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River Restoration

A strategic approach to planning and management

Part of a series on strategic water management

River Restoration

A strategic approach to planning and management

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Published in 2016 by the United Nations Educational,
Scientific and Cultural Organization
7, place de Fontenoy, 75352 Paris 07 SP, France

ISBN 978-92-3-100165-9

Website: www.unesco.org

Layout: Marie Moncet
Printed by UNESCO
Printed in Paris, France

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Citation

Speed, R., Li, Y., Tickner, D., Huang H., Naiman, R., Cao, J., Lei G., Yu, L., Sayers, P., Zhao, Z. & Yu, W., 2016. River Restoration: A Strategic Approach to Planning and Management. Paris, UNESCO.

Acknowledgements

This book has been drafted as part of an extended dialogue that took place between 2012 and 2015, between a team of international experts led by the World Wide Fund for Nature (WWF) and a Chinese policy team led by the General Institute of Water Resources and Hydropower Planning and Design (GIWP), Ministry of Water Resources, People's Republic of China.

The team from GIWP was led by Professor Li Yuanyuan, and has included Li Jianqiang, Huang Huojian, Cao Jianting, Yu Lili, and Zhao Zhongman. The international team included Lei Gang (WWF, China), Dave Tickner (WWF, United Kingdom), Wei Yu (WWF, China), Catherine Moncrieff (WWF, United Kingdom), Paul Sayers (Sayers and Partners, United Kingdom), Robert Speed (Okeanos Pty Ltd, Australia), Guy Pegram (Pegasys Strategy and Development, South Africa), Robert J. Naiman (University of Washington, US), and Stuart Bunn (Griffith University, Australia).

In addition to the lead authors and team members, this book has benefited from contributions by Nina Saxton (research towards the writing of chapters 2 and 11); Phil Weller, Walter Binder, Klaus Arzet (insights into Danube and Isar experiences); Clare Wilkinson and Neha Mittal (support on research and data); Martin Janes (information on UK and EU river restoration experiences); Kate Hodge, Hodge Environmental (graphic design).

The book drew on a series of global case studies on river restoration prepared by Nina Saxton (Southeast Queensland Catchments, Australia); Robert J. Naiman (Columbia River, US); Liao Kuei-Hsien (Singapore); Peter Batey (Mersey River, UK); Hyoseop Woo and Sun-Uk Choi (South Korea); Dave Tickner (Danube River); and Jose Antonio Rodriguez Tirado (Santiago River, Mexico).

The book also benefited from reviews by Martin Janes, Managing Director, the River Restoration Centre and Phillip Weller, Water Program Coordinator for the International Association of Water Supply Companies in the Danbue River Catchment Area.

Principal funding for the project was provided by HSBC through the HSBC Water Programme.

References

For the Chinese case studies referenced in this book, much of the material relies on contributions made by members of the GIWP team based on documents that are not publicly available. In these instances, the source of the material is referenced as 'GIWP'.

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ISBN 978-92-3-100165-9

Executive summary

Human development has resulted in a significant decline in the health of rivers globally. This is in turn impacting the many benefits that rivers provide to society — that is 'ecosystem services'. Population growth, urbanization and climate change, among other factors, are expected to place further pressure on river ecosystems over coming decades.

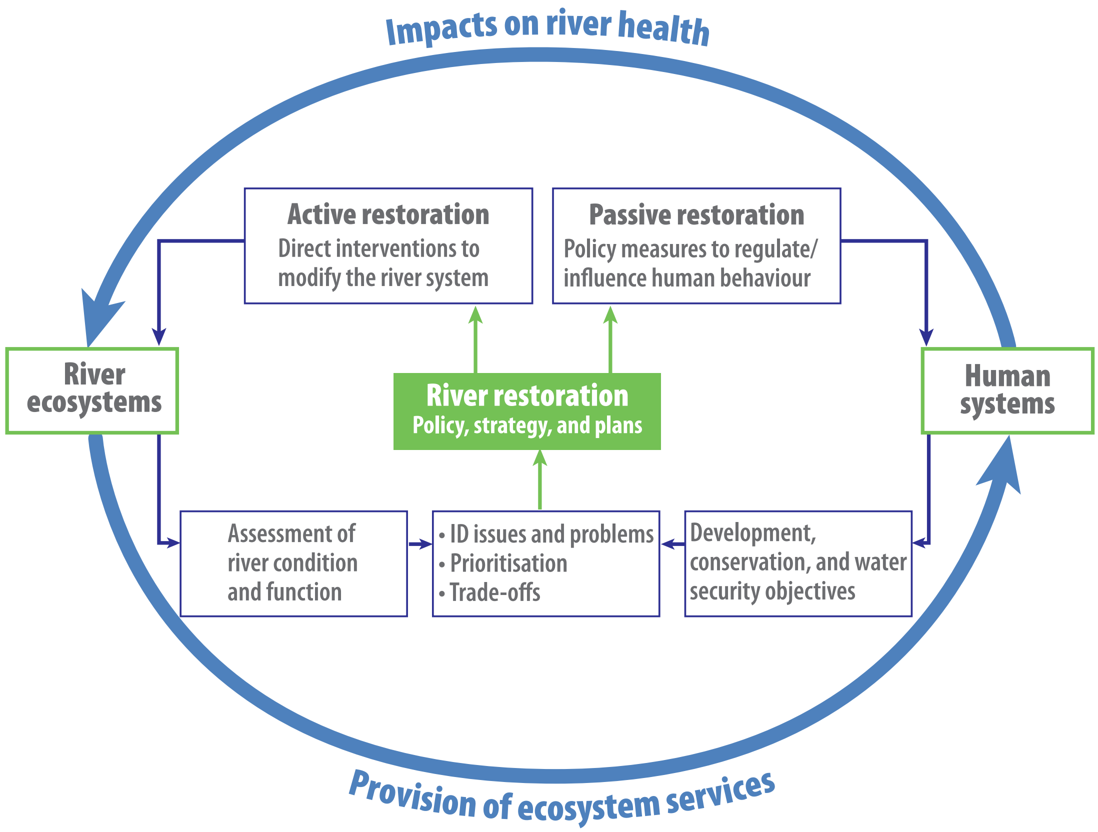
'River restoration' is now a common response to declining river health and its importance to water resources management can only be expected to grow. River restoration includes any action aimed at improving the health of a river, including improving ecosystem function and any related ecosystem services. This book defines river restoration as:

> *Assisting the recovery of ecological structure and function in a degraded river ecosystem by replacing lost, damaged or compromised elements and re-establishing the processes necessary to support the natural ecosystem and to improve the ecosystem services it provides.*

River restoration is necessary where river systems have degraded to the point where they can no longer provide the services required of them. Restoration may be triggered by ecological considerations, social and cultural factors, economic drivers, the need to protect infrastructure and assets from water-related risks and, increasingly from the multi-faceted objective of achieving 'water security'.

River restoration is an important part of the water resources management system. It can assist with balancing the needs of people for freshwater ecosystem services with anthropogenic pressures on river ecosystems. This requires an understanding of the relationship between the way a river functions and the demands and impacts people have on the river. River restoration has evolved over time from one dimensional responses aimed at addressing a single issue (e.g. water quality), to more sophisticated approaches that address multiple drivers and can involve both active restoration – physically changing the river or landscape – and passive restoration, which involves policy measures designed to change human behaviour (Figure A).

Figure A. The relationship between river restoration, river ecosystems and human systems



Challenges for modern river restoration

River managers face significant challenges in restoring river ecosystems. These challenges include:

1. **Returning rivers to a natural state is not feasible in most situations.** Traditional approaches to river restoration have relied on the use of natural rivers as a benchmark. The degree of change in river basins around the world means that in many cases returning rivers to a pre-development condition is now physically or economically impractical.
2. **Balancing the multiple roles of a river.** River restoration is now often required to achieve multiple objectives, by balancing the natural functions of the river with specific human needs, which can require trade-offs in the planning process.
3. **Complexity and scale.** Many restoration projects have failed as a result of tackling issues at the wrong spatial scale, often failing to consider basin-level processes. Operating at a larger scale requires consideration of a greater number of issues, engagement with a wider range of stakeholders and linking to a wider range of planning and management instruments.
4. **Increasing uncertainty over future conditions.** The gross uncertainty over the future of river basins makes it challenging to ensure that restored rivers are suited to the future world. Among other factors, uncertainty exists around changes in climate, land use, population growth and urban development.

A strategic approach

Increasingly, ad hoc or small-scale river restoration interventions are unlikely to be able to respond to these challenges. Rather, the dynamic and complex nature of river ecosystems requires a more strategic approach. This requires:

- a systems-based approach, recognising physical, socio-economic, political and cultural aspects of the connected river and human systems
- a greater role for river restoration planning in balancing trade-offs within the basin
- an adaptive approach, which tests the assumptions that underpin restoration efforts and allows for changes to goals and approaches over time.

Restoration strategies need to identify and respond to the links between external drivers, catchment and river processes, river health and the provision of ecosystem services and societal priorities. (Figure B).

River restoration can be supported by a combination of policies, strategies and project-level plans (Figure C). These different instruments should be aligned and develop synergies with one another, as well as with other regulatory and planning instruments. This includes river basin, development, and conservation plans.

Setting goals and objectives and developing a strategy

A restoration strategy should identify a long-term vision for the river basin, the desired outcome of the strategy over the planning horizon (goals), and specific, measurable targets to be achieved over the short to medium term (objectives). Goals and objectives should be framed, as much as possible, in terms of measurable changes to ecosystem function, the provision of ecosystem services, and desired socio-economic benefits.

Developing a strategy for action requires an iterative process of considering potential goals together with options for action (Figure D). This requires a consideration of:

- the current condition of the river system, its historical trajectory, and the likely future state of the system
- priorities for, and demands on, the basin, including those related to socio-economic development and ecosystem conservation
- feasibility of different options and potential constraints, such as limitations as a result of budget, capacity, political will, or institutional mandate
- the appropriate scale at which to intervene
- the effectiveness of different measures
- the efficiency of different measures
- the approaches that are more likely to be sustainable over the medium to long term.

Figure B. River restoration conceptual framework

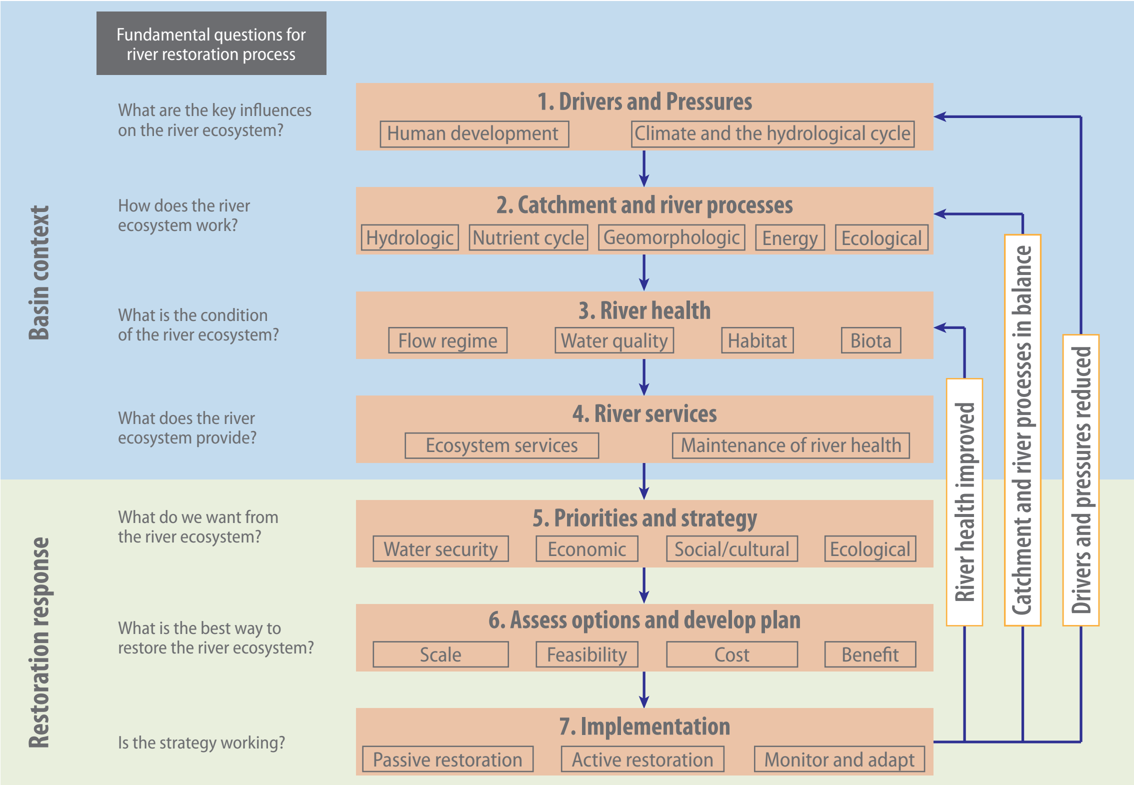


Figure C. River restoration planning hierarchy, showing linkages between restoration policy, restoration strategies and restoration project plans

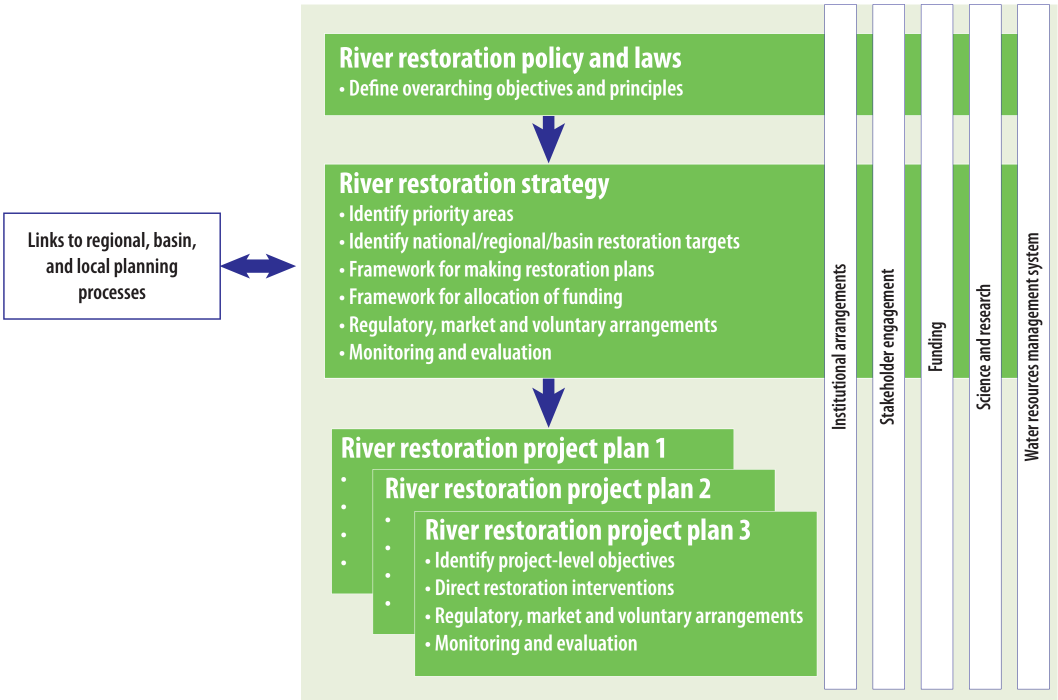
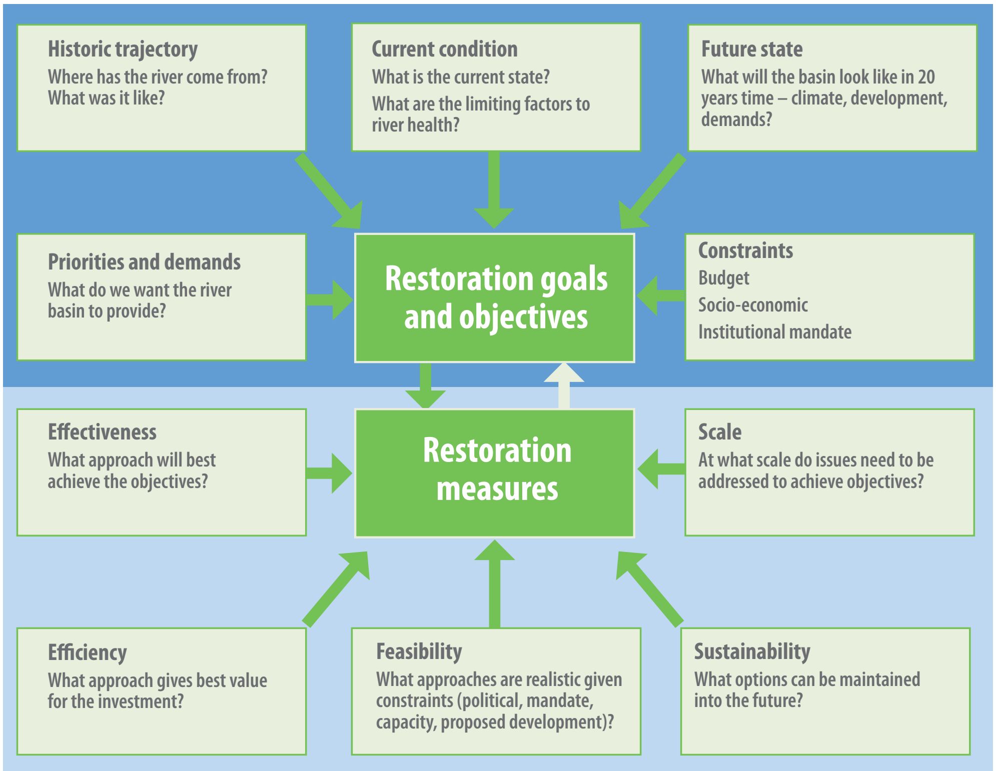


Figure D. Considerations in selecting restoration goals, objectives and measures



Measures for river restoration

There are many potential measures that can be implemented as part of a restoration strategy (Table A). Restoration measures can be classified based on the element of the river ecosystem that is the primary focus for river restoration. Restoring one element of the ecosystem (e.g. improving flows) can, of course, have significant impacts on other aspects of the system.

