7	9
Supporting capacity building, qualifications, training	7	2	9
Supporting consensus building (across policy areas, between water users, etc.)	6	3	9
Building political accountability	1	8	9
Helping opinion forming and development of preferences	4	5	9
Other – Specify	2	7	9

*One participant's information is missing

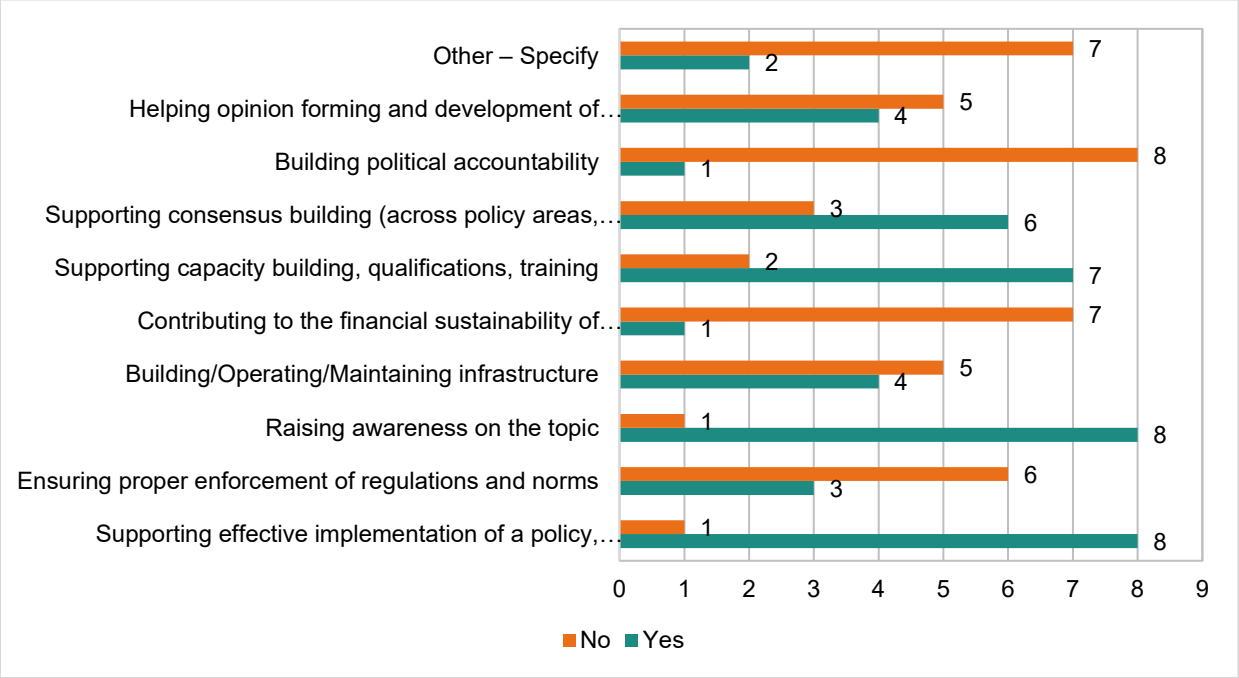


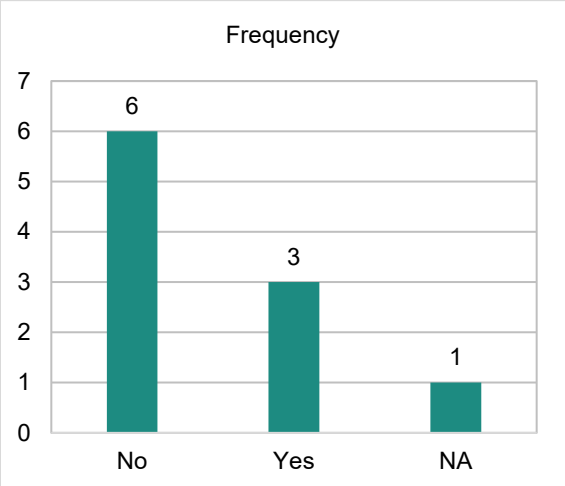
Figure II.17. Organisation engagement with the issue of hydromorphological alternations.

15. Are you a statutory consultee for projects that involve hydromorphological alterations?

As shown in Table II.12, out of the total of 10 responses, 6 answered negatively, and 3 positively, while 1 did not answer (Figure II.18).

Table II.12. Statutory consultee for projects that involve hydromorphological alterations.

Categories	Frequency	Percentage
No	6	60
Yes	3	30
NA	1	10
Total	10	100



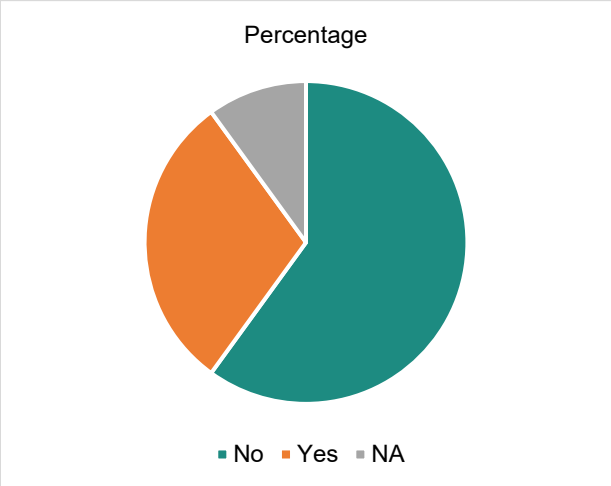


Figure II.18. Statutory consultee for projects that involve hydromorphological alterations.

16. At which stage of a water-related project or water policy does your organisation usually get involved?

According to Table II.13 out of the total 10 responses, 7 usually get involved in Development / Deliberation of which 1 very often, 3 often, 2 sometimes and 1 ever or rarely while no one is involved in the early stages (conception, planning, design, feasibility studies) (Figure II.19).

Table II.13. Stage of water-related project organisation usually gets involved.

Stage of development	Water project			
	Very often	Often	Some-times	Never or rarely
Early stages (conception, planning, design, feasibility studies)	0	0	0	0
Development / Deliberation	1	3	2	1
Implementation / Operation	0	1	2	3
Evaluation (including monitoring)	1	2	2	1
Throughout the cycle	1	0	2	0
Other – please specify	0	0	0	0

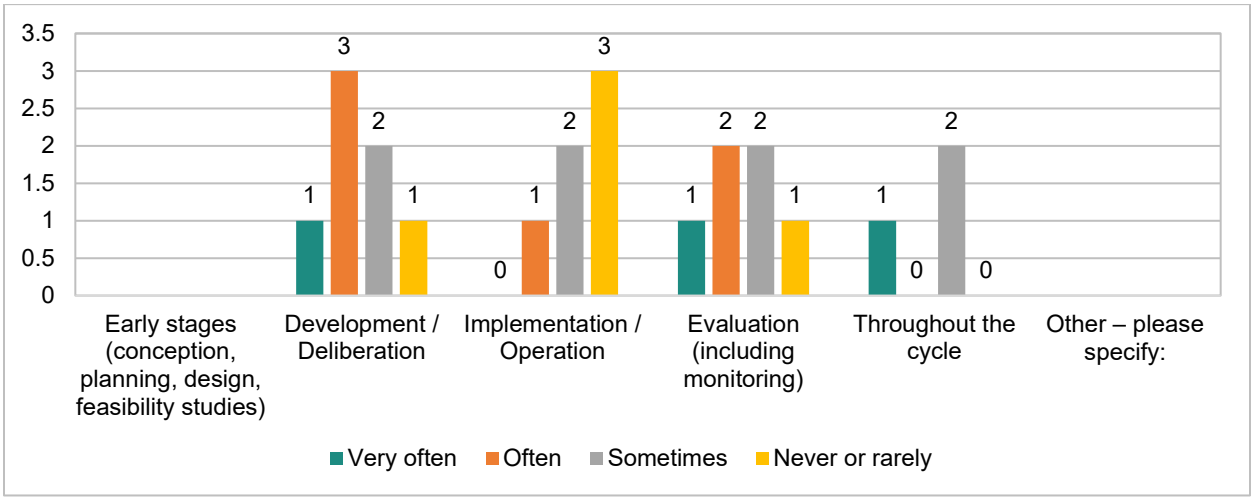


Figure II.19. Stage of water-related project organisation usually gets involved.