Monitoring and adaptive management

Monitoring against defined and measurable objectives is critical for assessing the effectiveness of river restoration measures and for guiding adaptive management. Monitoring programmes should validate (or disprove) the scientific assumptions that underpin the restoration strategy and should provide evidence about whether restoration projects have been successful.

Monitoring should be built into the design of river restoration projects at the start, and monitoring should begin at an appropriate time period before restoration actions begin. An appropriate scale of monitoring that will detect the impacts of restoration over a relevant timeframe is required and should continue long after the restoration actions have been 'completed'.

Table A. Typology of river restoration measures

Element of river ecosystem	River restoration measure	Used in river restoration to
Catchment	Catchment management	Alter the water, sediment, and other matter that enters the river channel
Flow regime	Flow modification	Change the volume, timing, frequency, and duration of flows
	Stormwater management	Alter the flow pattern of water running off from urban areas, e.g. altering flood peak
	Dam removal/ retrofit	Improve flows and ecological outcomes, including improving the movement of sediment and fish
	Floodplain reconnection	■ Reduce flood risk by increasing the capacity of the river system to store and release floodwaters ■ Allow for the movement of biota, sediment and other matter between the channel and floodplain ■ Increase assimilation of pollutants and groundwater recharge
Habitat (riparian)	Riparian management	Alter the water, sediment and other matter that enters the river channel; provide habitat; alter water temperature through shading; and support migration along the river corridor
	Land acquisition	Acquire riparian lands to control land use and/or allow for restoration works
Habitat (instream)	Instream habitat improvement	Promote or create habitat that supports biodiversity
	Bank stabilization	Reduce erosion/slumping of bank material into the river
	Channel reconfiguration	Altering the channel plan form or the longitudinal profile, increasing hydraulic diversity and habitat heterogeneity and decreasing channel slope
Water quality	Water quality management	Protect or improve water quality, including chemical composition and particulate load
Biodiversity	Instream species management	Protect or improve number/diversity of important species
Other	Aesthetics/ recreation/ education	Increase community value, such as by improving appearance, access, or knowledge

Financing river restoration

There can be significant financial costs and benefits associated with river restoration. Any analysis of river restoration options should consider who wins and who loses from each potential intervention. Options for financing river restoration include requiring the polluter, the beneficiary, or society (through taxation) as a whole to pay, or a combination of these.

Enabling environment

Beyond the specific technical and practical aspects of developing and implementing a river restoration strategy, there is a range of administrative, management, and other supporting elements that need to be considered. These include (Figure C):

- policies and laws to define the overarching objectives and principles for the restoration work, as well as to provide a head of power for certain actions
- institutional arrangements to establish the mandate and accountability for restoration, and to coordinate between different institutions
- stakeholder engagement to ensure different views are considered as part of the planning process and to strengthen political support, at all levels, for action
- funding to ensure that the financial resources are available to support implementation as well as to manage ongoing costs
- science, monitoring and research to provide a basis for rational decision making, as well as to assess compliance and impact (through monitoring) and to support adaptive management
- water resources management systems, to provide the tools for giving effect to elements of the restoration strategy, particularly through regulatory controls and other planning systems.

As well as providing a framework to support planning and implementation, these systems and processes can also be critical for ensuring the long-term sustainability of restoration efforts, for example, by ensuring long-term revenue streams to maintain or refresh capital works, by establishing appropriate institutional arrangements to ensure alignment with long-term development plans, and through regulatory arrangements that protect the gains made through restoration and avoid undermining of those efforts through ecologically harmful practices within the basin.

Golden rules of river restoration

Based on international experience, this book identifies eight 'golden rules' of strategic river restoration. They are:

1. **Identify, understand and work with the catchment and riverine processes.** Understanding the physical, chemical and biological processes that drive river health is critical to understanding the causes of declines in river health, the loss of ecosystem services and to identifying the most effective and efficient restoration measures. Restoration projects that work with, rather than against, natural processes are more likely to be self-sustaining.
2. **Link to socio-economic values and integrate with broader planning and development activities.** A strategic river restoration plan should recognize, incorporate and involve all of the existing strategies that affect the river, or are affected by it, to identify achievable objectives. Planning should reflect the priorities of different types of community while at the same time ensuring broad consistency with strategic objectives.
3. **Restore ecosystem structure and function by working at the appropriate scale to address limiting factors to river health.** Restoration measures need to respond to factors that are limiting river health wherever they may be. In most cases, coordinated delivery of planning, implementation and monitoring of restoration activities is required on a regional scale with local-scale delivery capabilities.
4. **Set clear, achievable and measurable goals.** Goals and objectives should be framed as much as possible in terms of measurable changes to ecosystem function, the provision of ecosystem services and, where feasible, socio-economic factors.
5. **Build resilience to future change.** Planning and implementation needs to consider likely changes in the landscape over time, including to the climate, land use, hydrology, pollutant loads and the river corridor. Given the gross uncertainty over future conditions, river restoration should aim to provide resilience to a range of scenarios.
6. **Ensure the sustainability of restoration outcomes.** River restoration strategies should be planned, implemented and managed with a view to achieving outcomes that are sustained over the long term.
7. **Involve all relevant stakeholders.** An integrated approach, addressing land and water issues, and involving inter-agency and community collaboration, is likely to achieve the best results.
8. **Monitor, evaluate, adapt and provide evidence of restoration outcomes.** Monitoring against defined and measurable objectives is critical as a means of guiding adaptive management.

Contents

About the authors 3

Acknowledgements 4

Executive summary 5

Acronyms 19

Glossary 20

Introduction 22

PART A. FRAMEWORK, PRINCIPLES AND ISSUES OF RIVER RESTORATION 23

CHAPTER 1. The Role of River Systems 24
- 1.1. The role of rivers in the natural environment 24
  - River ecosystem functions 24
  - The elements of a river ecosystem 27
- 1.2. The role of rivers in the human context 28
  - Freshwater ecosystem services 29
- 1.3. Issues and challenges 31
  - Major threats 31
  - Impacts on freshwater ecosystems and ecosystem services 34
  - Future challenges 34

CHAPTER 2. The Role of River Restoration **37**
- 2.1. Water resources management and the role of river restoration 37
- 2.2. What we mean by 'river restoration' 40
- 2.3. The need for river restoration 43
- 2.4. History and evolution of river restoration 45
  - River restoration in the United States 46
  - River restoration in Australia 48
  - River restoration in South Korea 49
  - River restoration in China 50
  - River restoration in Europe 51
  - River restoration in Singapore 53
- 2.5. Emerging challenges 54

CHAPTER 3. Framework for strategic river restoration **56**
- 3.1. Considerations and rationale for a strategic approach 57
- 3.2. Conceptual framework for strategic river restoration 58
  - Basin context 58
  - Restoration response 59
- 3.3. Planning hierarchy 60
  - Cross-cutting issues 62
  - River restoration and river basin plans 63
  - River restoration and other water plans 64
- 3.4. The different dimensions of River Restoration 65
- 3.5. Spatial scale 66
- 3.6. Time scale 67
- 3.7. Measures for river restoration 68
- 3.8. The Golden Rules of River Restoration 71

CHAPTER 4 Process and procedures for river restoration 73
4.1. Overview of the river restoration planning process 73
4.2. Situation assessment 75
Baseline assessment 76
Issues assessment 77
Trends assessment 78
4.3. Goals, objectives and developing the strategy 79
The iterative nature of strategy development 80
Setting goals 81
Defining objectives 83
Determining priorities for action 83
4.4. Content of a restoration strategy 84

CHAPTER 5. Monitoring and Adaptive Management 87
5.1. The role of monitoring, evaluation and adaptive management 87
5.2. Common challenges and problems for monitoring, evaluation and adaptive management of river restoration 88
5.3. Designing a monitoring and evaluation plan 90
What to monitor and evaluate 94
5.4. When to monitor and evaluate 95
5.5. How to monitor and evaluate 96
Project, programme and policy monitoring – higher-level indicators 96
Standard vs flexible monitoring protocols 97
Information sharing 97

CHAPTER 6. Costs, benefits and funding of river restoration 99
6.1. Costs of river restoration 99
The nature of river restoration costs 100
Estimating river restoration costs 100
6.2. Benefits of river restoration 102
The nature of river restoration benefits 102
Who benefits from river restoration? 104
6.3. Quantifying costs and benefits 104
6.4. Who pays, and how? 105
Sources of river restoration financing 105
Market mechanisms for river restoration: payments for ecosystem services 107
Challenges for financing river restoration 112

CHAPTER 7. Enabling Environment 113
7.1. Overview 113
7.2. Policy and legislation 114
7.3. Institutional arrangements and responsibilities for river restoration 116
International experience 118
7.4. Water resources and natural resource management 119
7.5. Stakeholder engagement 120

PART B. TOOLS AND TECHNIQUES 123

CHAPTER 8. River Health Assessment 124
8.1. River health and river health assessments 124
8.2. Objectives of a river health assessment and its role in river restoration 125
8.3. Framework and principles for assessing river health 126
8.4. Indicators of river health 131
8.5. Setting reference values 133
8.6. Management and operational issues 134
Site selection and sampling regime 134
Quality assurance procedures 135
Logistic issues 135

CHAPTER 9. Prioritising restoration measures and projects **136**
9.1. Introduction 136
Case study: using selection criteria to prioritize restoration in the Danube 138
9.2. Spatial and temporal scales 140
Spatial scale 141
Case study: Spatial prioritisation under South Africa's Working for Wetlands programme 141
Temporal scale 142
9.3. Approaches to prioritization 142
Case study: Prioritizing restoration sites in the Columbia River, United States 144
Case study: Prioritizing for multiple objectives in the Chesapeake Bay, United States 145
Case study: Optimising restoration in Southeast Queensland catchments, Australia 146
9.4. Prioritizing for ecosystem services 147
Prioritizing restoration in a semi-arid Mediterranean river basin 148
Prioritizing mangrove restoration based on ecosystem services 149

CHAPTER 10. Urban Water Management and Restoration of Urban Rivers **150**
10.1. Introduction 150
10.2. Evolution of urban water management 151
10.3. Urbanization and river health 152
Catchment processes 152
Flow regime 153
Water quality 153
Habitat 154
Aquatic and riparian biodiversity 154
Urban river syndrome 154
10.4. Special considerations in urban restoration 155
Challenges and opportunities 155
Understanding the system, drivers and stressors 155
Determining attainable goals 156
Engaging stakeholders 157
10.5. Measures for urban river restoration 158
Improving habitat 158
Protecting and enhancing biodiversity 159
Improving water quality and the flow regime 159

CHAPTER 11. Common measures for river restoration **161**
11.1. Introduction 161
11.2. Catchment management 164
Purpose of catchment management 164
The nature of catchment management 164
Considerations in applying catchment management 164
Further reference material 165
11.3. Flow modification 165
Purpose of flow modification 166
The nature of flow modification 166
Considerations in applying flow modification 167
Further reference material 167
11.4. Dam removal or retrofitting 167
Purpose of dam removal or retrofitting 167
The nature of dam removal or retrofitting 168
Considerations for dam removal or retrofitting 168
Further reference material 168
11.5. Stormwater management 169
Purpose of stormwater management 169
The nature of stormwater management 169
Considerations in applying stormwater management 169
Further reference material 170
11.6. Floodplain reconnection 171
Purpose of floodplain reconnection 171
The nature of floodplain reconnection 172
Considerations in floodplain reconnection 172
Further reference material 172

11.7. Riparian management 172
Purpose of riparian management 173
The nature of riparian management 173
Considerations in applying riparian management 173
Further reference material 174
11.8. Instream habitat improvement 174
Purpose of instream habitat improvement 174
The nature of instream habitat improvement 174
Considerations in applying instream habitat improvement 175
Further reference material 175
11.9. Bank stabilization 176
Purpose of bank stabilization 176
The nature of bank stabilization 176
Considerations in applying bank stabilization 176
Further reference material 177
11.10. Channel reconfiguration 177
Purpose of channel reconfiguration 177
The nature of channel reconfiguration 178
Considerations in applying channel reconfiguration 178
Further reference material 178
11.11. Water quality management 179
Purpose of water quality management 179
The nature of water quality management 179
Considerations in applying water quality management 180
Further reference material 180
11.12. Instream species management 181
Purpose of instream species management 181
The nature of instream species management 181
Considerations in applying instream species management 181
Further reference material 181

References 182

Figures, Tables and Boxes

List of Figures

Figure A. The relationship between river restoration, river ecosystems and human systems

Figure B. River restoration conceptual framework

Figure C. River restoration planning hierarchy, showing linkages between restoration policy, restoration strategies and restoration project plans

Figure D. Considerations in selecting restoration goals, objectives and measures

Figure 1.1. Six critical ecosystem functions

Figure 1.2. Rivers and the hydrological cycle

Figure 1.3. Key elements that contribute to the structure and function of a river ecosystem

Figure 1.4. Conceptual diagram of a river basin showing the freshwater ecosystem services provided by the basin

Figure 1.5. Examples of freshwater ecosystem services provided by a freshwater ecosystem

Figure 1.6. Threats and causes of decline in river health and their link to different elements of the river system

Figure 1.7. Conceptual diagram of a river basin showing threats to the river ecosystem

Figure 1.8. Living Planet Index for freshwater, showing a decline of 76 per cent between 1970 and 2010

Figure 2.1. The role of strategic water resources management in balancing the needs of human systems and demands on river ecosystems

Figure 2.2. The relationship between river restoration, river ecosystems and human system

Figure 2.3. The connections between science of restoration ecology and the practical application of that science as part of ecological restoration

Figure 2.4. One example of an approach to distinguishing between restoration, rehabilitation, and remediation

Figure 2.5. Comparison of ecosystem structure and function in an original river system, a degraded river system, and restored river systems, based on the definition of restoration adopted in this book

Figure 2.6. Common triggers for river restoration

Figure 2.7. Four phases in the evolution of river conservation and restoration

Figure 3.1. The adaptive nature of developing and implementing a river restoration strategy or plan

Figure 3.2. River restoration conceptual framework

Figure 3.3. River restoration planning hierarchy, showing linkages between restoration policy, restoration strategy, and restoration project plans

Figure 3.4. Hierarchy of restoration instruments in Spain

Figure 3.5. Strategic framework for restoration of the Avon River

Figure 3.6. Interface between development and conservation plans, the river basin plan and thematic plans, showing river restoration as one of the thematic plans giving effect to the basin plan

Figure 3.7. Interface between development and conservation plans, the river basin plan and thematic plans, showing the river restoration strategy as superior to the basin plan

Figure 3.8. Linkages between river restoration plans or strategies and other thematic plans

Figure 3.9. Relationship between the elements of a river ecosystem, different restoration measures, and the spatial scale at which interventions are made

Figure 3.10. Spatial scale relevant to different steps in the restoration planning process

Figure 3.11. Trajectories of degradation and restoration, showing changes in river health as stresses increase and then are alleviated by restoration measures. The arrows demonstrate change over time

Figure 3.12. Schematic showing relationship between different measures for river restoration and the elements of a river ecosystem

Figure 3.13. Breakdown of restoration projects based on the element of the river ecosystem that is most directly targeted by the project

Figure 4.1. The steps in developing and implementing a river restoration strategy

Figure 4.2. Steps in developing the Spanish River Restoration Strategy

Figure 4.3. Undertaking a situation assessment to inform river restoration planning

Figure 4.5. The process of assessing alternative futures in the Willamette River

Figure 4.6. Hierarchy of vision, goal, objectives, and actions under a basin plan

Figure 4.7. Hierarchy of vision, targets, plans, outcomes, and actions in the Southeast Queensland Healthy Waterways Strategy

Figure 4.8. The iterative process of prioritising outcomes and assessing options

Figure 4.9. Considerations in setting restoration goals and objectives
Figure 4.10. Considerations in deciding restoration measures and formulating a strategy
Figure 4.11. Typical content of a river restoration strategy
Figure 5.1. Adaptive management, often characterized as 'learning by doing'
Figure 5.2. Basic steps for establishing a monitoring and evaluation program for river restoration
Figure 5.3. The relationship between the types and purposes of monitoring and evaluation and the strategic framework for river restoration
Figure 6.1. Median costs in of river restoration interventions in the United States and Australia (US $)
Figure 6.2. Options for funding river restoration. Adapted from Holl and Howarth (2000)
Figure 7.1. Supporting systems and processes for river restoration
Figure 7.2. Organizational structure of the Mersey Basin Campaign
Figure 7.3. Role of stakeholders in the river restoration process
Figure 8.1. Framework for undertaking developing a river health assessment programme
Figure 8.2. Example conceptual diagrams showing links between river flows, geomorphology, vegetation, and maintenance of fisheries
Figure 8.3. Classification of the Taizi River basin
Figure 8.4. Ecosystem health report card for Southeast Queensland catchments
Figure 8.5. Examples of river health indicators relevant to different elements of a river ecosystem
Figure 9.1. Considerations in deciding restoration measures and formulating a strategy
Figure 9.2. The four steps in identifying and prioritising river restoration measures
Figure 9.3. Increase in habitat based on expenditure of USD $50m and $100m, depending on spatial and temporal scale used for prioritisation
Figure 9.4. Prioritisation of wetlands at different spatial scales
Figure 9.5. Framework for prioritizing projects in the lower Columbia River
Figure 9.6. Schematic showing grey and green options to reduce pollution, and links to ecosystem service indicators and the benefits to stakeholders from those services
Figure 9.7. Map of South East Queensland catchments showing the source of sediments entering Moreton Bay
Figure 9.8. Establishing priorities for restoration in SEQ
Figure 9.9. Number of overlapping ecosystem services per sub-basin (left) and number of overlapping hotspot services per sub-basin
Figure 9.10. Combined ecosystem services and environmental risk criteria as basis for establishing priority areas for restoration
Figure 10.1. Typology of different city states in transition towards sustainable urban water management
Figure 10.2. The water cycle in a forested catchment and an urbanised catchment
Figure 10.3. Impacts of urbanisation on the elements of a river system. The figure shows those factors that increase (Ý) or decrease (ß) as a result of urbanisation
Figure 10.4. Examples of best management practice in urban stormwater management
Figure 11.1. Conceptual model of a river basin, showing different river restoration measures
Figure 11.2. Number of U.S. river restoration projects based on type of restoration measure adopted
Figure 11.3. Number of EU river restoration projects based on type of restoration measure adopted
Figure 11.4. Number of river restoration projects in Victoria, Australia based on type of restoration measure adopted
Figure 11.5. The different components and ecological roles of a hypothetical hydrograph
Figure 11.6. The river channel in the Bishan-Ang Mo Kio Park before (top) and after (bottom) (image credit: Atelier Dreiseitl)

List of tables

Table A. Typology of river restoration measures
Table 1.1. Summary of primary activities affecting freshwater ecosystems and ecosystem services
Table 2.1. Evolution of definitions of restoration and rehabilitation
Table 2.2. Triggers, objectives and measures for river restoration in selected case studies
Table 2.3. Summary of works and budget associated with Korean Four Major Rivers Restoration Project
Table 3.1. Typology of river restoration measures
Table 4.1. Examples of general and specific river restoration objectives. Ideally, objectives should specific and measurable, rather than general in nature
Table 5.1. Example of monitoring plan, using the River Restoration Centre monitoring planning
Table 5.2. Satisfaction levels for the Taewha River, Korea in April 2004
Table 5.3. Definitions of monitoring types and examples of what might be monitored for a river restoration project targeting fish diversity and population.

Table 6.1. Average costs and removal efficiencies in the Chesapeake Bay restoration project for selected agricultural Better Management Practices
Table 6.2. Socio-economic benefits of river restoration interventions and their examples
Table 6.3. Techniques for evaluating costs and benefits of ecosystem restoration
Table 6.4. Sources of finance for river restoration
Table 7.1. Major policy, legislation and planning instruments relevant to river restoration in the Danube
Table 7.2. Institutional roles in river restoration and considerations
Table 7.3. River restoration programs in Korea by different agencies
Table 8.1. Categories of river health indicators
Table 8.2. The implications for site selection based on different program objectives
Table 8.3. Critical elements of a river health monitoring programme
Table 9.1. Information relevant to developing list of potential restoration projects
Table 9.2. Ideal and actual selection criteria used to select sites for restoration in the Danube River Basin
Table 9.3. Considerations in prioritising wetlands, based on different ecosystem services
Table 10.1. Examples of approaches and purpose for establishing riverine habita
Table 11.1. Common structures placed in rivers to improve fish habitat
Table 11.2. Potential water quality impacts of different restoration measures

List of boxes

Box 1: Key terminology
Box 2: The economic value of freshwater systems
Box 3: The human and economic cost of river degradation – the global experience
Box 4: Setting ecological red lines for rivers in China
Box 5: River restoration success stories
Box 6: Guidelines for river restoration planning in China
Box 7: International experience in aligning restoration plans, Spain
Box 8: Developing the Spanish National River Restoration Strategy
Box 9: A function-based approach to river restoration
Box 10: Identifying barriers to improved river health in the Spanish restoration strategy
Box 11: Alternative futures assessment for the Willamette River Basin, Oregon, United States
Box 12: Vision, targets, outcomes, and actions in the Southeast Healthy Waterways Strategy and the Columbia River Restoration Programme
Box 13: Goals for river restoration: examples from the global experience
Box 14: Prioritising restoration actions
Box 15: Examples of the content of restoration strategies and plans
Box 16: Definitions of monitoring, evaluation and adaptive management
Box 17: Adaptive management of biological systems – a review
Box 18: Structure decision-making and adaptive management
Box 19: Citizen science and river restoration
Box 20: Lower Danube Green Corridor economic analysis
Box 21: Dam removal on Elwha River, Washington, United States
Box 22: Principles for effective PES schemes
Box 23: Eco-compensation in the Xin'an River Basin, China
Box 24: Financing restoration in the Breede River catchment
Box 25: Common challenges for river restoration projects
Box 26: Policy and institutional arrangements to support river restoration in China
Box 27: Funding local organizations to coordinate strategic restoration
Box 28: Water entitlements and the Commonwealth Environmental Water Holder
Box 29: Examples of community engagement and voluntary action in river restoration
Box 30: Setting objectives for a river health assessment: the Yellow River, China
Box 31: Using conceptual diagrams in river health assessments
Box 32: Selecting indicators of ecosystem health in Southeast Queensland
Box 33: River classification in the Taizi River to support river health assessments
Box 34: Assessing the results and preparing a report card in Southeast Queensland as part of an ecosystem health monitoring programme
Box 35: The use of national frameworks for river health assessment
Box 36: Water quality standards in China
Box 37: Impacts of scale on prioritisation and cost-effectiveness in the Basin, United States
Box 38: Urbanized catchments
Box 39: Benefits of water sensitive urban design
Box 40: A holistic approach to conservation in an urban water river: the case of the Etowah River, United States
Box 41: Best management practices for urban stormwater management
Box 42: Existing river restoration guidelines and manuals

Box 43: Case studies – Improving water quality in the Great Barrier Reef and managing invasive weeds in South Africa
Box 44: Case Study – Murray–Darling Basin buy-back scheme
Box 45: Case studies – Lower Penobscot (Maine, United States) and Elhwa River (Washington, United States)
Box 46: Case study – Bishan-Ang Mo Kio Park, Singapore
Box 47: Case study – Yangtze River Basin
Box 48: Case study – Riparian re-vegetation in the Willamette River Basin, Oregon, United States
Box 49: Case study – Murray–Darling Basin, Australia
Box 50: Case study – Willow spilling, United Kingdom
Box 51: Case study – Isar River, Germany
Box 52: Case study – Mersey River, United Kingdom
Box 53: Case study – Reintroduction of beavers (Scotland) and anadromous fish (New York City)

Acronyms

ABC	Active Clean Beautiful (ABC Waters Programme, Singapore)
AM	Adaptive management
EHMP	Ecosystem health monitoring program (Southeast Queensland, Australia)
EIA	Effective impervious area
EPA	Environmental Protection Agency
EU	European Union
FRM	Flood risk management
GIWP	General Institute of Water Resources and Hydropower Planning and Design, Ministry of Water Resources, People's Republic of China
HLI	High-level indicator
ICPR	International Commission for the Protection of the Rhine
KICT	Korean Institute of Construction Technology
MWR	Ministry of Water Resources (China)
PES	Payment for ecosystem services
PUB	Public Utilities Board (Singapore)
SDM	Structured decision-making
SEQ	Southeast Queensland (Australia)
SUWM	Sustainable urban water management
TIA	Total impervious area
UWWT	Urban Waste Water Treatment
WFD	Water Framework Directive (EU)
WSUD	Water sensitive urban design
WWF	World Wide Fund for Nature

Glossary

Adaptive management	A structured, iterative process of robust decision-making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring
Catchment	See river basin
Ecosystem	A system that includes all living organisms in an area as well as its physical environment functioning together as a unit
Ecosystem structure	The composition of the ecosystem and the physical and biological organization defining how those parts are organized. For example, different plant and animal species are considered a component of an ecosystem and therefore part of its structure. The relationship between primary and secondary production is also part of the ecosystem structure, as this reflects the organization of the parts.
Ecosystem function	The different physical, chemical and biological processes that occur as a result of the interactions of plants, animals and other organisms in the ecosystem with each other or their environment. These processes include decomposition, production, nutrient cycling and fluxes of nutrients and energy. Ecosystem structures and functions, together, provide **ecosystem services**.
Ecosystem services	The benefits people obtain from ecosystems. These include: ■ **Regulatory services**: benefits obtained from the regulation of ecosystem processes. ■ **Provisioning services**: products obtained from ecosystems. ■ **Supporting services**: ecosystem services that are necessary for the production of all other ecosystem services. ■ **Cultural services**: nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.
Environmental flows	Environmental flows describe 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.
Integrated water resources management	A process that promotes the coordinated development and management of water, land and related resources to maximize the resulting economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

River basin The land area that is drained by a river and its tributaries. In some jurisdictions the terms 'watershed' or 'catchment' are used. This book uses 'river basin' and 'catchment' interchangeably. A sub-basin or sub-catchment refers to a geographical basin within a larger basin.

River basin plan A plan to coordinate and develop the water uses of a basin in harmony with other development processes both within and outside the basin.

River corridor A river and the land adjacent to it, including the talus slopes at the bases of cliffs, but not the cliffs themselves.

River ecosystem The ecosystem of a river, consisting of both living (biotic) and non-living (abiotic) components of a river and the riparian zone, and the interactions between those components.

River health The overall state or condition of a river. Good river health is often equated with biological integrity. Biological integrity can be defined as the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a composition and diversity comparable to that of the natural habitats of the region. River health will reflect the ecosystem structure and function and the ecosystem services provided by the river.

River reach A segment of a stream, river, or ditch generally defined from confluence to confluence, or by some other distinguishing hydrologic feature. Typically, this segment will consist of a length of channel that is uniform with respect to discharge, depth, area and slope.

River restoration Assisting the recovery of ecological structure and function in a degraded river ecosystem by replacing lost, damaged or compromised elements and re-establishing the processes necessary to support the natural ecosystem and to improve the ecosystem services it provides.

Water allocation plan An instrument – usually issued by government or a government agency – that defines the water available for allocation and sets out the rules for managing the take and use of water resources. The plan may allocate water directly to regions or sectors. Alternatively, it may define a process for allocating the available resources.

Introduction

This book is the result of a collaborative effort between the World Wide Fund for Nature (WWF) and the General Institute of Water Resources and Hydropower Planning and Design, Ministry of Water Resources, People's Republic of China (GIWP). GIWP has been tasked with coordinating a major programme of work to improve the condition of small and medium-sized river basins in China. Many of these rivers have become severely impacted as a result of pollution, over-abstraction of water, dredging and other works within the channel and adjoining floodplain. This book was originally conceived to provide support to the planning and management of China's river restoration programme by reviewing approaches to river restoration and identifying frameworks and methods suitable to the Chinese situation. The content is, however, considered to be universally applicable.

This book is part of a series on strategic water management. Other topics covered as part of the series include strategic basin planning, basin water allocation, flood risk management and drought risk management.

Definitions of 'river restoration' have evolved significantly over time, and there are differing views of what should be considered as the restoration of a river ecosystem. In this book, a broad view of the term is adopted. River restoration is considered to include any action aimed to improve river health, including improving ecosystem function and any of the related ecosystem services. Definitions of river restoration are discussed further in section 2.2.

There are of course many different aspects of river basin and water resources management that contribute to improving river health. Indeed, given the poor condition of rivers globally, in most instances many, if not most, water resources management plans incorporate some components that aim to restore river health. These components include reducing or removing factors that have a negative impact on the river system, such as controlling the discharge of pollutants, and active intervention to improve river health, such as manipulating habitat structure and water flow. Restoration can address invasive species, or to reinstate or invigorate native species. River restoration can also aim to improve the amenity values of rivers. This book looks at the full suite of responses available to river managers for improving river health.

The book aims to identify the principles, procedures, and approaches that most commonly underpin restoration efforts. It is designed to distil the lessons from international experience and provide guidance for those undertaking river restoration programmes. The book is not designed to replace the many detailed technical manuals that exist for designing and implementing river restoration at the project level (see for example FISRWG, 1998 Rutherfurd *et al.*, 2000; or RRC, 2013 and see also Box 42). Rather, the book focuses on the strategic aspects of programme design, including the linkages between river restoration, basin planning and management processes and how restoration activities can be incorporated into or aligned with broader water management activities and objectives. In addition, the book considers river restoration in the context of heavily modified, and often significantly degraded, river systems where restoration is most commonly focused on balancing ecosystem functions and human needs.

Finally, in considering river restoration issues, and taking a basin-wide view of management actions, this book details restoration of the river corridor. While land use changes are significant factors affecting rivers, for reasons of concision and practicality, this book focuses mainly on river corridor restoration rather than the much broader issue of land-use and river health. The book also touches on restoration efforts for lakes and wetlands, but these freshwater systems are not its major focus.

This book consists of two parts:

- Part A provides an overview of the history and evolution of river restoration, it sets out a framework for planning and implementing river restoration, and it addresses some key principles, issues and methods for restoring rivers in the wider context of water resource management and river basin planning.
- Part B includes more detailed discussion of techniques and approaches to river restoration, including chapters on assessing river health, prioritising restoration projects, restoration of urban rivers, and river restoration measures.

PART A

FRAMEWORK, PRINCIPLES AND ISSUES OF RIVER RESTORATION

CHAPTER 1
THE ROLE OF RIVER SYSTEMS

OVERVIEW AND KEY MESSAGES

This chapter describes the role rivers play in the natural landscape as well as their role in providing a range of benefits to society. It includes a summary of the threats to rivers, the resulting impacts for ecosystems and society and related challenges. Key messages from the chapter are:

- Rivers are highly dynamic systems. These systems involve a large number of basin-scale processes that influence river flows, water quality, the structure of the river channel and aquatic and riparian biota.
- Rivers provide significant benefits to people, including water for consumption, transport corridors, flood mitigation, energy for hydropower production and waste assimilation. These benefits are referred to as ecosystem services. As rivers degrade, they lose their capacity to provide many of these services.
- Human development has resulted in a significant decline in the health of many rivers. River ecosystems are among the most threatened ecosystems in the world. Population growth, urbanization, and other factors are expected to place further pressure on river ecosystems over the coming decades.
- Understanding the complex physical, chemical and biological processes that drive river health is critical for understanding the causes of declines in river health and the provision of ecosystem services, and for identifying the most effective and efficient restoration measures. Such an understanding is also vital to ensure that the potential benefits of a healthy river system and associated ecosystem services are fully recognized.

1.1. The role of rivers in the natural environment

Rivers are an integral part of the natural landscape. As conduits for water, sediments and other matter as they move down the river basin, rivers both drive and are a consequence of a range of fundamental, inter-related natural processes (Harman, 2012). The combination of these processes give rise to what we recognize as rivers and other freshwater ecosystems: the river channel and the water within it, floodplains and lakes, and the plants and animals that live in and around those systems.

RIVER ECOSYSTEM FUNCTIONS

Rivers ecosystems perform a number of critical ecosystem functions.[1] These functions include:

- Acting as a conduit: Rivers provide a pathway for transporting energy, materials and organisms. This pathway allows the movement of water, but also sediment, organic matter, nutrients, seeds and biota. Rivers also allow the movement of energy, including mechanical energy, as a result of gravity-

1. For definitions of ecosystem functions and related terms, see **Box 1**.

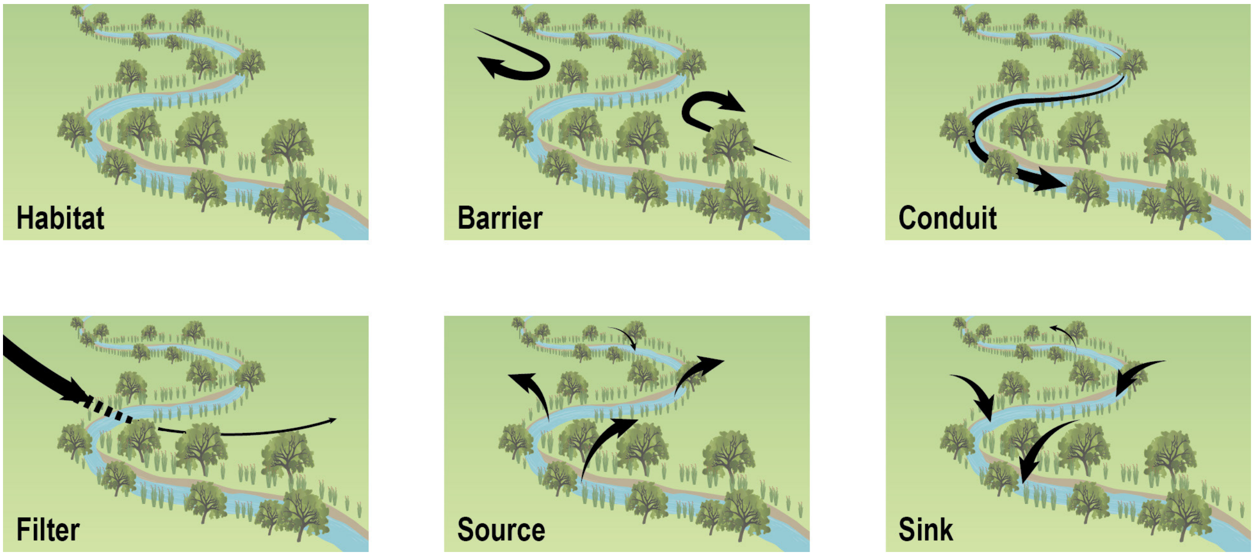
based motion; heat energy, for example absorbed through sunlight; and chemical energy in the form of organic matter.

- Acting as a barrier and a filter: Rivers can slow or stop the movement, or allow the selective penetration, of energy, materials and organisms. In addition to directing and retaining water, rivers can limit the movement of water-based pollution, sediment and other materials, as well as chemically transforming carbon and nutrients.
- Acting as a source and a sink: Rivers contribute energy, materials, and organisms to the surrounding landscape, as well as acting as a sink. For example, floodplains and their associated vegetation may provide a sink for water or sediments during flooding, but they can also be a source of soil organic matter.
- Provision of habitat: Rivers provide the physical environment in which species live, reproduce, eat and move. Some species may spend their entire life within a particular river; others may use a river for reproduction, or as a source of food or water. Terrestrial animals may use river corridors for migration. Habitat functions exist at a range of scales, and different habitats can be found in the riverbed and banks, pools and riffle zones, lakes and floodplains, and the riparian zone (FISRWG, 2001; also see Figure 1.1).

These functions can rely on any and all of the various parts that make up a river ecosystem. Notably, riparian zones are an integral part of rivers, and act in concert with the river channel to establish the vitality of the system (Naiman *et al.*, 2005).

The way and extent to which a river ecosystem performs these functions will depend on its physical structure, the inputs and outputs to and from the system, and the various processes that occur within the river ecosystem. The relationship between these different elements of a river is discussed further in this chapter.