Table II.14 shows the response regarding the stage of water policy at which the organisation usually gets involved. Out of the total 10 responses, 4 are usually involved in the Development / Deliberation of which 1 mentioned very often and 1 often, 0 mentioned some time and 2 mentioned never or rarely while no one is involved in the early stages (conception, planning, design, feasibility studies) (Figure II.20).

Table II.14. Stage of water policy organisation usually gets involved.

Stage of development	Water policy			
	Very often	Often	Some-times	Never or rarely
Early stages (conception, planning, design, feasibilitystudies)	0	0	0	0
Development / Deliberation	1	1	0	2
Implementation / Operation	0	0	1	2
Evaluation (includingmonitoring)	1	0	2	1
Throughout the cycle	1	1	0	1
Other – please specify	0	0	0	1

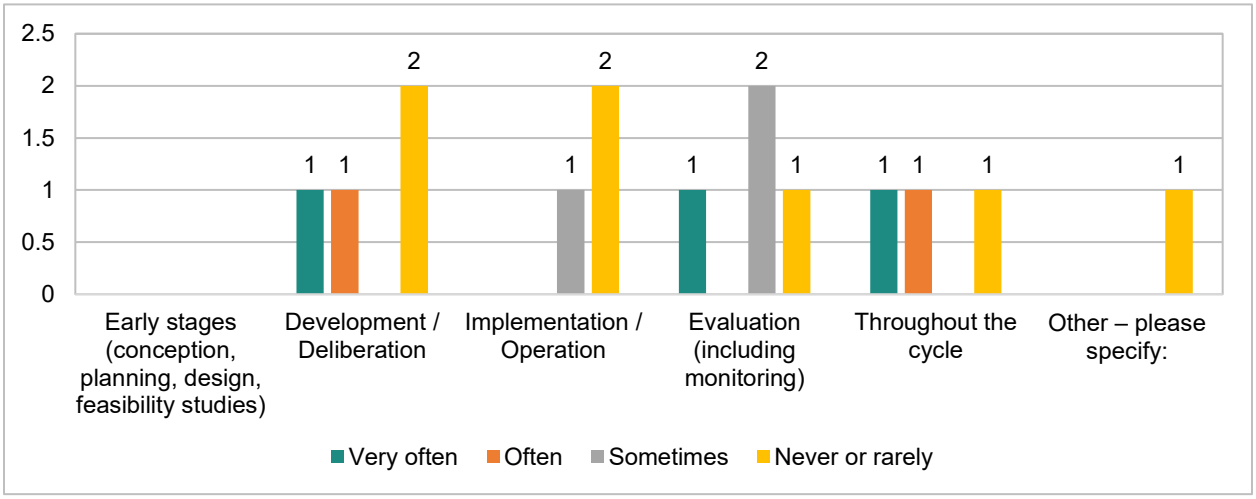


Figure II.20. Stage of water policy organisation usually gets involved.

17. Which of the following stakeholder engagement mechanisms does your organisation take part in?

Table II.15 displays the responses regarding stakeholder engagement mechanisms that their organisation takes part in. Out of the total 8 responses, 8 usually take part in consultations in regulatory processes, workshops and meetings followed by 6 respondents who take part in expert panels (Figure II.21).

Table II.15. Engagement mechanisms that the stakeholders' organisations take part in.

Mechanism	Frequency
River basin organisations	4
Water associations (e.g. associations of water utilities, water regulators, etc.)	1
Decentralised assemblies	2
Surveys / Polls	4
Hotlines	0
Referendum	1
Consultations in regulatory processes	8
Workshops	8
Meetings	8
Expert panels	6
Alert systems	2
Focus groups	3
Citizen committees	2
Consensus conferences	2
Social media and other relevant fora	4
Conventional media	5
Capacity development (institutional or individual)	3
Stakeholder mapping/analysis	2
Other – please specify	1

*Two participant information is missing

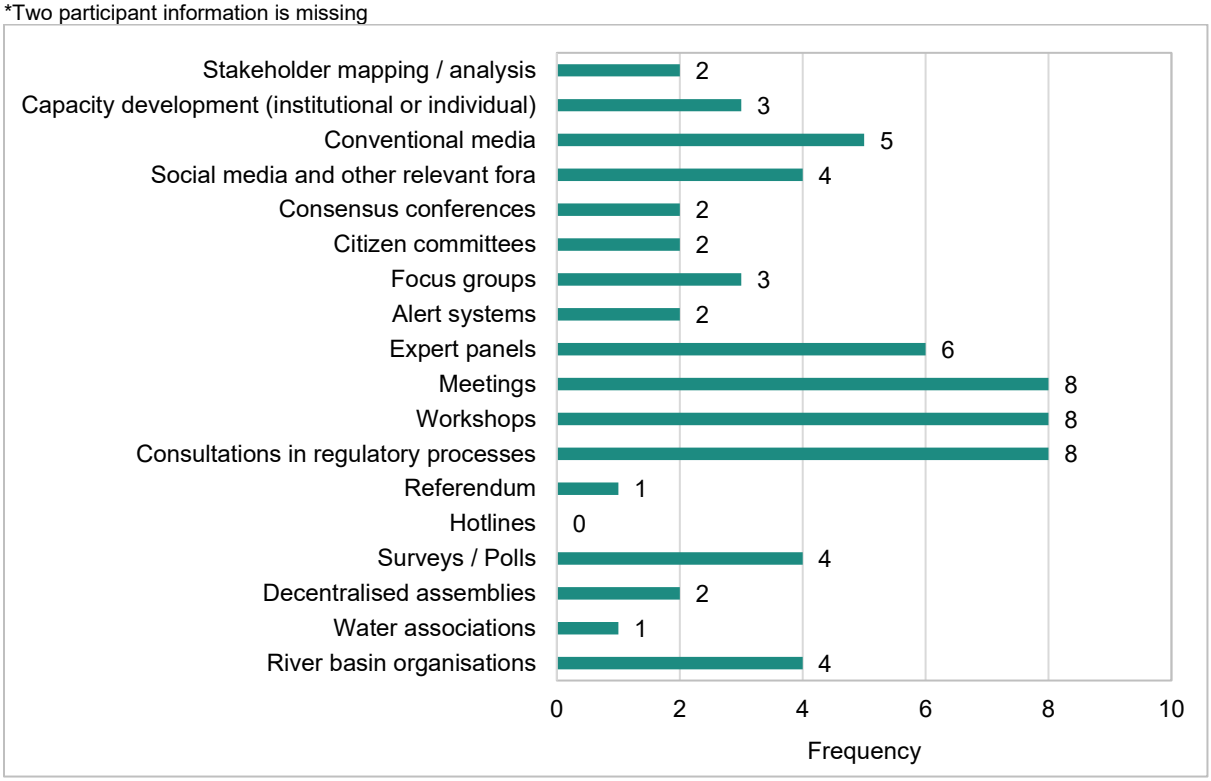


Figure II.21 Engagement mechanisms that the stakeholders' organisations take part in.

18. Are the above-listed mechanisms sufficient to engage stakeholders effectively?

Table II.16 shows the responses regarding whether the mechanisms listed in question 17 are sufficient to engage stakeholders effectively. Out of the 10 responses citizen science, one-to-one,

or a small group, non-statutory Public Consultation Days and Training were mntioned once, while 6 did not answer (Figure II.22).

Table II.16. Listed mechanisms that are sufficient to engage stakeholders effectively.

Categories	Frequency	Percentage
Citizen science	1	10
One to one, or one to a small group	1	10
Non-statutory Public Consultation Days	1	10
Training	1	10
NA	6	60
Total	10	100

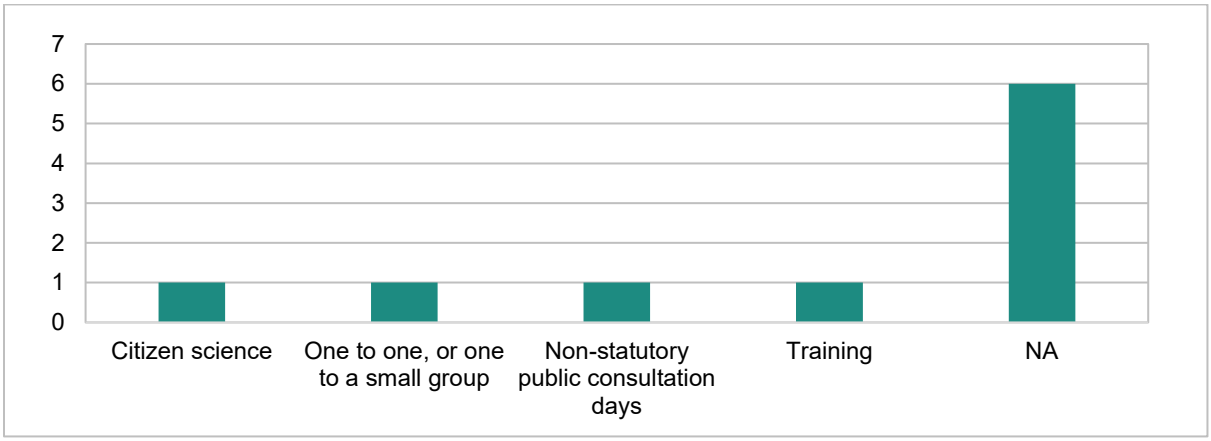


Figure II.22. Listed mechanisms sufficient to engage stakeholders effectively.

19. Which of the following success criteria are the most important for effective engagement of your organisation as a stakeholder?

Figure II.23 presents the responses regarding the most important success criteria for the effective engagement of an organisation as a stakeholder. It has been recorded that, the most important success criteria is the willingness of the other stakeholders to contribute (sense of community, etc.) followed by transparency of the process and human resources to ensure proper engagement (Figure II.23).

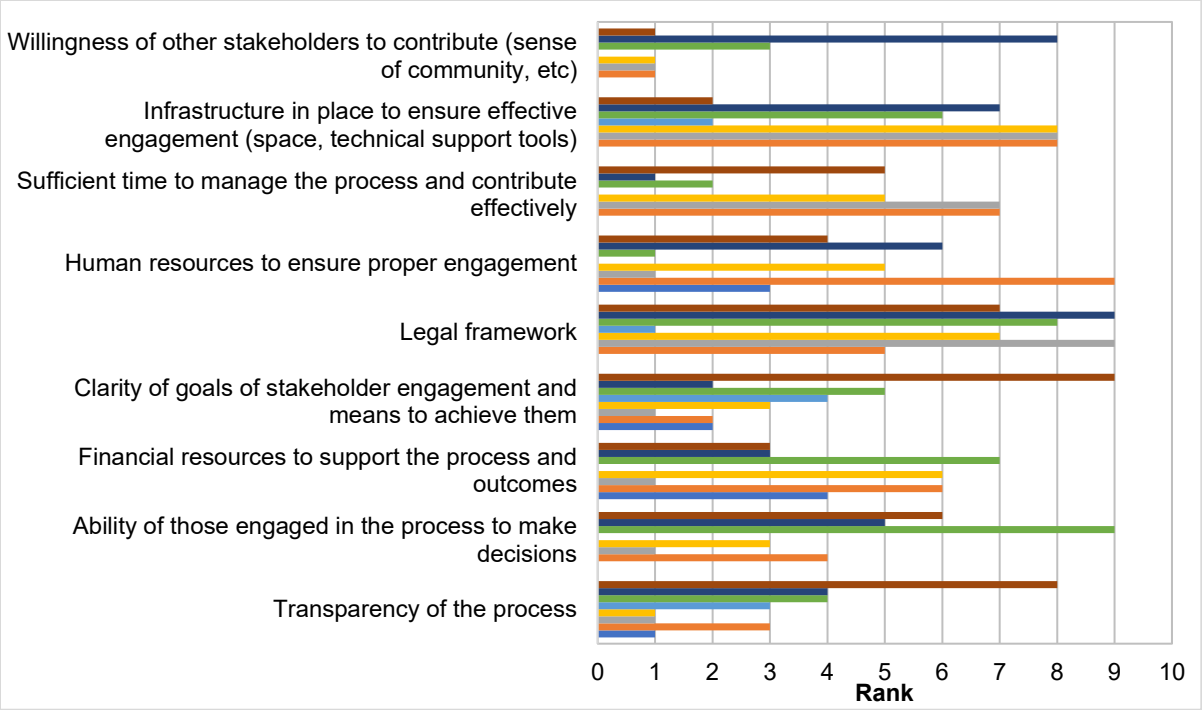


Figure II.23. Most important success criteria for effective engagement of organisation as a stakeholder. Rank from 1 to 9 starting with the most critical factor (1) to the least important one (9). See also legend Fig. II.3.

20. How would you assess the impact of stakeholder engagement on your organisation's objectives when your organisation is in the stakeholder position?

Table II.17 presents the respondents' responses. It has been recorded that out of the total of 9 responses 6 mentioned supporting effective implementation of a policy, reform or project as crucial, 2 important and 1 secondary the same can be observed for other factors (Figure II.24).

Table II.17. Assess the impact of stakeholder engagement on the organisation's objectives.

Objective	Stakeholder engagement contribution Frequency			
	Crucial	Important	Secondary	Minimal
Supporting effective implementation of a policy, reform or project	6	2	1	0
Ensuring proper enforcement of regulations and norms	3	3	1	0
Raising awareness on the topic	5	4	0	0
Building/Operating/Maintaining infrastructure	5	0	2	1
Contributing to the financial sustainability of ecosystem management	2	1	1	2
Supporting capacity building, qualifications, training	1	4		2
Supporting consensus building (policy areas, water users, etc.)	6	1	1	1
Building political accountability	2	3		2
Helping opinion forming and development of preferences	4	2	1	1
Other – Specify	0	0	0	0

*One participant's information is missing.