Figure 1.1. Six critical ecosystem functions

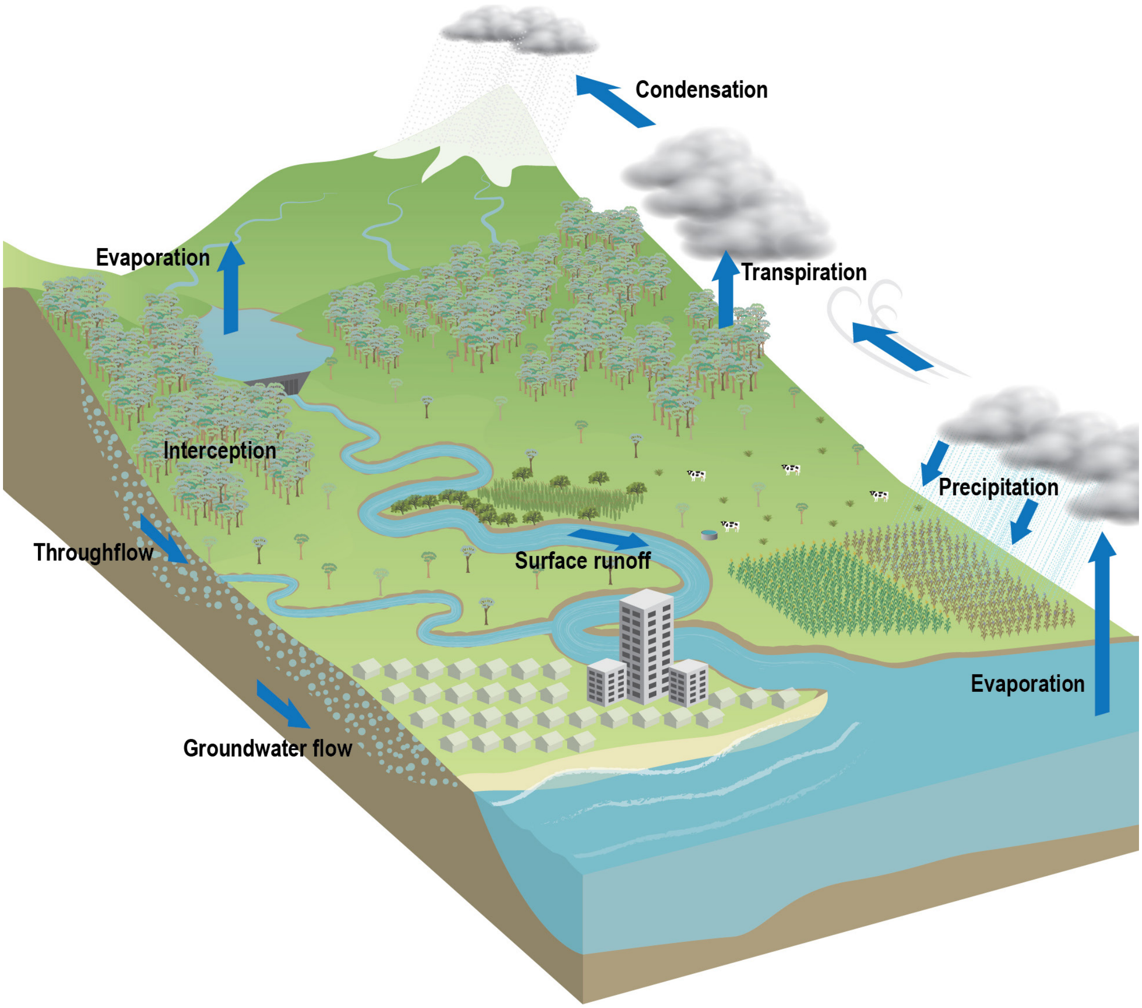


Source: Adapted from FISRWG, 1998

Rivers play a key role in the hydrological cycle as well as being fundamentally influenced by the cycle (see Figure 1.2). A river's hydrology is driven by the precipitation, infiltration, evapotranspiration and runoff within its catchment. These elements provide the water and energy, which in turn drive many of the fluvial processes. At the same time, river networks provide the pathway for surface runoff and, in some instances, groundwater flow to move down the catchment to terminal lakes, estuaries, and the sea.

The river network and channel morphology are primarily determined by interactions between the landscape and the flow of water through the catchment from higher to lower elevations (Knighton, 1998). The interactions involve the entrainment, transport and deposition of erodible material from the channel boundaries, shaped by the potential energy in the river system created by the change in elevation from the top to the bottom of the system (Schumm, 1984). This potential energy develops a complex fluvial network as the river moves through the landscape. Excess energy is dissipated by many means, including contact with instream and channel bank vegetation, turbulence in the river profiles, erosion at meander bends and, most importantly, through the transport of sediment (Kondolf, 2002).

Figure 1.2. Rivers and the hydrological cycle



The nature and outcome of these processes varies significantly between and within rivers. For example, an upland river will typically have a steeper bed slope and faster flow, which can transport cobbles and gravels along the bed, creating a more diverse habitat. Fine sediments are usually carried downstream, resulting in lower turbidity in upland rivers. Nutrients are also usually lower as a result of limited opportunities for benthic vegetation production and decomposition due to a narrow channel width and shade from riparian vegetation.

In contrast, lowland rivers are more likely to have a low bed slope and wider channel with slower flow velocity and usually a more sinuous longitudinal profile. Erosion and deposition are usually in dynamic equilibrium in this zone of a river, at least in a healthy system, and bed materials are smaller, with the deposition of fine silts and clays from the upper catchment and through erosion of bank material. Nutrient concentrations are typically higher as benthic and emergent vegetation are more likely to have sufficient light to establish along the riverbed and at the margins of the channel due to a wider channel and less shade from riparian vegetation (Acuna *et al.*, 2013).

The hyporheic zone, an active ecotone at the interface between rivers and groundwater, plays a critical role in maintaining river health. Within the zone, the upwelling of subsurface water can be a source of nutrients and downwelling of river water can provide oxygen and organic matter, both of which contribute to maintaining water quality and healthy biota (Boulton *et al.*, 1998).

Many species rely on rivers to survive, and rivers and adjacent riparian areas are some of the most highly productive, diverse and complex habitats (Naiman *et al.*, 1993). High levels of biodiversity occur in response to the dynamic nature of river systems and the interaction between aquatic and terrestrial environments during high and low flow events (DéCamps *et al.*, 2004). Importantly, rivers are integrated systems, and instream and riparian communities along the length of a river share a close connection with and strong dependence on the multiple processes that occur throughout a river system and that drive the form of the river channel, the hydrological cycle of the catchment and the transport of energy, materials and species (Vannote *et al.*, 1980).

THE ELEMENTS OF A RIVER ECOSYSTEM

While basin characteristics vary from one region to another, all river basins support common physical, chemical and biological processes (the ecosystem functions of the basin) and are made up of a common set of physical and biological components (the ecosystem structure of the basin) that constitute the river ecosystem (Harman *et al.*, 2012). This book considers these characteristics in terms of five distinct, but related, elements.

1. **Catchment processes** drive the creation of the major inputs into a river. The interaction between the hydrological cycle and the topography, geology and vegetation within a basin, along with land use practices, all influence catchment-scale processes such as the infiltration and runoff of water and the generation of sediment, carbon, nutrients, and other chemicals and their movement via the river system. Catchment processes determine the composition and timing of the water, energy and materials that enter the river channel.
2. These factors strongly influence the instream **flow regime,** which is primarily a product of the catchment runoff that collects within the river corridor, as well as surface, groundwater and hyporheic interactions. The flow regime describes the magnitude, timing, frequency and duration of flows in the river basin.
3. The flow regime is a major driver of the geomorphic processes that shape the physical structure of the river system, and therefore the creation of different **habitats** across the river corridor: riffles, ponds, floodplains, hyporheic zones, riparian zones and the river channel itself. The interaction of the physical structure of a river ecosystem and the flow regime also create the pattern of hydraulic habitat and influence connectivity – that is, the extent to which water, biota, sediment and other materials can move up and down the river channel (longitudinal connectivity) and move between the river channel and the flood plain (lateral connectivity).
4. Instream **water quality** is primarily a consequence of the inputs from the upstream catchment and the riparian zone, the nature of flow regime, the physical structure (including the soil properties) of the river itself, and its interactions with the hyporheic zone. Together these inputs determine the physical and chemical characteristics of stream flow, including the sediment chemistry, water temperature and levels of nutrients and toxins.
5. Finally, the **aquatic and riparian biodiversity** within a river system will depend on, and develop in response to, the flow regime, the water quality, and the available habitat, as well as the species pool that is available for colonization. These factors will shape the abundance, diversity and composition of plants, animals and microorganisms within a river ecosystem.

These elements of a river ecosystem[2], and the relationship between them, are shown in Figure 1.3. The figure shows a rough hierarchy of drivers and responses. Some responses are also drivers of other processes. Further, while the figure shows the primary direction of influence between different processes and components, there can also be influences in the other direction. For example, aquatic and riparian biodiversity will be significantly influenced by catchment processes, the flow regime, the available habitat, and the water quality, but can also influence those same elements. For example, riparian vegetation can trap sediment and organic matter and prevent it entering the river channel, affecting both habitat and water quality, or influence water temperature as a result of shading.

Each of these elements capture physical and biological aspects of a river ecosystem and therefore are part of the river's ecosystem structure. In addition, they also involve interactions or processes within or between those parts and are also part of the river's ecosystem functions (see Box 1). These elements give rise to rivers, and allow river ecosystems to perform the critical functions described. River ecosystems also play a central role in supporting human civilization.

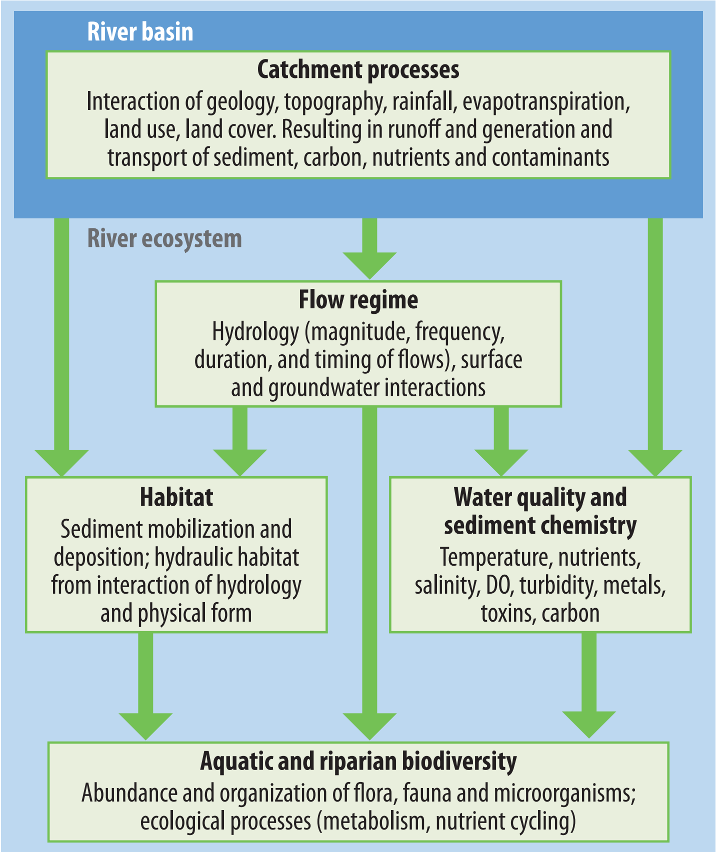
Box 1: Key terminology

There are a variety of terms used to describe different aspects of a river, and different terms are sometimes used in different ways. This box defines some of the most commonly used terms in this book, and the way they relate to each other.

- River ecosystem refers to both the living (biotic) and non-living (abiotic) components of a river and the riparian zone, and the interactions between those parts.
- Ecosystem structure refers to the composition of the ecosystem and how it is organized – that is, the parts that make up an ecosystem (such as a river ecosystem) and the way they are put together.
- Ecosystem function refers to the different physical, chemical, and biological processes that occur as a result of the interactions of plants, animals and other organisms in the ecosystem with each other or their environment, including decomposition, production, nutrient cycling and fluxes of nutrients and energy.
- The ecosystem structure and associated functions allow an ecosystem (such as a river) to provide ecosystem services, which are the benefits people derive from the river.
- River health refers to the overall ecological condition of a river, and reflects the combination of the ecosystem structure and function and the ecosystem services provided by the river.

2. The catchment processes do not strictly form part of the river ecosystem, but are an external input to the river ecosystem that for the purposes of this book is limited to the river corridor. Therefore, catchment processes are shown as part of the river basin.

Figure 1.3. Key elements that contribute to the structure and function of a river ecosystem



Source: Adapted from Gippel and Speed, 2010.

1.2. The role of rivers in the human context

For millennia, human populations have settled close to major rivers to take advantage of the supply of water for drinking and irrigation, the fertile soils of surrounding floodplains to support agriculture, the availability of freshwater fish and the benefits of rivers as a means of transport. The first civilizations developed on the banks and floodplains of major rivers, such as in the Fertile Crescent and along the Indus and Yellow Rivers.

Rivers are significant to many cultures. The notion of 'Mother River' is found in many places, including in China, India, Thailand and Russia, reinforcing the role of rivers in sustaining life and fertility (McCully, 2001). Rivers are also places of cultural and spiritual significance in many parts of the world. Rivers are also playing an increasing role as recreational spaces as urbanisation has reduced the green space available to a growing number of city dwellers.

The direct abstraction and consumption of freshwater is, perhaps, the most obvious benefit derived from rivers; surface freshwaters supply approximately 75% of the water withdrawn for human use (Carpenter *et al.*, 2011). Agriculture is by far the largest user of freshwater, accounting for around 70% of freshwater withdrawals and more than 90% of consumptive use (Hoekstra & Mekonnen, 2012). Without efficiency gains, withdrawals for agriculture are expected to increase by nearly 50% by 2030 (Water Resources Group 2030, 2009). While irrigated agriculture may represent only a fraction of total agriculture by area, its production value is far higher, with irrigated crop yields 2.7 times those of rain-fed farming (FAO, 2011). For example, in Australia, irrigated land represents 0.5% of all agricultural land, but produces around 28% of the total gross value of agriculture production (NIC, n.d.).

Freshwater ecosystems provide far more than just water for consumption. Rivers play a critical role as transport corridors. China has over 110,000 km of navigable rivers, which carry nearly 1.2 trillion tons of freight per year (World Wide Inland Navigation Network, n.d.). In the EU, inland waterways accounted for the transport of 527 million tons of freight in 2013 and transport on inland waterways produced approximately €8 billion of gross value-added (EuroStat, n.d.). In the US, waterways are used to transport around 12% of national freight based on domestic ton-miles (National Transportation Statistics, 2010).

Rivers are also a major source of food. Fish represent by far the largest share of freshwater aquaculture, at 96% of the total (FAO, 2008). The annual capture of freshwater fish, including both wild and aquaculture, is estimated to be 149 million tons (FAO, 2012a) and inland fisheries (including aquaculture) now contribute 33% of total global fish catch and provide more than 6% of the world's annual animal protein supplies for humans (FAO, 2007). Recreational fishing alone is estimated to have a value of US $116 billion per year (Helfman, 2007).

Hydropower accounts for around 16% of global electricity production (IEA, 2010). In Europe, it accounts for around 70% of all renewable energy production (ETC/ICM, 2012) and plays an important role in reducing carbon emissions related to Europe's electricity sector. Water is also a critical input in the production of thermoelectric power, especially for cooling power-producing equipment. In the US, thermoelectric-power withdrawals account for more than 50% of water abstracted from surface water sources (USGS, n.d.(a)).

FRESHWATER ECOSYSTEM SERVICES

The benefits people derive from ecosystems are referred to as ecosystem services. These services are commonly considered in four categories (MEA, 2005):

1. Provisioning services are products obtained from ecosystems. In the case of freshwater ecosystems, provisioning services include water for consumptive use, such as for drinking, domestic use, agricultural use and industrial use. Provisioning services also include water for non-consumptive use, such as for generating power, for transport and for navigation. Aquatic organisms for food and medicines are also examples of a provisioning service.
2. Regulatory services are benefits obtained from the regulation of ecosystem processes, for example maintaining water quality as a result of natural filtration and water treatment. It also includes the attenuation of floods and erosion control through water and land interactions.
3. Cultural services are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. Examples include recreation, such as river rafting or fishing, tourism, and 'existence values', such as the personal satisfaction from healthy and free-flowing rivers.
4. Supporting services are the ecosystem services that are necessary for all other ecosystem services. Examples include the role that rivers play in nutrient cycling, in maintaining floodplain fertility, and in primary production, as well as in maintaining predator/prey relationships and enhancing ecosystem resilience.

Box 2: The economic value of freshwater systems

Estimates of the economic value of freshwater ecosystem services suggest that freshwater systems are 10 to 20 times more valuable by unit area than marine and terrestrial ecosystems. For example, one hectare of wetland is estimated to provide services valued at US $14,785 per year, amounting to US $4–9 trillion in value annually at the global scale (Costanza *et al.*, 1997). Some of the efforts to quantify the economic value of different freshwater ecosystem services are described below.

Potable water supply: Perhaps the most important ecosystem service that river systems provide is water for drinking. The value of drinking water is apparent when river systems become degraded and additional treatment costs must be incurred before water taken from a river is fit for human consumption. For example, studies undertaken in the 1990s of the system that provides drinking water for New York City estimated that the cost of building a new water filtration system to meet water quality standards would be US $6 billion to US $8 billion (Ashendorff *et al.*, 1997). This infrastructure was being considered because the degradation of the upper catchment had resulted in decreased water quality. This highlights the cost of the alternative – treated water – to the natural supplies that may otherwise be available, and hence the value of those natural supplies.

Fish production: Coastal wetlands, which rely on inflows of freshwater from the upstream catchment, provide important habitat for many commercially harvested fish, as well as crustaceans and molluscs. There have also been various efforts to estimate the value of coastal wetlands for fisheries production. For example, Barbier and Strand (1998) estimated that the loss of 1 km^2 of mangroves in Campeche, Mexico reduced the value of annual shrimp harvest by more than US $150,000.