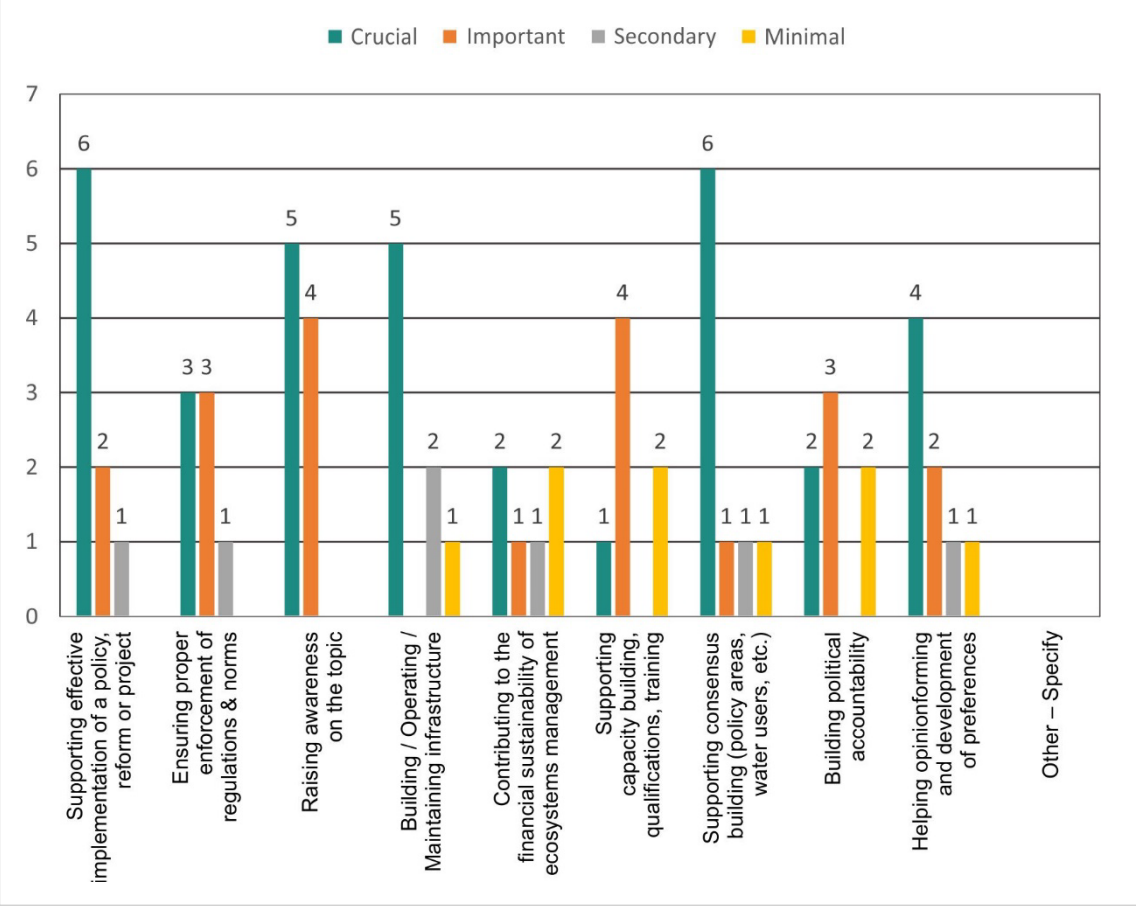


Figure II.24. Assessment of the impact of stakeholders' engagement on organisation's objectives.

21. At which stage of a project does your organisation mostly influence decision-making as a stakeholder?

Table II.18 presents the respondents' responses to the stage of a project that their organisation mostly influences decision-making as a stakeholder. It has been recorded that out of the total 9 responses, 8 respondents selected early stages (conception, planning, design, feasibility studies) of which 4 mentioned sufficient influence and 4 some influence (Figure II.25).

Table II.18. The Stage of a project organisation mostly influences decision-making as a stakeholder.

Stage of development of a project	Frequency			
	Significant influence	Some influence	Little influence	No influence
Early stages (conception, planning, design, feasibility studies)	4	4	0	0
Development / Deliberation	4	2	1	0
Implementation / Operation	1		5	0
Evaluation (including monitoring)		6	1	0
Throughout the process (oversight, financing)	1	4	2	2
Other – please specify	0	0	0	0

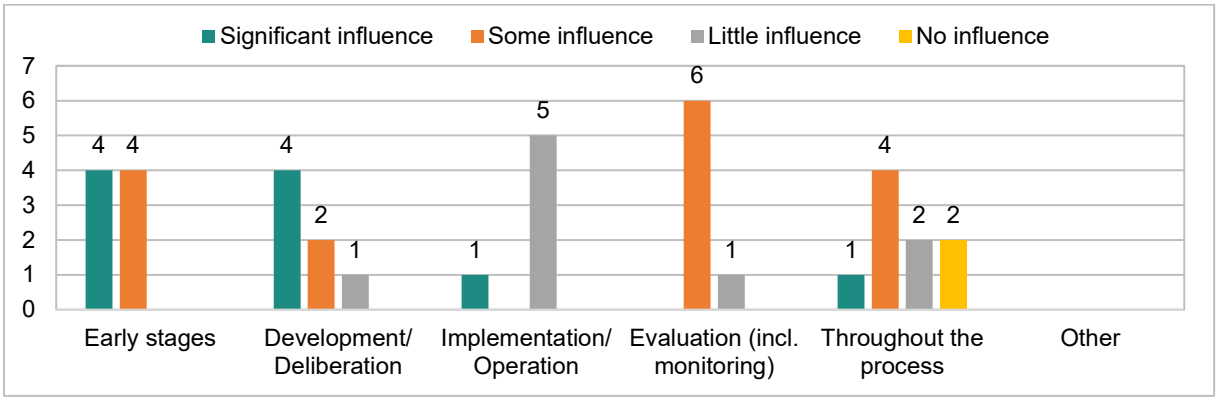


Figure II.25. Stage of a project organisation mostly influences decision-making as a stakeholder.

22. Do you believe that stakeholder engagement: a) between statutory bodies/stakeholders and b) between statutory bodies and sectoral stakeholders (i.e. civil society) is currently effective?

Table II.19 displays the responses regarding current effectiveness of the stakeholder engagement between statutory bodies/stakeholders and between statutory bodies and sectoral stakeholders. Out of the total of 9 responses 3 mentioned both a and b, 3 only and neither a nor b. (Figure II.26).

Table II.19. Current effectiveness of the stakeholder engagement.

Statement	Frequency	Percentage
Both a and b apply	3	33.33
Only a applies	3	33.33
Only b applies	0	0.00
Neither a nor b applies	3	33.33
Total	9	100.00

*One participant's information is missing.

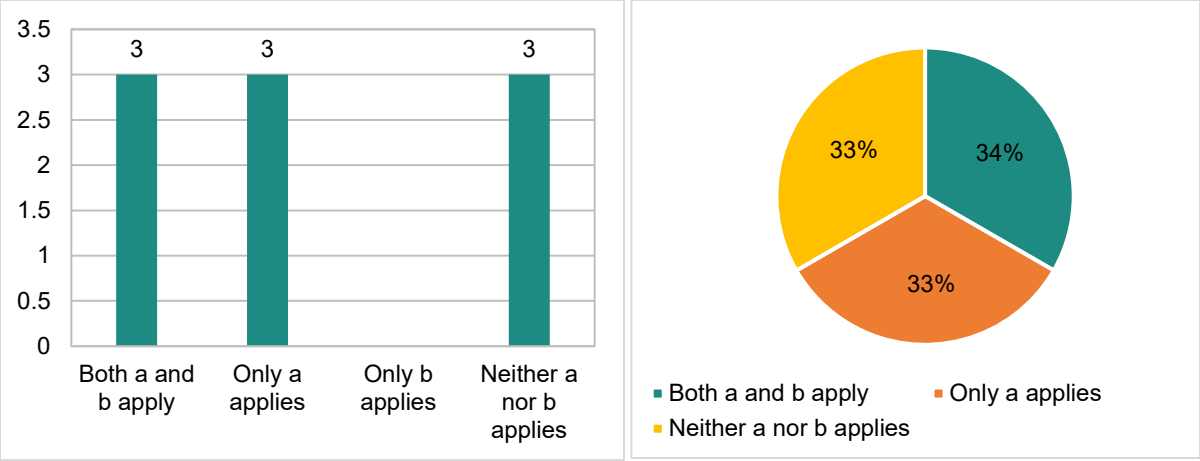


Figure II.26. Current effectiveness of the stakeholder engagement.

23. If the answer to question 22 is not that both a and b apply, what does your organisation see as the "missing link" or "gap" in stakeholder engagement where public authorities could play a role, if any?

Table II.20. What does your organisation see as the "missing link" or "gap" in stakeholder engagement where public authorities could play a role?