Flood protection services: Storing and transporting floodwaters is one of the critical ecosystem services that rivers and floodplains provide. One way of determining the value of floodplains is to determine the avoided costs of flood control through dikes, levees or flood-control dams. In evaluating the options for reducing flood risk on the Charles River, Massachusetts, the US Army Corps of Engineers purchased 3,440 hectares of floodplain wetlands. The floodplain was estimated to have the equivalent flood storage capacity of a proposed flood-protection dam, but for one-tenth of the cost: US $10 million for purchasing part of the floodplain versus US $100 million for a dam and levee project (Faber, 1996).

The provision of freshwater ecosystem services from a river depends, either directly or indirectly, on one or more of the elements that constitute the river. Figure 1.5 shows different services linked to components of the river system, noting that a particular service may be dependent on multiple aspects of the river system. For example, the provision of water for consumptive purposes will depend on the flow regime – ensuring that the required volume of water is available at the time and reliability required – as well as the water quality will determine if the available supplies are fit for purpose. The capacity of a river to transport floodwaters and to attenuate their impact will depend on the nature of the catchment (which will influence runoff), the flow regime (which will dictate the timing, frequency, and size of flood-inducing flows), and the physical form of the river corridor and floodplain (which determine the physical limits of the system). Changes to any one of those elements – the catchment, the hydrology, or the physical form – may impact on the flood attenuation capacity of the river basin.

Understanding the way that river ecosystem function can influence the provision of ecosystem services is critical to assessing the likely impact of changes within a river ecosystem to the provision of those services. Equally, such an understanding is central to ensuring river restoration efforts effectively address the root causes of problems and that those efforts will ultimately deliver the overall goals of restoration.

Figure 1.4. Conceptual diagram of a river basin showing the freshwater ecosystem services provided by the basin

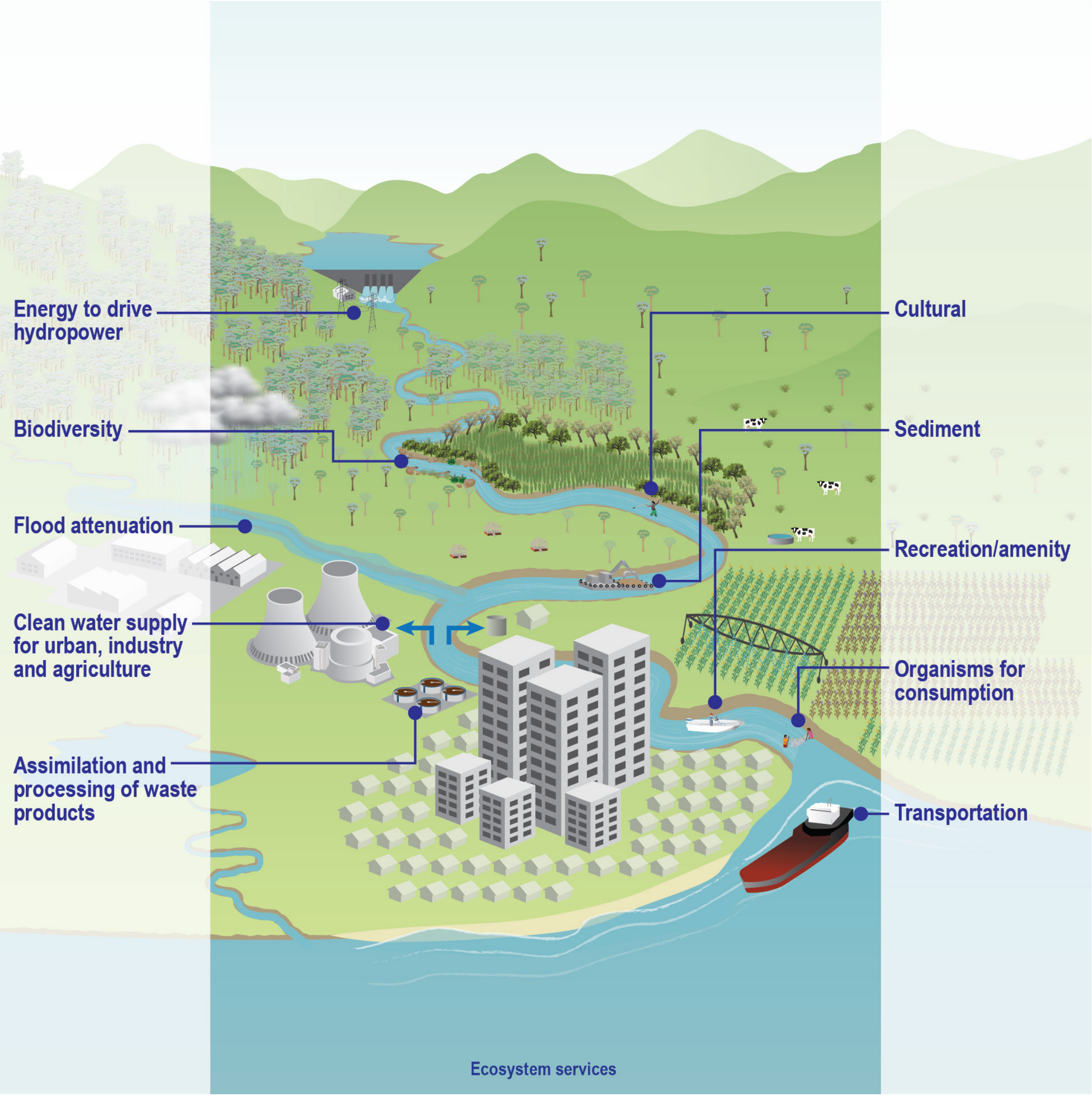
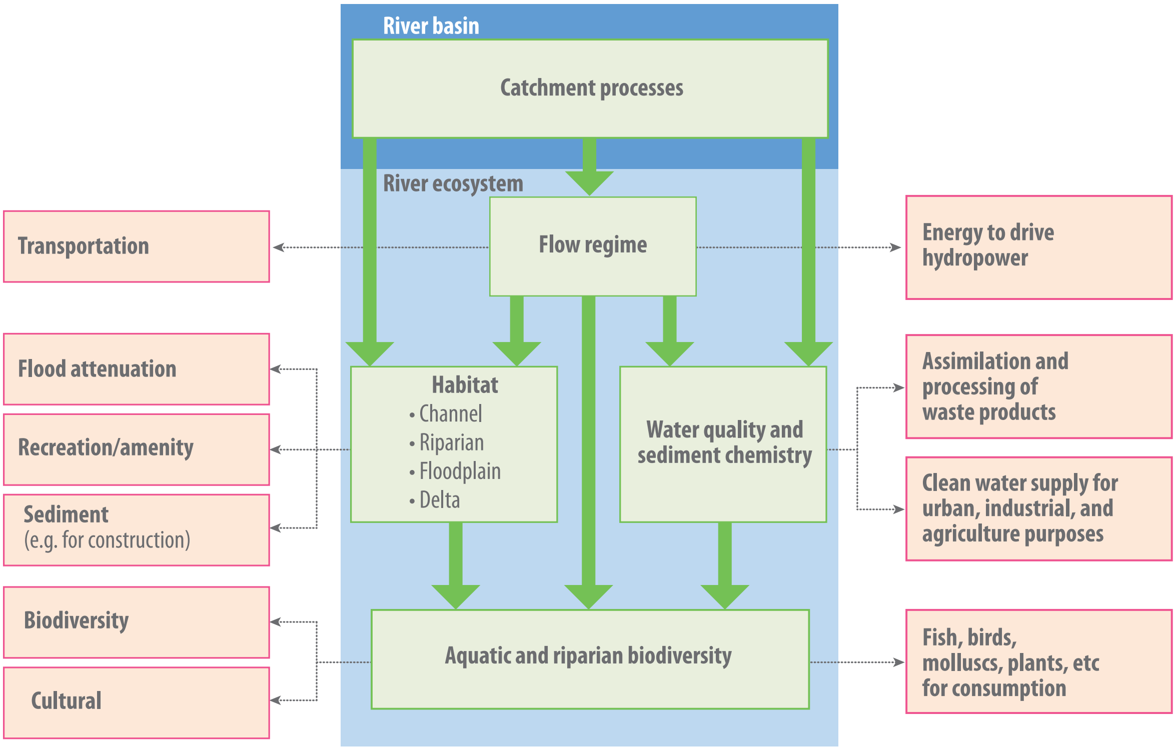


Figure 1.5. Examples of freshwater ecosystem services provided by a freshwater ecosystem



1.3. Issues and challenges

Humans have exploited rivers more than any other type of ecosystem (Boon *et al.*, 1992; Richter, 2014), for over 5,000 years. While this relationship with rivers has brought many benefits to human society, it has also had significant impacts on the rivers, in some cases fundamentally changing the way they function (Nienhuis and Leuven, 2001). The changes induced by human activity over the last century were exceptionally large (Carpenter et al., 2011; Vorosmarty *et al.*, 2010) and the consequent impacts are threatening the capacity of river ecosystems to continue to provide the services human societies have come to depend on, as well as the capacity for rivers to meet new demands.

Rivers are especially vulnerable to the impacts of human behaviour because they traverse and are the topographic low points on the landscape. Aquatic ecosystems are therefore the ultimate recipients of materials from human action on the land and in the atmosphere (Turner *et al.*, 1993; Naiman *et al.*, 1995). As a result of these impacts and other factors, freshwater ecosystems may be the most endangered ecosystems in the world (Dudgeon *et al.*, 2005).

MAJOR THREATS

The major threats to freshwater biodiversity, and by implication freshwater ecosystems more broadly, can be grouped into five interacting categories: flow modification, water pollution, changes to freshwater habitat, overexploitation of biota, and invasion of exotic species. In addition, there are a number of cross-cutting environmental changes occurring at a global scale – most notably climate change – which can be overlaid across these five categories (Dudgeon el al., 2005).

Flow modification can involve changing the magnitude, frequency, duration, timing, seasonality or variability of flow events or altering surface and subsurface water levels. Many human activities influence the flow regime, including the construction of dams or levee banks; the abstraction or diversion of water; or changes to the catchment, which can alter runoff. Flow modification can reduce the volume and reliability of water available for human consumption, can affect the lifecycles of freshwater biodiversity, and can alter natural processes, like sediment transport. In some rivers, particularly in arid regions, water abstractions have increased to such an extent that effectively all the river flow is now removed, fundamentally changing the nature of the river and resulting in drastic consequences for dependent human communities as well as aquatic and riparian biota.

There are many causes of water pollution. Every day, an estimated 2 million tons of sewage, and industrial and agricultural waste is discharged into the world's water supply (UN WWAP, 2003). Excess nutrients can enter river systems from diffuse sources (e.g. farming) or point sources (urban wastewater discharge), degrading water quality, reducing amenity values and leading to an increase in plant growth including, in some cases, toxic algal blooms. Large amounts of organic waste, such as from sewage, can result in a high biological oxygen demand, leading to de-oxygenation, which can have a devastating effect on aquatic biota. The discharge of heavy metals, pesticides, herbicides and other toxins into rivers can also have major adverse effects on river health. Increasingly, there are concerns related to non-traditional pollutants, such as hormones or antibiotics (Behera *et al.*, 2011). Loss of local connectivity to the hyporheic zone is a key contributor to poor water quality, with many rivers losing their ability to self-purify. Water quality problems can also result from the operation of reservoirs, such as where water is released from stratified water layers in a reservoir, resulting in the release of cold, oxygen-deficient water.

Changes to freshwater habitat occur in many ways: through reclamation of the floodplain for agriculture or urban development; dredging of the river channel to extract materials for building or to improve navigation; and channelization (the widening, straightening or lining of river channels) to manage flows, ease navigation and reduce flooding. These activities can result in the simplification of channel forms and the loss of instream habitats and the outright loss of floodplain habitats and associated services. Riparian and floodplain habitat, including wetlands, can be lost as a result of the clearance and drainage of these zones for human uses (such as farming and urban development) or grazing by livestock may severely degrade river systems. More than 500,000 km of waterways have been altered for navigation (Revenga and Kura, 2003, cited by MEA, 2005). By some estimates, 50% of inland water habitats may have been lost during the 20th century (MEA, 2005), although others estimate that the area lost is far higher (Davidson, 2014).

Freshwater habitat can also be directly influenced by the construction of dams and other infrastructure. Dams and levees can fragment a river system, inhibiting the passage of river biota and impeding the transport of sediments and pollutants. Dams and weirs also change the hydraulic habitat of a river, both upstream (via impoundment of water) and downstream (as a result of changes to the flow regime). Levee banks built for flood control can reduce or remove connections between the river channel and adjacent wetlands and floodplains. The number of large dams globally increased from 5,000 in 1950 to more than 45,000 in 2000 (World Commission on Dams, 2000) and dams or other major infrastructure have been constructed on around 60% of the world's 227 biggest rivers (UN WWAP, 2003). In addition, globally there are an estimated 16.7 million small dams (>0.01 ha), which can have a substantial impact on flow alterations and connectivity, despite their small size (Lehner *et al.*, 2011).

Overexploitation of biota is a result of overharvesting fish and other aquatic animal and plant life. This can affect the long-term sustainability of the populations of species being harvested, as well has having consequences for ecosystem processes and for other species.

Human activity has resulted in many plants and animals expanding beyond their native ranges or being introduced from other parts of the world, allowing the invasion of exotic species. This can be a result of the accidental or intentional introduction of species into a new area. Alternatively, changes to the flow regime, habitat or other aspects of a river system may facilitate the invasion of exotic species or create conditions that advantage invasive species at the expense of native species (e.g. Bunn and Arthington, 2002). Such species can become pests. The adverse impacts can include the predation of native species, impeding watercourses (e.g. invasive aquatic weeds) or changing ecosystem processes, such as nutrient cycling.

Climate change is expected to affect river ecosystems in multiple ways. The most direct impacts are likely to be through changes to air temperature, which will increase evaporative losses, changes to precipitation (including greater variability) and hence to catchment runoff and streamflow, and (over the longer-term) changes to sea levels. In addition, climate change is resulting in glaciers shrinking in size, which is resulting in decreasing critical late-summer flows in many major rivers (Bates *et al.*, 2008).

Each of these factors may directly influence one or more of the elements of the river ecosystem (Figure 1.6, Figure 1.7). The consequences, though, can be far reaching, with changes to catchment processes, for example, ultimately affecting the flow regime, habitat, water quality and aquatic biota. The impact of particular threats will of course vary with the nature and severity of change to the river ecosystem. From an anthropogenic perspective, the significance of that change will depend on the way and extent to which human communities rely on the river and the ecosystem services it provides.

Figure 1.6. Threats and causes of decline in river health and their link to different elements of the river system

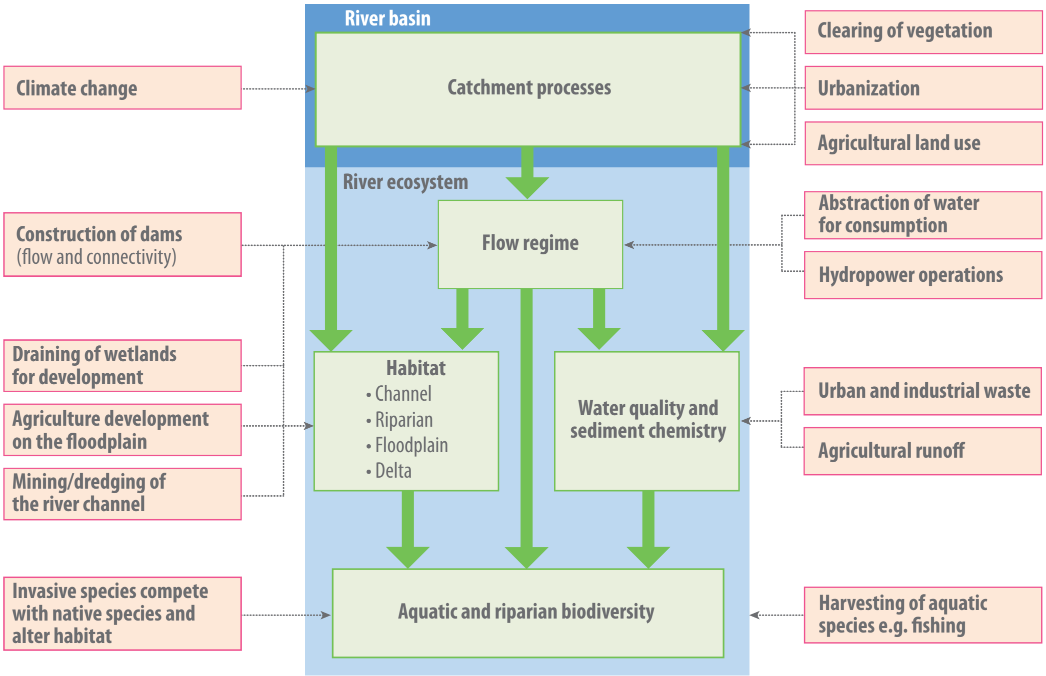
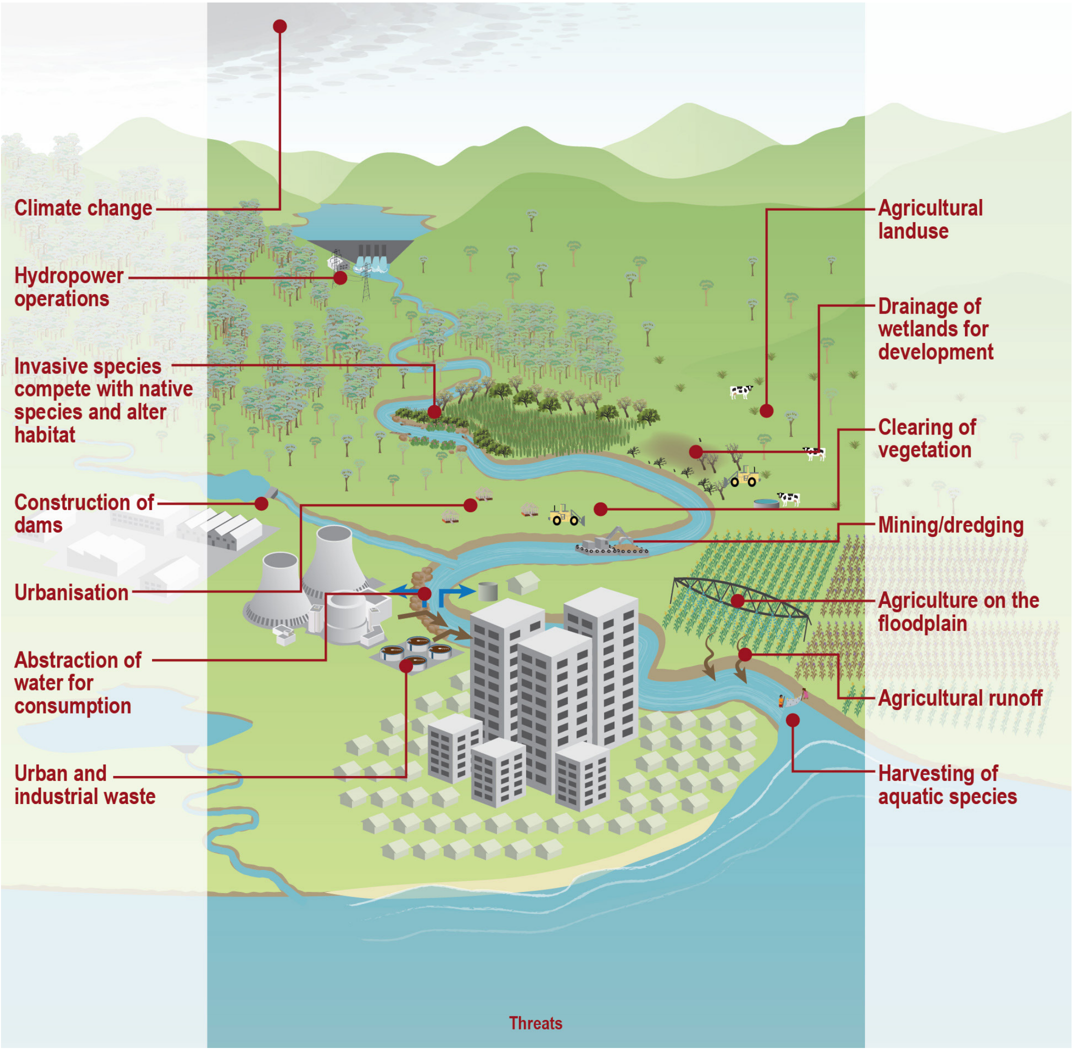


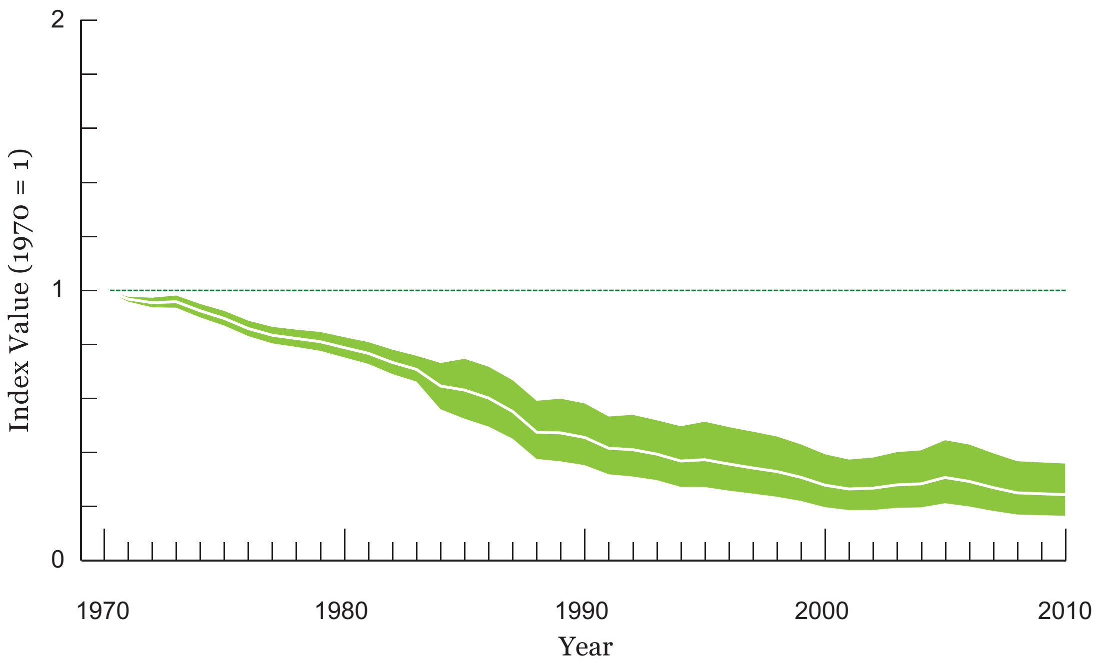
Figure 1.7. Conceptual diagram of a river basin showing threats to the river ecosystem



IMPACTS ON FRESHWATER ECOSYSTEMS AND ECOSYSTEM SERVICES

The impact of human development on freshwater species has been severe and declines in freshwater species populations have been markedly steeper than for forest or ocean wildlife, with an estimated global drop in freshwater vertebrate populations of 76% since 1970 as shown in Figure 1.8 (WWF, 2014). The data in Figure 1.8 is based on trends in 3,066 populations of 757 mammal, bird, reptile, amphibian, and fish species. The margins indicate the confidence limits (WWF, 2014).

Figure 1.8. Living Planet Index for freshwater, showing a decline of 76 per cent between 1970 and 2010



Source: WWF, 2014

The potential consequences for human society as a result of over-exploited and degraded freshwater systems are enormous, with more than 80% of the world's population exposed to a high level of threat to water security and an equally alarming level of threat to river biodiversity (Vorosmarty *et al.*, 2010). Habitats associated with 65% of continental discharge are classified as moderately to highly threatened (Vorosmarty *et al.*, 2010). In the US, for example, of the 5.3 million km of rivers, 98% are affected by human activities and impoundments (Palmer *et al.*, 2007; Palmer *et al.*, 2014). Around 50% of water bodies across the European Union member states are heavily impacted by hydro-morphological alterations (ETC/ICM, 2012).

As a consequence, many of the ecosystem services provided by river systems are at risk. A summary of the impacts of different human activities on the ecosystem and on ecosystem services are shown in Table 1.1.

FUTURE CHALLENGES

The consequences of river degradation are evident in many river basins around the world (see Box 3). The loss of freshwater services comes at a time when they are needed more than ever. Population growth, urbanization and a burgeoning middle class are all placing further pressure on our river systems.

The Food and Agriculture Organization (FAO) estimates that global agricultural production will increase by 60% by 2050 to respond to the growing population and changing consumption patterns (FAO, 2012b). This implies more intensive agriculture, which suggests more water will be required for irrigation, more fertilizer will be applied to fields (and hence more nutrient runoff), and pressure will grow to expand into any undeveloped parts of the catchment or remaining floodplains.

The International Energy Agency (IEA) estimates around 50% more primary energy will be required by 2030. This, coupled with the pressure to reduce carbon emissions, is resulting in a push for further hydropower development. To date, only around 19% of the global technically exploitable hydropower has been developed (IEA, n.d.), although how much further hydropower can be developed in a way that is economically, socially, and environmentally sustainable is a matter of significant debate. Around 3,700 major hydropower dams are either planned or under construction (Zarfl *et al.*, 2015).

Table 1.1. Summary of primary activities affecting freshwater ecosystems and ecosystem services

Human Activity	Impact on ecosystem	Services at risk
Dam construction	Alters timing and quantity of river flows, water temperature, nutrient and sediment transport, delta replenishment, blocks fish migrations	Provision of habitat for native species, recreational and commercial fisheries, maintenance of deltas and their economies, productivity of estuarine fisheries
Dike and levee construction	Destroys hydrologic connection between river and floodplain habitat	Habitat, sport and commercial fisheries, natural floodplain fertility, natural flood control
Diversions	Depletes stream flow	Habitat, sport and commercial fisheries, recreation, pollution dilution, hydropower, transportation
Draining of wetlands	Eliminates key component of aquatic ecosystem	Natural flood control, habitat for fish and waterfowl, recreation, deforestation/ land use natural water purification
Deforestation/land use	Alters runoff patterns, inhibits natural recharge, fills water bodies with silt	Water supply quality and quantity, fish and wildlife habitat, transportation, flood control
Release of polluted effluents	Diminishes water quality	Water supply, habitat, commercial fisheries, recreation
Overharvesting	Depletes species populations	Sport and commercial fisheries, waterfowl, other biotic populations
Introduction of exotic species	Eliminates native species, alters production and nutrient cycling	Sport and commercial fisheries, waterfowl, water quality, fish and wildlife habitat, transportation
Release of metals and acid forming pollutants into the atmosphere	Alters chemistry of rivers and lakes	Habitat, fisheries, recreation, water quality
Emission of climate altering air pollutants	Potential for changes in runoff patterns from increase in temperature and changes in rainfall	Water supply, hydropower, transportation, fish and wildlife habitat, pollution dilution, recreation, fisheries, flood control

Source: Postel and Richter, 2003 cited by MEA, 2005

Since 1930, the percentage of the global population living in urban areas has increased from 30% to 54%. That figure is expected to rise to 66% by 2050. Combined with continuing population growth, urbanization is projected to add 2.5 billion people to the world's urban population by 2050 (UN, 2014). As urbanization and industrialization continues, localized pressures on river systems are expected to increase. In the absence of improved waste management, pollution loads will increase. Remaining floodplains surrounding urban centres will become increasingly valuable to property developers when the ability of floodplains to reduce the impact of flooding to support assimilation of waste will be less than ever before. Furthermore, as populations become more affluent they are likely to be less willing to tolerate poor environmental conditions.

At the same time, management and policy decisions that have already been made will result in continued environmental disruption as well as population and species extinctions (Palmer *et al.*, 2005 and 2008; Strayer and Dudgeon, 2010). All the key threats to river systems – human water use, climate change, use of fertilizers and chemicals, dam and hydrologic alterations, and overexploitation of fisheries – are escalating at the global scale. These trends are expected to continue while sediments and toxins already en route from expanding land use practices find their way into rivers (Naiman *et al.*, 2012; Naiman 2013). For these and other related reasons, stresses on river ecosystems and organisms are likely to increase significantly in coming decades. Even with no new human impacts on inland waters, many populations and species probably are no longer viable over the long term and will disappear or change spatial distributions (Strayer and Dudgeon, 2010; ISAB, 2011).

The costs, risks and challenges associated with river exploitation and degradation have driven global efforts to halt the decline of freshwater systems. Increasingly, this has included efforts not only to remove existing pressures, but also to reverse the declines of the past by restoring rivers and their related ecosystem services.

Box 3: The human and economic cost of river degradation – the global experience

Excessive water abstractions over a period of decades led to declines of more than 90 per cent in the annual inflows from the Amu Darya River to the inland lake that constitutes the Aral Sea in Central Asia. This has resulted in a 90% decline in the lake's volume, and salinity increasing to levels comparable to seawater (World Bank, 2001; International Lake Environment Committee, 2004). These changes led to the extinction of all 24 endemic fish species, the collapse of the local fisheries industry, and resultant declines in nutrition in surrounding communities. The desiccation of the sea has led to major declines in the quality of both surface and groundwater, as well as soil erosion and resultant air pollution. The impacts on human health have also been enormous, with raised levels of infectious diseases and the local population of 5 million now inhabiting 'some of the most chronically sick places on earth' (Small *et al.*, 2001).

Five decades of oil exploration and 1.5 million tons of oil spills have turned the Niger River Delta into the most oil spill vulnerable region in the world (IUCN/ CEESP, 2006; Olsson and Zabbey, 2012). The fourth largest mangrove belt in the world, it is a vital breeding ground for more than 60% of commercial fish in the Gulf of Guinea, and livelihood of 30 million people (Nandy and Mitra, 2004; UNDP, 2006). Although approximately 80% of government revenue and 97% of Nigeria's of foreign exchange comes from this oil-rich region, it has severe human development and environmental problems (UNDP, 2006). A persistent layer of floating oil has ruined fish farms in the creeks and fish habitat in mangroves. Drinking water wells in some communities are contaminated with benzene, a known carcinogen, and hydrocarbons, at levels approximately 1,000 times higher than World Health Organization guidelines (UNEP, 2011). Financial valuation of environmental damages due to oil exploration activities has been estimated to be tens of billions of dollars. (IUCN/ CEESP, 2006).

Categorised as one of the top ten toxic places on the Earth, the Citarum River is a vital source of water supply to 35 million people on the island of Java, Indonesia (Biello, 2014; DGWR, 2007). Apart from domestic and agricultural discharge, which contributes faecal matter, nitrogen and phosphorus, around 2,000 textile, gold mines, cement, and chemical industries have caused heavy metal contamination such as lead, arsenic and mercury (DGWR, 2007). While the consumption of contaminated fish is increasing health risks in communities, fish kills, which are a common phenomenon, are putting poor fishing families at risk.

Overfishing, pollution and dam building along the Yangtze River in China has altered river water quantity and quality leading to environmental degradation. This degradation is characterized by the extinction of the Yangtze River dolphin (Lipotes vexillifer) and has reduced the population of Yangtze finless porpoise (Neophocaena asiaeorientalis) to only around 1,000 (Qiu, 2012). The catch of wild fish in the river has declined by 75%, which is affecting local fishing communities (Liu and Diamond, 2005). Billions of tons of annual discharge of sewage and industrial effluents, ship discharge and agricultural runoff has deteriorated the water quality making it unfit for drinking. Consumption of fish contaminated by heavy metals can lead to the risk of adverse health effects (Fu *et al.*, 2013). The excessive sediment discharge from erosion, which exceeds the combined discharges of the Nile and Amazon, (Liu and Diamond, 2005) and reclamation of floodplains for agriculture has increased the frequency of dangerous flooding, further threatening human life and economy (Pittock and Xu, 2010).

CHAPTER 2
THE ROLE OF RIVER RESTORATION

OVERVIEW AND KEY MESSAGES

This discusses the role of water resources management and river restoration in balancing the demands on freshwater systems. This discussion defines how the term 'river restoration' is used in this book. The chapter concludes with a brief overview of the evolution of river restoration in a number of countries and a discussion of emerging challenges for restoring river ecosystems. The key messages from the chapter are:

- River restoration is an important part of the water resources management system. It assists with balancing the needs of people for freshwater ecosystem services with anthropogenic pressures on river ecosystems. This balance requires an understanding of the relationship between the way rivers function and the demands and impacts people have on rivers.
- River restoration has become necessary where river systems have degraded to the point that they can no longer provide the services required of them. Restoration may be triggered by ecological considerations, social and cultural factors, economic drivers, the need to protect infrastructure and assets from water related risks, and (increasingly) water security concerns.
- River restoration has evolved over time from one-dimensional responses aimed at addressing a single issue (e.g. water quality), to more sophisticated approaches that involve both active restoration (physically changing the river or landscape) or passive restoration (policy measures to change human behaviour). Increasingly, restoration approaches are being integrated with broader management and development considerations.
- River managers face significant challenges in implementing river restoration measures: the need to balance a range of competing interests, the complexity and scale of issues, uncertainty over future conditions within a basin, ensuring that restoration outcomes are enduring, and the need for a sound scientific basis to support restoration measures.

2.1. Water resources management and the role of river restoration

Water resources management sits at the interface between human and freshwater systems (see Figure 2.1). In doing so, it plays a critical role in managing:

1. the provision of freshwater ecosystem services to meet human needs, and
2. the impact of anthropogenic activities on river ecosystems and the way they function.

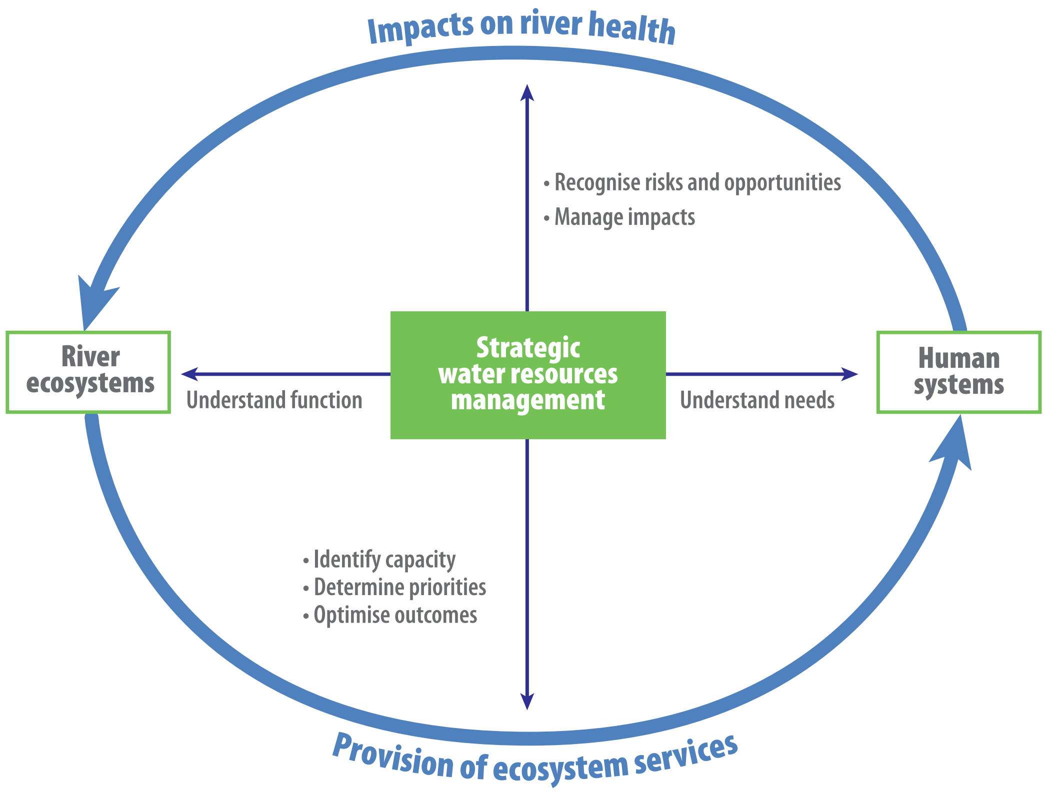
Escalating demand for the benefits that rivers provide, the inherent conflicts between some of those demands, and the limited capacity of rivers to meet all of society's needs now require a more strategic approach to the planning and management of water resources (Pegram *et al.*, 2013). Adopting a strategic approach requires that decisions about the management of river ecosystems and related development be undertaken in a way so that water resource managers understand and recognize:

- the way that rivers function and how different elements of a river ecosystem contribute to river health;
- the long-term needs and objectives of human society for freshwater ecosystem services;
- the capacity of the river to meet or support the needs of society and the extent to which a river ecosystem can provide ecosystem services under different conditions;
- the impact of human society on river health and how different development scenarios can affect the structure and function of a river ecosystem, including how they may affect the river's ability to provide ecosystem services.