Categories	Frequency	Percentage
Role of central governmental bodies		
LAWPRO	1	
Feedback following consultation with transparency	1	
Multiple engagements	1	
implementation	1	
Stakeholder engagement	1	
Interdepartmental groups are essential	1	
More joined thinking across government departments, with a common goal	1	
Provide more funding		
NA	2	
Role of regional governmental bodies		
Regional Assemblies	1	10
Ensuring that national objectives are communicated throughout communities	1	
Feedback following consultation with transparency	1	
Interdepartmental groups are essential	1	
Multiple engagements	1	
(b) is improving in Ireland with the key role of LAWPRO and Rivers Trusts	1	
implementation	1	
NA	3	
Total	10	100

24. Do you have project reports or other relevant resources that are available to share and could assist this project?

Table II.21 presents the responses. Out of the total of 10 responses, 1 answered negatively, 4 positively, and 6 did not answer (Figure II.27).

Table II.21. Existence of project reports or other relevant resources that can be shared and could assist this project.

Categories	Frequency	Percentage
No	1	
Yes	4	
NA	6	10
Total	10	100

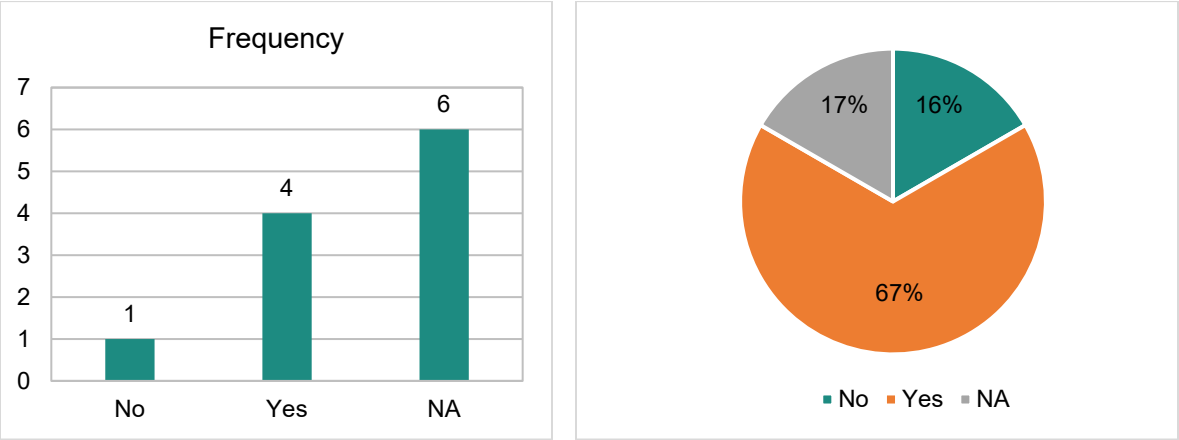


Figure II.27. Available project reports or other relevant resources that can be shared and could assist this project.

25. Is your organisation willing to share any relevant internal reports?

As shown in Table II.22, out of the total of 10 respondents, 4 answered positively while 6 did not answer (Figure II.28).

Table II.22. Possibility of sharing any relevant internal reports.

Categories	Frequency	Percentage
Yes	4	40
NA	6	60
Total	10	100

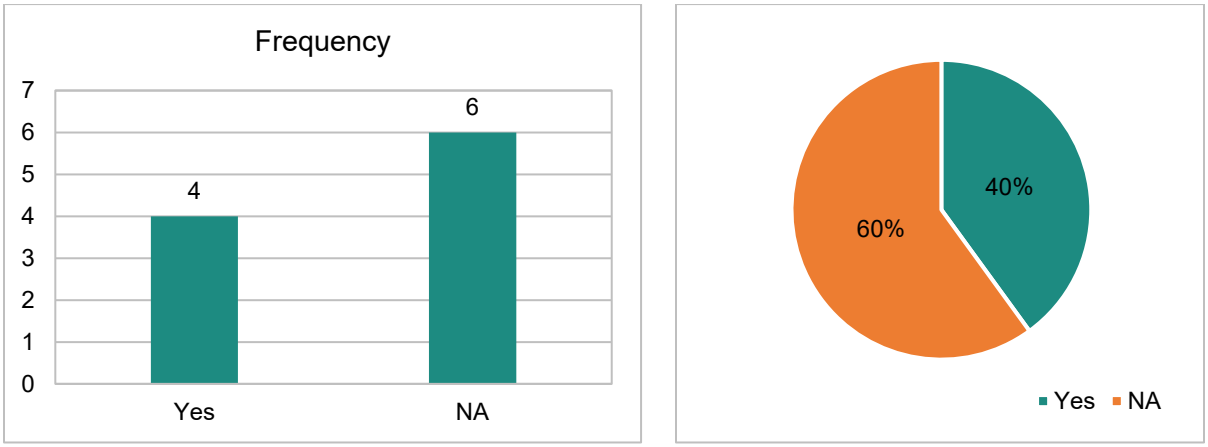


Figure II.28. Organisation willing to share any relevant internal reports.

ANNEX II: Report of the stakeholders' workshop

Project: Physical modifications of Ireland's water resources and implications for meeting the Water Framework Directive (Directive 2000/60/EC)

Project No. SW-PM-07

Report on the Hydromorphological Workshop 28th June 2021

Introduction and background

The Sustainable Water Network (SWAN) opened a tender for a short desk-based research project on physical modifications as a significant water management issue in Ireland, entitled 'Physical modifications of Ireland's water resources and implications for meeting Water Framework Directive objectives. The tender was won by IHE Delft Institute for Water Education (The Netherlands), whose mission is to support sustainable water management through its research, teaching and capacity building programmes. The study will focus on physical and hydromorphological alternations of surface water, groundwater and groundwater-dependent terrestrial ecosystems (GWDTEs) in Ireland in relation to the implementation of the WFD.

Key objectives of the project are:

- Literature review of effects of hydromorphological alterations on water bodies, including cumulative impacts;
- Overview of current relevant EU and Irish policy, legislation and guidance governing hydromorphological alterations;
- Analysis of policy and legislative provisions governing hydromorphological alterations re WFD requirements;
- Identify case studies to inform best practices to support meeting hydromorphological objectives in Ireland;
- Present a discussion of findings leading to a set of recommendations;
- Submission of an article for a peer-reviewed journal.

Key stakeholders were identified from previous reports, projects and river basin and flood risk management plans, and fora related to the implementation of Water Framework Directive (WFD) in Ireland as it relates to hydromorphology. A range of what were judged key stakeholders from an array of sectors were surveyed as to their role in hydromorphological assessment and management that would have potential effect on hydromorphology. This mapping exercise was done as a prelude to a stakeholder workshop held on 28th June 2021. Altogether 38 individuals across relevant sectors were invited to the workshop, of which 18 were able to attend.

Most significant pressures on achieving WFD environmental objectives in Ireland

In Ireland, there are 74,000 km of river channel including 38,000 km of the smallest order streams (Byrne and Fanning, 2015). Overall, 53% of surface water bodies assessed are in satisfactory ecological health being in either good or high ecological status. The remaining 47% of surface water bodies are in moderate, poor or bad ecological status. The most significant pressures on Irish waters reported by the EPA (2020) are shown in Figure 1.