As such, strategic water resources management aims to prioritize and optimise the use of freshwater resources in a way that recognizes the limitations of the river, minimises the impacts of human activity on river health, and manages trade-offs between competing demands. This can involve, for example, preparing and implementing plans that determine where water resources development will occur, how water will be allocated amongst different water users, and what limits will be placed on the release of pollutants into a river. For example, a new policy introduced by the Chinese Government as part of the 'No. 1 Policy Document' in 2011 requires the establishment of 'the most stringent water resources management system' (CCCPC and State Council, 2010). This will be underpinned by a series of 'red lines', which set limits on, amongst other things, the release of pollutants into freshwater systems and the abstraction of water resource (see Box 4).

Water resources development – such as the construction of dams and the abstraction of water – is one element of water resources management and in many ways creates the physical interface between human society and river ecosystems. Such development has the potential to harness specific ecosystem services provided by a river, for example by improving the capacity of a basin to store floodwaters, or increasing the water available for abstraction during dry periods. At the same time, it can, whether by default or by design, materially alter a river's structure and function, and thereby reduce other ecosystem services provided by the river.

Figure 2.1. The role of strategic water resources management in balancing the needs of human systems and demands on river ecosystems



River restoration is one aspect of water resources management and primarily plays a role when a river ecosystem has been degraded to the extent that a river can no longer provide the services that are required of it, such as where water quality is not fit for purpose or the loss of floodplains has reduced the ability of the river system to store or transport flood waters.

In such cases, conventional engineering-led planning, allocation and management of water resources alone may be inadequate to satisfy society's expectations of the river ecosystem (Rieman *et al.*, 2015). Different, more direct, interventions may be required to improve or restore those services that have been lost, or to enhance the capacity of the river to provide certain services identified as a priority. Such interventions may need to blend engineering with other disciplines, including ecology.

As for other aspects of strategic water resources management, river restoration policies, strategies and plans need to be developed with a clear understanding of both the dependent human system (and associated demands and priorities) and the relevant freshwater ecosystem. This understanding allows for informed and strategic decision making about priorities for restoration, trade-offs between competing objectives and strategies for interventions.

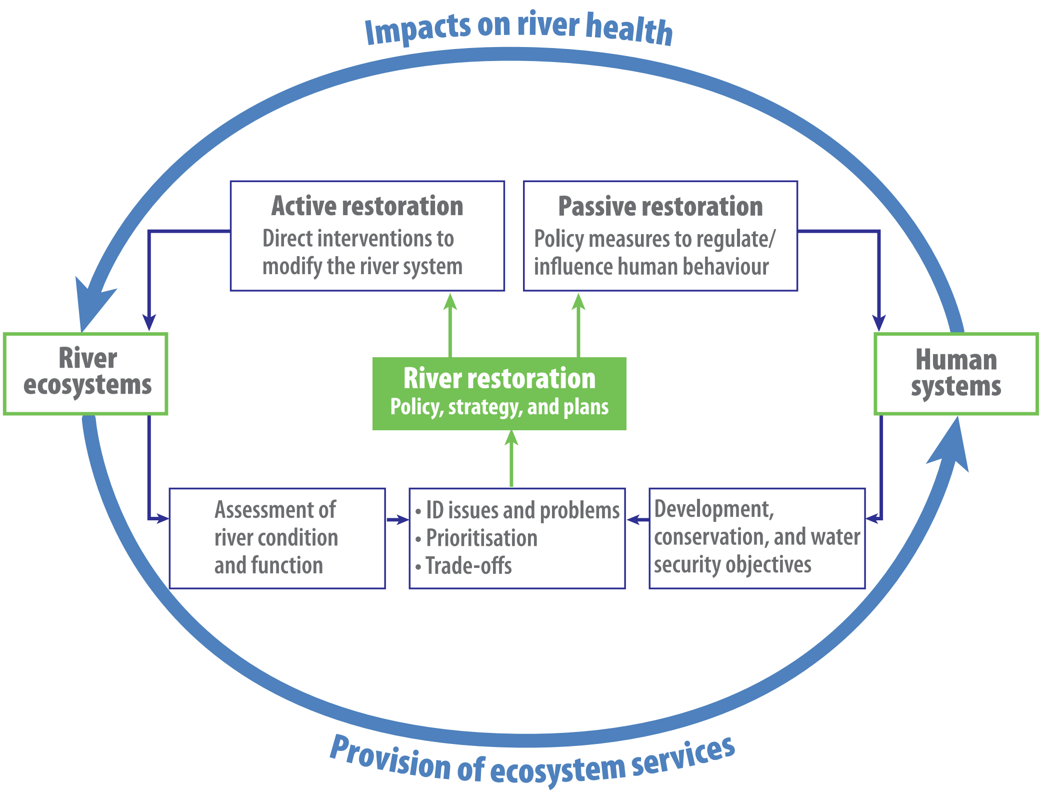
River restoration can involve active or passive restoration (Roni and Beechie, 2013). Passive restoration primarily involves changing the way human systems – that is people, government, businesses, and societies more broadly – operate, with the goal of reducing their impact on river ecosystems. This can involve regulatory measures to restrict or mandate certain behaviour, education to encourage voluntary changes in behaviour, or market measures to provide economic incentives. When used in isolation, such approaches rely on the capacity of river ecosystems to naturally recover provided that the causes of degradation have been removed.

Active restoration involves direct interventions to modify the river system. Examples include planting riparian vegetation, modifying or removing barriers within the river channel, or reintroducing native species. Different approaches to restoration are discussed in detail in Chapter 11.

These aspects of river restoration and the relationship between them are shown in Figure 2.2.

While river restoration forms part of the broader water resources management system, it can also depend on other aspects of the system. Restoration measures may include, or be dependent on, planning arrangements and regulatory controls to either reduce existing pressures (e.g. pollution or water abstractions), or to ensure that future development does not undermine gains achieved through restoration actions. The role of water resources management in achieving restoration outcomes is discussed further in Chapter 5.

Figure 2.2. The relationship between river restoration, river ecosystems and human system



Box 4: Setting ecological red lines for rivers in China

In response to environmental degradation, societies have increasingly established boundaries or set limits on what can be emitted to and extracted from the environment, and how much the environment could be changed by direct modification (see for example Steffen *et al.*, 2015). Such measures recognize that there are limits beyond which there is a high risk that key ecosystem functions will collapse.

Setting ecological limits can serve as a basis for managing freshwater ecosystems by defining, for example, limits on hydrological alteration (e.g. the amount of water that can be abstracted) or on the amount of pollution that may be discharged. Limits can also be used to define the trigger points for action and targets for restoration.

In China, the No. 1 Policy Document for 2011 issued by the Central Committee of the Communist Party of China and the State Council provides for the establishment of the 'Most Stringent Water Resources Management System', which is built around the so called 'three red lines'. The first red line is a cap on the total amount of water resources that can be used, and defines the maximum water use. Separate limits are to be set for each river basin, region, sector and water user. The second red line aims at improving water use efficiency, and defines the targets for water use efficiency by region and sector. The third red line relates to pollution discharge. It defines the maximum allowable pollution loads for rivers and lakes.

'Opinions of the State Council on the Implementation of the Most Stringent Water Resources Management System' issued by the State Council in 2012 sets red lines and related targets at the national level. The Opinion requires that by 2030: the national water use amount will be no more than 700 billion m^3; water use will be close to the most efficient in the world; water consumption for each ¥10,000 of industrial added value will decrease to below 40 m^3; the effective utilization coefficient of irrigation water will increase to above 0.6; and the amount of pollution entering rivers and lakes will be within the limits specified based on the national 'water function zone' system, which designates water use requirements for different water bodies and related water quality standards. The Ministry of Water Resources has primary responsibility for implementing the three redlines.

At the same time, the Ministry of Environment protection has issued a technical guideline for the establishment of 'Ecological Protection Red Lines'. These are designed to identify and protect the spatial limits of key ecosystems. The guideline sets out techniques for selecting and defining areas, such as areas that perform key ecology functions or that are ecological sensitive or vulnerable, where industrialization and urbanization are prohibited, in an effort to protect rare, endangered and typical species and to maintain key ecosystem functions. Nature reserves, forest gardens, major national scenic locations, World Heritage sites, and geoparks are also identified and protected from development under the system.

Source: GIWP

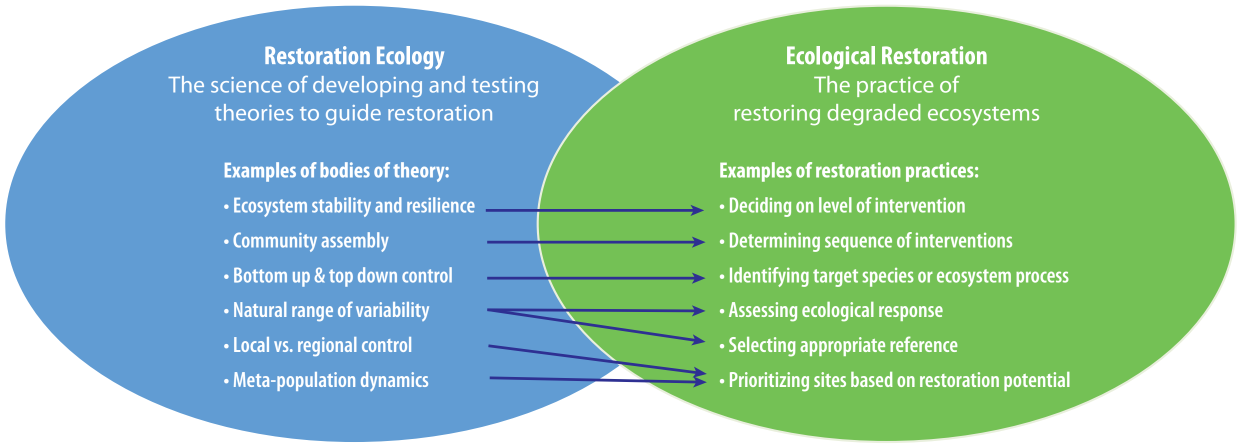
2.2. What we mean by 'river restoration'

Restoration ecology is now a well-established scientific discipline, which draws on a range of concepts and models to explain how natural systems are likely to respond to different interventions aimed at restoring ecosystem function. The practical application of this science – ecological restoration interventions – involves taking scientific understanding and applying it to resource management challenges. This practical application includes using science to support decisions around setting priorities for intervention, the nature of interventions, and determining realistic restoration targets (Palmer, 2008; see also Figure 2.3).

The term 'restoration' is used in various ways in the context of ecosystem management. Ecological restoration has commonly been used to refer to the process of returning an ecosystem, such as a river, to its natural or pre-development state. The US National Research Council (1992) defines restoration as:

> *… the return of an ecosystem to a close approximation of its condition prior to disturbance. In restoration, ecological damage to the resource is repaired. Both the structure and the functions of the ecosystem are recreated … The goal is to emulate a natural, functioning, self-regulating system that is integrated with the ecological landscape in which it occurs.*

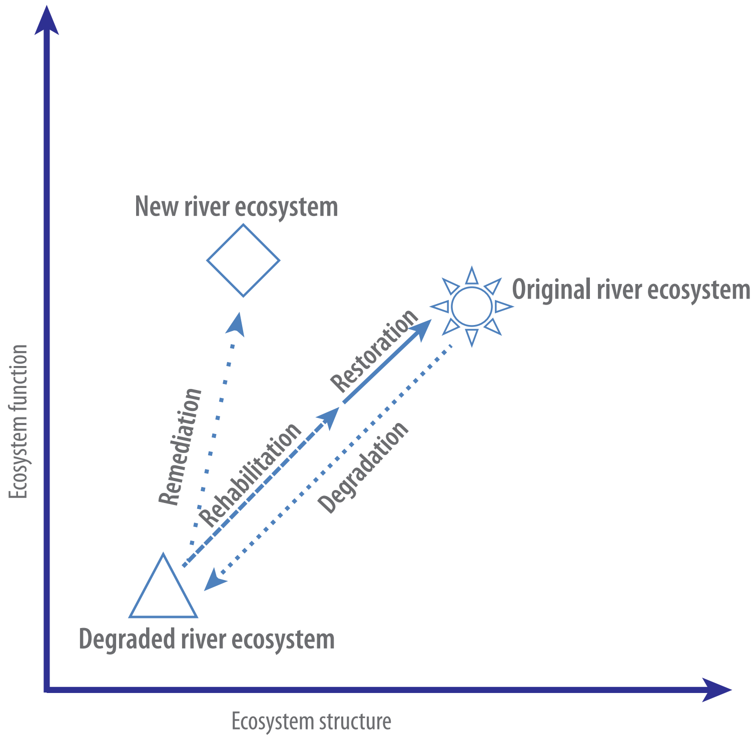
Figure 2.3. The connections between science of restoration ecology and the practical application of that science as part of ecological restoration



Source: Adapted from Palmer, 2008.

In these cases, restoration is distinguished from 'rehabilitation', which describes measures that address only some elements of change within a degraded system, but still aim to return the ecosystem closer to its original condition. In contrast, using this nomenclature, 'remediation' may refer to changing an ecosystem to an alternate condition, that is one that differs from both its current and original state, albeit with some improved values or functions (Figure 2.4). The concepts of rehabilitation and remediation recognize that, in many cases, the extent of alterations caused by humans over many years, together with the impacts associated with on going human activity, make restoring ecosystems to their natural condition either unrealistic or undesirable.

Figure 2.4. One example of an approach to distinguishing between restoration, rehabilitation, and remediation



Source: Based on Bradshaw, 1996.

Others have taken a broader approach to defining ecological restoration. The Society for Ecological Restoration (SER, 2004) define restoration as the '…process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.' The Society of Wetlands Scientists (SWS, 2000), defines (wetland) restoration as 'actions taken in a converted or degraded natural wetland that result in the re-establishment of ecological processes, function, and biotic/abiotic linkages and lead to a persistent, resilient system integrated within its landscape'.

Ecological restoration is now undertaken across many parts of the landscape, including river ecosystems. In applying restoration approaches to river ecosystems, the concept has evolved along with our understanding of the way rivers function, the nature of the issues affecting rivers, and the types of responses that have been required to address problems related to degradation and the loss of ecosystem services. Over time, definitions for both ecological restoration and river restoration have shifted from a somewhat idealised notion of returning ecosystems to a natural or pristine state, to a more pragmatic and utilitarian approach to viewing and managing (river) ecosystems (Table 2.1).

Wohl *et al.* (2005) define river restoration as 'assisting the establishment of improved hydrologic, geomorphic, and ecological processes in a degraded watershed system and replacing lost, damaged, or compromised elements of the natural system'. As the authors note, this approach provides scope for subjectivity and societal values in the definition of what constitutes 'improved', where improved may include protecting property, enhancing aesthetic values, or facilitating recreation. 'Ecological river restoration' is specifically defined as 'assisting the recovery of ecological integrity in a degraded watershed system by re-establishing the processes necessary to support the natural ecosystem within a watershed'. 'Rehabilitation' is included within the scope of river restoration 'to the extent that it focuses on causes of system degradation through attainable reestablishment of processes and replacement of elements, rather than treating symptoms to achieve a particular condition or static endpoint'.