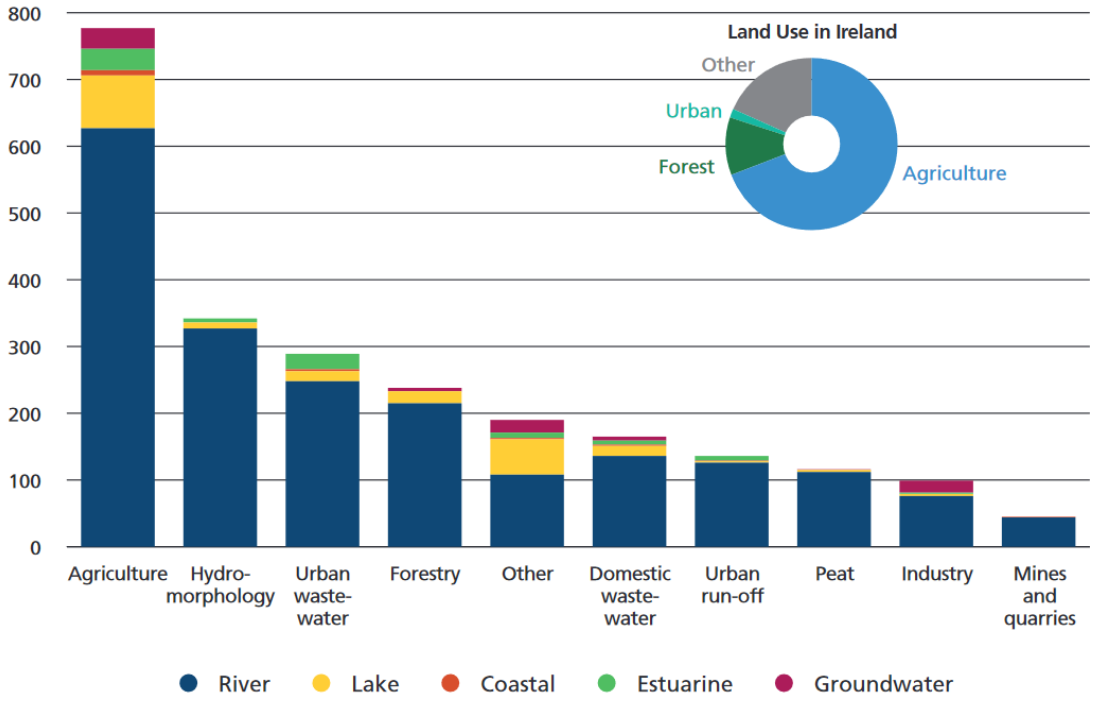


Figure 1: The most significant pressures in Ireland (EPA, 2020).

Pressures and impacts can vary across water body types. We often focus on lakes and rivers, but connections of inland and surface waters with groundwater and coastal and estuarine waters are also important. Groundwater is an important hydrological element related to maintaining the flow, quality and ecology of dependent surface waters. Disconnection of groundwater affects the hydrological regime of the river and groundwater dependent ecosystems. In Ireland, karst is an important geological phenomenon and plays an important role in the connection between rivers and groundwater bodies.

The productivity of the coastal ecosystem largely depends on the health of coastal lagoons which in turn provides support to a variety of salt marshes and seagrasses. Lagoons play a central role in providing habitat for fish but are also under pressure in Ireland and, generally, globally.

The initial results of a scoping exercise (Table 1) of the drivers, likely pressures and potential impacts of hydromorphology in Ireland indicate a range of issues to be considered for measures that can assist with meeting WFD environmental objectives. Figure 1 and Table 1 were presented to provide a stimulus for the stakeholder workshop.

Table 1: Scoping of pressures and impacts of potential importance of Irish waters.

Driving force(s)	Likely Pressure(s)	Potential Impact(s)
Surface waters		
Rivers		
Agriculture	Irrigation and water abstraction Overgrazing Livestock access to waterways Nutrient management (lots of information already on this) Arterial Drainage Riparian wetland drainage 'Clearance' of rivers by landowners; bank clearance, dredging and channelising***	Modification of the flow regime. Destabilisation of riverbanks. Interactive effects of physical and chemical impact. Removal of lateral connectivity leading to impairment of natural river function/response to disturbance. Altered structure and conditions of bed and banks Increased sediment load
Forestry	Low-level effects on Blue dot/ High-status waters Hydromorphological alterations are in the top 2 pressures on Blue dot / high status waters and while the nature of / sources of these are not known to us, it may well be from forestry. We believe this needs to be explored further.	Disrupt attenuation Contribute silts & threaten catchment dynamics Loss of biodiversity and ecological refuse areas
Urbanisation/ Industrialisation	Abstraction and impoundment (i.e. dams (e.g. Ardnacrusha and Lee River), small-scale hydropower plants, weirs and other barriers)	Alterations in flow regimes. Interruption of the longitudinal continuity of rivers. Erosion of the river bottom due to reduced sediment transport. Modification of water quality. Altered structure and conditions of bed and banks downstream. Decline of species biodiversity and reproduction. Barrier to fish migration.
Flood protection measures	River re-sectioning or straightening / cross profile constructions, dykes, channelisation, river bed and bank reinforcement and fixations, embankments and dredging, lateral dykes, weirs, etc. Culverting	Impact on flow and habitats, and opening for invasive species Altered erosion/deposition. Water flow and structure of water bodies. Reduction of the connectivity in the riverine landscape and altered the fluvial dynamics that support habitat heterogeneity. Lateral connectivity of river systems. Recreation e.g. boating
Peat extraction		Increased erosion rates. Modification of water quality. Siltation Loss of flood retention

Lakes		
Agriculture/ Urbanisation	Abstractions Physical/morphological alterations to the lake's shoreline (both littoral and riparian zones) Afforestation and deforestation and removal of riparian vegetation	Alteration in water levels. Habitat alteration. Potential effects on the riparian zone Alterations of groundwater regimes feeding lakes.
Groundwater / GWDTEs e.g. springs		
Agriculture	Drainage* Nutrient enrichment Abstraction	Alteration of the surface water-groundwater interactions between the river and the shallow aquifer. Alteration of the vertical connectivity river/aquifer. Alteration of lateral connectivity. Lowering of the water table. Modification of groundwater quality. Disconnection of groundwater which affects the hydrological regime of the GWDTEs. Very relevant for Ireland, where karst formations play an important role in the connection between river and groundwater bodies. Effects on the soil moisture and groundwater regimes differentially across the floodplain. Alteration of the discharge flow rate of springs. Impact on biodiversity in priority habitat under the Habitats Directive
Transitional and coastal water		
Navigation	Coastal and estuarine dredging Hard constructions i.e. harbours	Alteration of silt movements, loss of habitat, erosion of coastal and salt marsh habitats.
Urbanisation/ Industrialisation/ Flood protection and erosion control	Shoreline reinforcement and use of unsuitable materials for erosion control	Fragmenting continuous coastlines. change of near-shore currents Changes to sediment supply Accretion and erosion (west coast)
Urbanisation/ Agriculture	River management Land drainage – in transitional and coastal water bodies Impoundments Nutrient enrichment	Alteration of water flow. Alteration of sediment supply. Alteration of habitats.

*There are interactions among pressures and water body types. The interconnection of the different water bodies has as a consequence that any pressure posed on one of them might also have an impact on another. **There will be a prioritisation of likely impacts, both in terms of local/general scale and in the scale of importance for the project. ***McCarthy, C. (June 17th, 2020) 'Two years on the ground: identifying problems and fixing them', EPA, National Water Event. Available online

Key points identified as relevant for hydromorphological assessment ahead of the stakeholder workshop

Hydromorphological pressures comprise all physical changes that can alter the hydromorphology of water bodies and which can threaten aquatic ecosystems. Good hydromorphological support conditions commensurate with good status for aquatic ecosystems, such as water flow and substrate provide physical habitat for biota such as fish, invertebrates and aquatic macrophytes). Several pressures may act in combination with other pressures, such as nutrient additions and invasive species. Climate change effects can accentuate existing pressures.

- Across Europe, a large number of surface water bodies remain at risk of failing to achieve good ecological status, and for a high proportion of these, it is because of alterations to morphological characteristics, impacts on water flow and level regimes, and barriers to biotic movements, especially fish.
- Monitoring of hydromorphological effects on WFD ecological status of water bodies should include hydrological regimes, continuity (migrant aquatic life such as fish, sediment) and morphological condition of water bodies. Various projects (e.g. The River Hydromorphology Assessment Technique (RHAT), Morphological Quality Index (MQI), and Small Stream Risk Assessment) have supported assessment hydromorphology in Ireland, with a number of others ongoing.
- Current work of IFI and OPW is developing assessment methods and identifying small and larger barriers to fish movements, and measures to assist: a) the assessment of the potential impact of flood management measures on WFD objectives, b) the identification of appropriate mitigation measures; and potential derogations of achieving environmental objectives under the WFD.
- An important “sister” Directive to the WFD is The Flood Risks Directive (Directive 2007/60/EC). Its implementation requires coordination with the WFD. Across Europe, only 17% of European floodplain habitats and species are considered to have good conservation status. Flood risk is managed in very different ways across the EU, with greater attention being paid to so-called Nature Based Solutions. This includes investing in flood mitigation through providing room for expansion of river and coastal flooding, and protection of wetlands. Global evidence of the value that wetlands can provide for the mitigation of flooding is very clear. SloWATERS Programme is funded by the Environmental Protection Agency (EPA) and the Office of Public Works (OPW) and aims to assess the benefits of Natural Water Retention Measures (NWRM) for agricultural catchments in Ireland. The Coastal Lagoons: Ecology and Restoration (CLEAR) Programme of EPA and the National Parks & Wildlife Service (NPWS) is a pilot addressing water pollution and hydrological modification on lagoon ecology.
- Several Irish, EU and international research projects that can be useful for the future understanding and management of hydromorphological impact on inland and coastal waters and cross-compliance with other legislation and policies. Attention is not only on the achievement of WFD good status, but protection of few remaining high-status waters in Ireland, as illustrated by the Blue Dot Catchments Programme.

The Pearl Mussel Programme of Measures and EU KerryLife project are important to assess the combined pressures of nutrients, sediment and hydromorphological change on the vulnerable mussel.

- Case studies so far being assembled are Shannon River, River Lee, River Erne, Pollaphuca Reservoir, River Inny, and Bantry Bay.

Key Legislative issues

Several key legislative issues identified ahead of the stakeholder workshop were:

Arterial Drainage Acts 1945-1995:

- Mandatory clearing of vegetation (by OPW) in the vicinity of river systems in order to maintain drainage benefitting agricultural use/land.
- Calls for mandatory EIA / EIA screening in advance of such clearance work (to assess critical environmental impacts, identify possible mitigation measures, etc.)

Planning and Development Act 2000 (as amended):

- Breadth of "exempted development" in respect of "agricultural purposes" under PDA section 4(1)(a) and in respect of "land reclamation" activities under Schedule 2, Part 3 to the 2001 Planning and Development Regulations.
- Implications of key case law: Case 392/96: Commission v. Ireland [1999] ECR I-5901 (re requirement for EIA of significant forestry and turbary activities); Irish Wild Bird Conservancy v. Clonakilty Golf and Country Club Ltd., Unrep., High Court, 23 July 1996 (re activities covered by agricultural exemption).

Implications for compliance with the WFD

- Legally binding nature of WFD objectives and the obligation to refuse authorisation from individual projects estimated to compromise WFD water quality objectives;
- Relevance of the so-called "non-deterioration" principle.

Notes from the Stakeholder Workshop

Present:

Micheál Bruen (UCD), Colin Byrne (DHLGH), Donal Daly, Karin Dubsky (Coastwatch), Elvira de Eyto (Marine Institute), Cathal Gallagher (IFI), Ken Irvine (IHE), Konstantina Katsanou (IHE), Fergal Kelly (OPW), Sean Langan (OPW), Greg McCleary (NIEA), Elaine McGoff (*An Taisce*), Trish Murphy (Inishowen River Trust), Claire Parke (NIEA), Paul O'Brien (IFA), Sinead O'Brien (SWAN), Shane Regan (NPWS), Neil Walker (IBEC), Bernie White (LAWPro), Jenny Deakin (EPA)

Introduction and Overview of the Workshop

An introduction to the objectives of the workshop was provided by Ken Irvine, supported by a short presentation (Annex 1), that followed from the preliminary material sent to the participants and summarised above.

The meeting was facilitated by Harriet Emerson of *Adjust* who organised three "breakout rooms" for smaller group discussions of four topics. Each topic was followed by a summary and discussion in plenary sessions. Membership of the groups was the same for Topics 1 and 2, and then groups were recognised for Topics 3 and 4.

Breakout group discussion

After the discussion about each topic, the three groups joined again the main room where the moderators of each group (Ken, Harriet and Konstantina) reported back on the main points of their conversation, with the opportunity for participants to add further comments.

Topic I: Key Knowledge gaps to support best practice

Report from breakout room 1:

- Engineering structures can affect ecological status, but the local impact of these are currently not considered at a river basin, or even a water body, scale.
- Physical structures that cross rivers and unregulated abstractions are common hydromorphological pressures.
- There appears little appreciation of future climate effects and adaptation (floods and droughts).
- Further to the summary feedback, there was a view that further planning guidance is required so that planners can make decisions based on the requirements of the WFD.

Report from breakout room 2:

- The importance of lateral connectivity between water bodies and land was emphasised, as the current focus is mainly on up and downstream links.
- Determining reference conditions for hydromorphological alteration is a particular challenge.
- There is still a strong need to provide digestible information on hydromorphology and its importance to practitioners and to the public, which also relates to the further development and roll-out of assessment methods.
- A further comment was that gaps remain in understanding the structure and function of high-status waters and how that influences water quality and biodiversity within those channels.

Report from breakout room 3:

- There was discussion about the use of aquifer maps and what information was needed, what scale is best and the availability of appropriate scales.
- Moreover, the question of whether there is enough focus on the pressures or the quantitative risk for abstraction for groundwater.
- Greater clarity on the classification (of good ecological potential) of highly modified water bodies is needed.
- Important to bear in mind what can be realistically achieved, and maybe a greater link with the Ecosystem Services concept and techniques. For rivers particularly, this also includes ideas and assessment of environmental flow.

In the plenary discussion, additional points were:

- Peatland management practices are important since peat extraction especially affects the drainage downstream.
- The implications of hydromorphological assessment and its relevance for heavily modified water bodies (HMWBs) was raised, with an opinion that more of these should be designated. This has implications as the environmental objective would be good ecological potential rather than good ecological status, and other opinions were that this may not be desirable. Nevertheless, a technical assessment of heavily modified water bodies has provided a better position on this topic, leading to what is considered a more robust and objective assessment method. EPA is working on finishing the technical assessment, after which there will be a consultation process that will help with how best to incorporate this into the pending draft River Basin Management Plan. It is recognised that the first River Basin Cycle relied a lot on expert judgement. New guidance on hydromorphology also has occurred through the Common Implementation Strategy (CIS) at EU level.
- More work is needed on ecological flows and the interaction between hydromorphology and lateral conductivity, with knowledge gaps in the extent and distribution of water extractions, and how that interacts with changes in the morphology of rivers.

Topic II: Identifying and examining the importance of combined pressures involving hydromorphology

Report from breakout room 1:

- There was an emphasis on climate change as an overarching importance. This included both the impact of floods and the droughts in Ireland.
- Other pressures discussed include forestry, heritage places, recreational areas and multiple land uses.
- It was further mentioned that there is no overarching kind of Irish authority in charge of the Water Framework Directive. For example, local authorities make decisions on planning, Forest Service decisions on forestry and the OPW decisions on arterial drainage works.
- Greater use of NBS can be effective in mitigating impacts from hydromorphological as well as from other pressures.

Report from breakout room 2:

- There was a consensus that hydrology and sediment loads are crucial and that these are connected with land use. The connection between hydromorphological alteration, for example, drainage, and the water bodies provides the conduit for sediment, nutrients, and pesticides entering water bodies
- Localised effects of sediment disturbance can be very important in affecting ecological status, but hard to generalise the extent of the problem. For example, in some catchments access of cattle to water can be a problem in one place or (sub-)catchment, but not in another.
- A clear recommendation is that there needs to be more attention paid to the multiple effects of smaller drains.

- Mention was also made of the importance of smaller pressures such as landslides connected with management regimes, and very localised pressures affecting hydrology such as occurring around bridges.

Report from breakout room 3:

- The group heard about a description of an Australian situation that captured the challenges of cumulative processes. This included issues around dredging and what it means in terms of silt movement and changes in bottom biota.
- Some, not very frequent pressures such as emissions of industrial cooling waters in very warm conditions were discussed, as well as how that interacts with other pressures (e.g. nutrients).
- In general, considerations of environmental flows (eflows) often involve multiple pressures all affected by reductions in flows or alterations of flow regimes.
- Assessing and managing cumulative pressure requires a combination of key variables and parameters that aid decision-making to address those pressures. This level of complexity has not yet been addressed effectively.

In the plenary discussion, additional points were:

- There is a need to consider dredging in the vicinity of ports, with Waterford used as an example, and whether similar issues occurred elsewhere. Dredging can occur throughout an estuary.
- Addressing the pressures from alien invasive species and the responsible authority to tackle this problem can be difficult, not only for transitional and coastal waters but more generally. The issue of the important connection between invasive species spread and linkage to hydromorphology was mentioned as an important combined pressure, including that invasive species such as the zebra mussel can be the cause of alteration of the physical structure of a lakebed.

Topic III: Policy framework

Before entering the break-out rooms Ken Irvine mentioned that the policy is fragmented, with so many coordinating units, and hence recommendations are welcomed to make it less complicated and where useful connections across policies would be required.

Report from breakout room 1:

- Problems with the WFD were realised early on in the WFD and should have been aligned with the legislation as soon as it was introduced.
- The benefits of better alignment of objectives across different directives are recognised and are presumably an ongoing process.
- An overarching authority in managing the WFD was suggested as still an important need, with commensurate changes in relevant legislation. This could include a consolidated Water Act.
- Greater engagement and processes for receiving input from the public are necessary.
- It may be that planning authorities should no longer give planning permission for an activity that would have an impact on the status of a water body. This would require an amendment to the Planning and Development Act.

Report from breakout room 2:

- Transboundary approaches to hydromorphology and pressures, in general, can differ markedly across the Republic of Ireland and Northern Ireland for coastal zones. This affects the permissions for coastal cage aquaculture.
- For coastal areas marine spatial planning provides a huge opportunity for environmental safeguards.
- There are many different views on how we use land and water, but no overall management framework, and influenced by many varying interests.
- Collaboration across sectors is recognised as an opportunity, but difficult to effect in practice. Some sectors have responded to the need to adapt to policy changes.

Report from breakout room 3:

- Effective governance is integral to how agencies work together. It is not just about their coming together to co-ordinate their work, but how together they manage the environment. A national Land Use Plan/Map, constructed around RBMPs, was suggested in which all actors feed into this.
- It was proposed that the roles of some agencies could be better aligned, or even amalgamated.
- As some stakeholders have more say in relation to the development of some policies and some are more “powerful” than others, attention to greater equity was suggested. Strong governance is imperative if we are to have effective delivery of WFD objectives.
- Certainly, there is scope for OPW and IFI to deliver enhancements for rivers, with a challenge to improve practices and scope for better synergies among different stakeholders.
- We need to have agencies that can name the problem and provide the solution and be permitted to provide extra expertise acceptable to all stakeholders.

In the plenary discussion, additional points were:

- From the draft River Basin Plan there was a proposal to develop a new Bill covering hydromorphology and associated secondary legislation. A DHLGH interdepartmental and interagency will help in teasing out an appropriate regulatory framework, including benefits of public consultation. This prompted the suggestion for a facilitated session that would include experts, academia, and stakeholders.
- Clarification is needed about the issue of land ownership and riparian rights, and the effect of (or change to) old legislation that gives rights to landowners that can affect hydromorphology. A response to a question of clarification from the Chair was the proposed Bill would intend for a more simplified and streamlined process, but the engagement will be important to provide an overall workable system.
- This also raised a comment about the need for better enforcement to achieve management objectives.

Topic IV: Land use and water body hydromorphology

Report from breakout room 1:

- For land erosion and sediment transport, different programmes (e.g. EPA programmes) should try to determine best practices for holistic solutions.
- Other studies are being developed on a catchment basis to do with flooding.
- More funding and clearer legislation and planning regulations would support teams dealing with catchment scale management issues.

Report from breakout room 2:

- In general, a more coherent approach to RBMPs, and the associated legislation, while an opportunity to develop a more coherent approach, is recognised as complicated. However, the knowledge is there in topics like peatlands hydrology, nutrient emissions and related topics but it seems that there are gaps in knowledge of other topics like floods which is a major issue and needs better understanding.
- The multiple actors involved and the legacy of land use are important.
- At landscape scale, there are a number of difficulties in coherent management. Taking the example of the bog areas where today there has been discussion around the hydrology of peatlands if you think about the multiple ownerships then it is quite challenging for one farmer to block a drain because they want to rewet a land as that will have consequences for their neighbours. So, the idea of paying or more correctly maybe being compensated for ecosystem services needs a more coherent approach.
- Finding solutions to the effect of land-use on hydromorphology involves important social and economic issues and expertise.
- Schemes to recognise and reward quality, such as occurred in the Blue Flag beaches are worthy of further consideration.
- Buffer strips between land and water increasingly are recognised as a management option, but no single approach is necessarily effective.

Report from breakout room 3:

- There is a need for increased awareness raising and education to provide information on the importance of, and effects of altering, hydromorphology.
- A result-based payment system can reward those delivering benefits.
- Pilot initiatives are important to develop learning, but this must be mainstreamed if they are to generate long-term benefits.

In the plenary discussion, additional points were:

- The social implications for natural flood management are extensive. Considerations were suggested for paying or incentives for relevant stakeholders or landowners can mitigate impact from downstream flooding.
- There is a need for a better integrated control system that balances the voluntary measures and incentives based on the water framework objectives.

Summary/Final comments

- The WFD has been with us now for over 20 years, and some aspects concerning hydromorphology still need further consideration and transposed into Irish legislative framework.
- The EPA have been developing a new tool for assessing hydromorphological condition over the last number of years called the Morphological Quality Index that is based on an Italian method. It has been rolled out across the country and aligned with the WFD status.

End of the meeting

The meeting was closed at 13:30 with a thanks to all those who participated.

Final Reflections by organisers of the workshop

The meeting was attended by a good cross-section of interested stakeholders, also recognising that some key stakeholders who were invited could not attend. It is also worth bearing in mind that the views expressed should be considered as those of the participants and not necessarily representing those of the organisations that the participants may be employed by. Some participants were rightly cautious about views being expressed on behalf of others.

The concept of reference condition for hydromorphology is difficult, and many human built structures are very old (c.f. water mills, weirs, fords). Practically this means that a common-sense approach in considering how the reference concept is applied is important. This difficulty is not unique to hydromorphology but applies to the wider definition and understanding of reference states and has been subject to much discussion.

A view, or need that came out of the meeting, was that generally there could be greater water literacy in the country, an emphasis needed on the catchment approach and that things are interconnected. This includes a need for a focus on hydrology as well as morphology. This is clearly part of the definition of hydromorphology in the WFD and is outlined in Annex 1 of this report. Hydrology can be of particular importance in upstream high-quality water bodies.

The Morphological Quality Index is a desk-based approach done through GIS. The previous project and technique that led to the RHAT was site-specific. Reference was made to EPA project 2019-W-MS-45 “Biological Tools to measure impacts of flows and Ecology in Irish Rivers.” These and other projects, including those that are ongoing should be useful for developing regulatory schemes.

Many hydromorphological pressures arise from land-use and agriculture, and how to interact with the sector for common purpose, and the further need for a policy framework to help with that, is a key need. Greater links and advice to and from the ASSAP programme can be useful here. The SWELL project “Living with Water” was referred to as relevant.

There are clearly many more topics important to the views of hydromorphology and its assessment that could have been discussed. The workshop, however, provided an important and stimulating sharing of views, and the organisers were very appreciative of the time and effort that participants put into the day.

Sustainable Water Network

SWAN