Table 2.1. Evolution of definitions of restoration and rehabilitation

Definition of ecological restoration	Reference
A return 'from a disturbed or totally altered condition to a previously existing natural, or altered condition by some action of man,' but 'for restoration to occur it is not necessary that a system be returned to pristine condition.'	Lewis (1990)
The complete structural and functional return to a pre-disturbance state.	Cairns (1991)
Restoration is re-establishment of the structure and function of ecosystems.	NRC (1992)
Distinction between restoration and rehabilitation: the latter are suggested when 'thresholds of irreversibility' have been crossed in the course of ecosystem degradation, and when 'passive' restoration to a presumed pre-disturbance condition is deemed impossible.	Gore and Shields (1995)
Rehabilitation involves the recovery of ecosystem functions and processes in a degraded habitat. Rehabilitation does not necessarily re-establish the pre-disturbance condition.	Dunster and Dunster (1996)
Ecological restoration is the process of returning an ecosystem as closely as possible to pre-disturbance conditions and functions. It is therefore not possible to re-create a system exactly. The restoration process re-establishes the general structure, function and dynamic but self-sustaining behaviour of the ecosystem.	FISRWG (1998)
Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed to repair ecosystem processes, productivity and services, as well as re-establish the pre-existing biotic integrity in terms of species composition and community structure. Restoration thus consists in correcting multiple changes in various components of the ecosystem.	SER (2004)
Definition of river restoration	**Reference**
River restoration is the process of recovery enhancement. Recovery enhancement should establish a return to an ecosystem, which closely resembles unstressed surrounding areas.	Gore (1985)
A restoration program should aim to create a system with a stable channel or a channel in dynamic equilibrium that supports a self-sustaining and functionally diverse community assemblage.	Osborne *et al.* (1993)
Assisting the establishment of improved hydrologic, geomorphic, and ecological processes in a degraded watershed system and replacing lost, damaged, or compromised elements of the natural system.	Wohl *et al.* (2005)

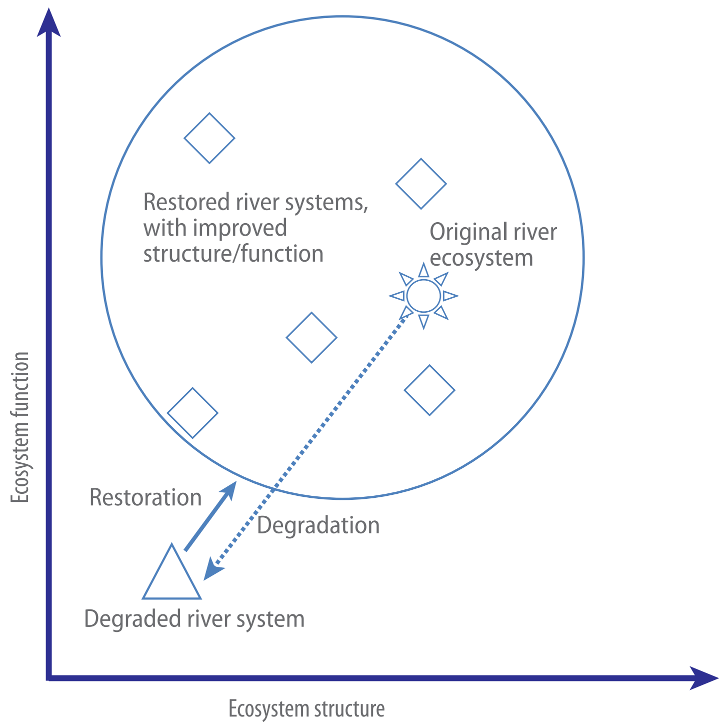
Source: Adapted from Dufour and Piegay, 2009

This book adopts a similar, broad approach. 'River restoration' is used to refer to any intervention to improve ecosystem function, river health and related ecosystem services. These interventions include measures that aim to achieve a state that differs from the river's original natural condition. The restored river systems do not necessarily reflect the function or structure of the original system, but do evidence improved function or structures compared with the degraded system.

River restoration is defined as:

> *Assisting the recovery of ecological structure and function in a degraded river ecosystem by replacing lost, damaged or compromised elements and re-establishing the processes necessary to support the natural ecosystem and to improve the ecosystem services it provides.*

Figure 2.5. Comparison of ecosystem structure and function in an original river system, a degraded river system, and restored river systems, based on the definition of restoration adopted in this book



2.3. The need for river restoration

River restoration efforts globally have come about as a consequence of two factors:

1. The degradation of river ecosystems such as through pollution, over-abstraction of water, or channelization
2. The loss of services historically provided by rivers as a consequence of degraded river ecosystems including decreased water availability, a loss of amenity, collapse of important fisheries, and increased flood or drought risk.

These factors, in turn, have resulted in responses aimed at halting or reversing the degradation and enhancing or restoring the ecosystem services provided by rivers. Importantly, it is only where both factors exist – where a river has been degraded and that has had significant impact on a dependent human population – that river restoration is generally contemplated.

While the degradation of river ecosystems might be the underlying cause of river restoration, human demand for more or improved freshwater ecosystem services is the primary factor that creates the need for river restoration. The desire to improve ecosystem services can be considered within a number of categories, each related to different services that rivers provide.

Historically, restoration projects were often conservation-orientated activities, aimed at protecting or improving ecological values, with restoration undertaken in response to concerns over the loss of iconic freshwater species or habitats. For example, restoration of the Columbia River in the United States was motivated by the desire to restore a collapsed salmon fishery (Lichatowich 1999; Rieman, *et al.*, 2015).

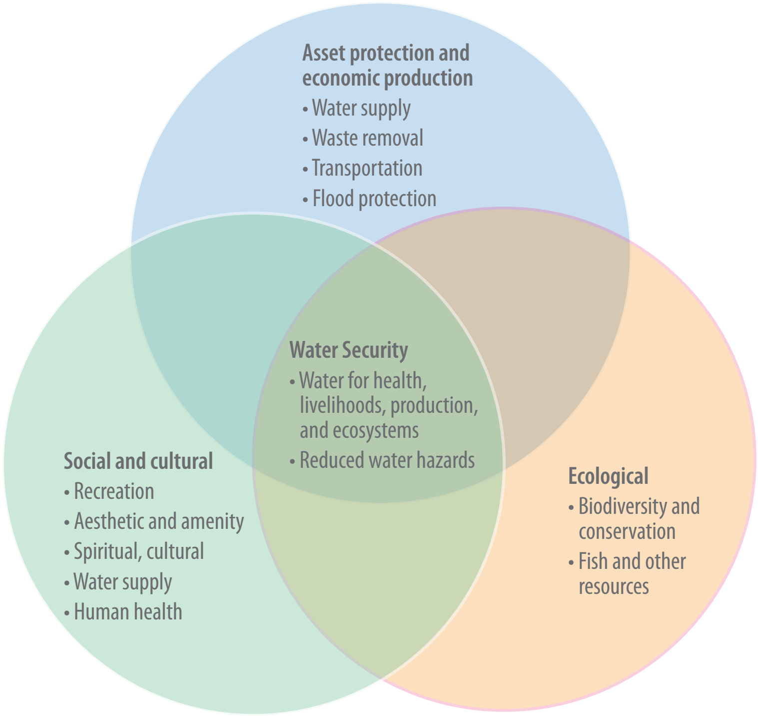
While safeguarding biodiversity remains central to many restoration efforts, increasingly it has been economic factors providing the impetus for river restoration. Restoration strategies now commonly recognize that ecosystem degradation is damaging long-term development and repairing or improving ecosystems is necessary and valuable because it provides services and goods (Dufour and Piegay, 2009). Urbanization, in particular, has become a motivating factor for improving the health of rivers. The limited space available within expanding metropolises increases the incentive to make the riparian zones of urban rivers suitable for property development and amenity use, which require improvements to how rivers look and smell, as well requiring issues like flood risks to be managed. These and other factors have become major economic drivers for restoration projects. In a similar vein, as society comes more closely into contact with river systems through development within the river corridor, the risks from water-related hazards, notably flooding, have increased. This has increased the need to protect infrastructure – houses, roads, bridges and other assets – from hazards associated with rivers, and asset protection is now a significant reason for undertaking river restoration projects.

A range of social and cultural factors can also trigger restoration efforts. The consequences of river degradation for human health can lead to efforts to improve river health and with it the health of neighbouring people and communities (Naiman and Dudgeon, 2011). Social expectations can also be an important motivator, with communities' dissatisfaction with the poor state of their rivers leading to political motivations to take action. Responses can be aimed at improving the aesthetic qualities of a river system, reducing odour or improving water quality to allow swimming or fishing, or creating riparian recreational areas. Cultural aspects of river systems also remain important in many countries. For example, efforts to improve environmental flows and overall river health in the Ganges River are in a major part due to the sacred nature of the river for Hindus (O'Keeffe *et al.*, 2012).

Cutting across these categories is the concept of water security, that is, the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks (Grey and Sadoff, 2007). Improving water security has been a key driver for restoration efforts in China, Singapore, Australia and Mexico (see Table 2.2).

Triggers for restoration can be considered in terms of these four categories: economic production and asset protection; ecological factors; social and cultural factors; and water security (Figure 2.6). The categories are not exclusive, and there can be significant overlaps in both motivations and outcomes from restoration works.

Figure 2.6. Common triggers for river restoration



It is relevant to distinguish between the trigger for a river restoration initiative, and the objectives of that initiative. The trigger refers to the reason the river restoration is undertaken in the first place – it is usually something that demands a response and results in action. The objectives are what people want to achieve from the river restoration process. The two are closely linked, and in some instances one is simply a reflection of the other. The objectives can be more expansive, such as where the initial driver creates the energy or opportunity to address additional problems within the basin, issues that, on their own, may have been left unresolved had they not been captured by a broader restoration programme. Defining objectives for river restoration is discussed in detail in section 4.3.

Table 2.2. Triggers, objectives and measures for river restoration in selected case studies

Restoration program	Trigger	Primary objectives of restoration
China (various rivers)	Water security	Improved water quality; flood control; improve water availability; improved amenity and related development opportunities;
Columbia River, U.S.	Ecological and economic factors (collapse of fisheries)	Conserve and restore native fisheries and wildlife
Danube River (multiple countries)	Water security and ecological factors (biodiversity)	Improved flood protection; improved water quality; biodiversity restoration
Mersey River, U.K.	Social and economic factors	River health improved such that the river could contribute to social and economic rejuvenation and improved quality of life
Santiago River, Mexico	Water security	Improved water supply, water quality and flood mitigation
Murray–Darling Basin, Australia	Water security and ecological factors	Improve river and wetland health; viability of rural and regional centres
South East Queensland Catchments, Australia	Economic and social/cultural factors	Improve water quality and reduce sediment inflows to Moreton Bay
Singapore (ABC Waters Program)	Water security	Simultaneously improve the water quality, physical appearance, recreational value, and biodiversity.
South Korea (Taewha River and Cheonggyecheon)	Social and cultural factors (improved amenity value)	Varied, but include flood mitigation, water quality improvement, expanded recreational areas, ecological outcomes

Sources: Batey, 2013; Liao, 2013; Saxton, 2013; Naiman, 2013; GIWP, 2013; Woo and Choi, 2013

2.4. History and evolution of river restoration

River restoration is a relatively recent phenomenon, starting in the 1970s and 1980s in many countries, particularly in response to water quality issues associated with industrial development. In the United States, major works to protect and improve freshwater systems were, to a great extent, driven by the 1972 Clean Water Act. In Europe, the first major restoration projects included those in the Rhine, the Mersey, and the Danube Rivers, undertaken during the 1980s and 1990s. More recently, the European Water Framework Directive laid out the goal of achieving and maintaining a 'good ecological status' for surface waters in Europe, including its rivers, lakes, estuaries and coasts (2000/60/EC), which in turn has created significant efforts to restore the health of rivers across the continent. In Australia, the most significant river restoration effort has been the multi-billion dollar investment to restore river flows to the Murray–Darling Basin, a process started in 2006, although efforts to protect the basin extend much further back.

Until recently there have been limited examples of river restoration within developing countries. There are a number of possible explanations for this. Firstly, it may be that restoration has simply not been necessary. Until relatively recently, river systems within less developed countries or regions have been subjected to fewer stresses, although this is no longer the case in many places. Secondly, short-term economic growth through rapid industrialization and agricultural development has often been given priority over environmental issues, meaning that development has been allowed to progress at the expense of the environment. Finally, many developed countries are less likely to have had the institutional, technical or financial capacity to undertake many water resource management activities, including river restoration.

A number of common themes for how river restoration has evolved have emerged. The first step in the process is inevitably recognizing that there is a problem: that is, recognizing the impacts of human activity on rivers and river basins and the related consequences. This recognition often involved a major event or incident that brought widespread attention to what may have been a long-standing environmental problem. In the US, in 1969, the Cuyahoga River famously caught on fire in and, in part, spurred the introduction of the 1972 Clean Water Act. In the Murray–Darling Basin in Australia, algal blooms appeared in the 1990s, stretching more than 1,000 km, which captured the attention of policy makers and the public and was one of the early drivers of a series of reforms aimed at restoring flows in the basin.

Often linked to this recognition, has been a change over time in how communities use and rely on river systems, which is accompanied by a better understanding of the benefits of a healthy river. This understanding grows as rivers become degraded and ecosystem function declines. These changes can also be accompanied by changes in community values, including community views on what is valuable within the river system. As levels of development increase, communities tend to be less accepting of (or better able to object to) poor environmental health, including river health, and place a greater priority on environmental well-being.

In the first instance, the most common responses to address river degradation are measures aimed at conserving existing ecosystem function and limiting or reducing human impacts on rivers. Such measures, often under the banner of integrated water resources management, have included addressing the effects of point and diffuse pollution, and over-abstraction of water and development in the catchment, riparian zone, and the watercourse itself. Primary drivers of change have tended to be water quality (particularly point-source pollution in the first instance) and reducing flood risk through improving the condition of the floodplain.

More direct intervention has been undertaken where river systems have degraded to such an extent that removing existing impacts alone will not restore ecosystem function to the level required. This intervention can involve changes to alter the physical structure of the watercourse (e.g. to improve habitat), removing or reducing the impacts of barriers within a watercourse, increasing flows within the river, or re-vegetating important parts of the catchment and riparian zone.

More recently, river restoration has been characterized by greater integration with other aspects of human development, in recognition of both the challenge and importance of maintaining ecosystem function within highly developed river basins. Such integration acknowledges the limitations on restoration activities where major human influence is likely to remain, as well as the imperatives for improving river health as demands increase for water supply, flood protection and improved amenity, as well as protecting and enhancing ecological values. Linked to this integration has been recognition of the potential for river restoration to act as a catalyst for urban rejuvenation (e.g. the Mersey River), or to ensure the long-term sustainability of communities that are dependent on a declining river system (e.g. the Murray–Darling Basin).

Box 5: River restoration success stories

River restoration is still a relatively new discipline and practice that continues to evolve. Hundreds – if not thousands – of river restoration projects have now been implemented around the world with positive ecological and socio-economic outcomes. As a result, river restoration is increasingly seen as a mainstream approach in both ecosystem management and water resource management.

In North America, for instance, restoration efforts along the Columbia River have seen conditions improve for salmon populations (Diefenderfer *et al.*, 2013). Dam removal on rivers such as the Elwha has seen sediment flows to downstream reaches replenished (Peters *et al.*, 2015). Efforts to re-plan hydropower in the Penebscot River have begun to restore connectivity for 11 migratory fish species along 1,500 km of river while maintaining energy generation capacity and yielding US $5 m in jobs for the region (NOAA, n.d.). Invasive plant species have been successfully removed from the banks of south-western rivers, with benefits for native vegetation (Harms & Hiebert, 2006), and flow has been returned, albeit briefly, to the lower reaches of the Colorado river for the first time in years (Jensen, 2014). Across the US, the 1972 Clean Water Act has driven substantial reductions in pollution, especially point source pollution, in US rivers so that twice as many meet standards for swimming and fishing (Stoner, 2012).

Impacts of river restoration in Europe have also included significant improvements in water quality in rivers such as the Thames and Rhine as a result of major investment in wastewater treatment, driven by EU legislation. The Thames is now a focal point for cultural life in London and a thoroughfare for numerous pleasure cruises, after causing the 'Great Stink' of 1858 and being declared 'biologically dead' in the 1950s. Large restoration initiatives have been developed along some of the continent's major waterways. For example, approximately 60,000 hectares of floodplain wetlands have been restored along the lower Danube as a result of an international agreement signed in 2000 by ministers in Romania, Bulgaria, Moldova and Ukraine (WWF, n.d.). Many small restoration projects have led to improved habitats, increased amenity values and socio-economic benefits. The restoration of the Isar River in Germany is an example. This project provided new riverbank parkland for Munich and contributed to improved flood management. The European Centre for River Restoration's website[3] now lists 924 individual projects from 24 countries[4], which reflects the extent to which enthusiasm for river restoration has spread across the continent.

Success stories are not confined to developed countries. River restoration is gathering pace elsewhere, especially in Asia. In China, for instance, restoration of links between three floodplain lakes and the Yangtze River in Hubei Province resulted in rapid improvements in lake water quality, up to 17% increase in fishery inland production, increases in biodiversity and reduced vulnerability of downstream communities to flooding (Yu *et al.*, 2009). The results of these pilot restoration projects stimulated authorities in other provinces to replicate the river–lake reconnection approach. In Singapore, strategic concerns about water security led to significant investment in river restoration among a portfolio of measures. Through the Active, Beautiful Clean Waters (ABC) programme, rivers that were previously concrete-lined canals serving only one or two purposes (such as storm water drainage or reservoir replenishment) have been transformed into multi-functional waterways that increase environmental quality, enhance recreational opportunities and improve water quality. Importantly, this programme has also led to increased public awareness and ownership of river health (Liao, 2013).

3. http://www.ecrr.org/ accessed 20 July 2015
4. as at 20 August 2015

The following sections briefly summarize how river restoration has evolved in different parts of the world.

RIVER RESTORATION IN THE UNITED STATES

In many ways, river restoration efforts in the United States started with the Federal Water Pollution Control Act, otherwise known as the Clean Water Act, in 1972. The Act was passed at a time of national concern about untreated sewage, industrial and toxic discharges, destruction of wetlands, and contaminated runoff (US EPA, n.d.). The Act followed an number of high-profile incidents of water pollution: bacteria levels in the Hudson River that were 170 times the safe limit; record number of fish kills; and in 1969 a floating oil slick on the Cuyahoga River in Ohio that burst into flames (US EPA, n.d.). These incidents triggered a political response in the form of the Clean Water Act. The objective of the Act was, and still is, 'to restore and maintain the chemical, physical, and biological integrity of the nation's waters'.

The Act provides a mechanism for individual states to establish water quality standards, which determine acceptable pollution loads, the waters to be restored, and any protection measures. The Act also establishes a water permit system for pollution discharge. Before the 1987, the Clean Water Act programmes focused primarily on point source pollution. An amendment to the Act established a new federal programme to reduce pollution from diffuse sources such as agriculture. The programme provides grants to identify watercourses impaired as a result of non-point source pollution and to assist stakeholders implement best management practices to reduce runoff. The Clean Water Act in 1972 was accompanied by a significant commitment of financial resources and more than US $84 billion has been provided for wastewater treatment, non-point source runoff and watershed and estuary management (US EPA, n.d.).

While initial efforts as a result of the Act focused on improving water quality, more recently, the restoration of aquatic ecosystems is becoming commonplace in the United States (NRC, 1992). Restoration efforts are often undertaken to restore or improve natural resources that are of economic, cultural, or spiritual importance. Restoration typically occurs in a single reach or in reaches spread throughout a catchment; restoration includes both riparian and upland activities as well as activities in the lowlands, for example reconnecting floodplains and adding habitat structures to streams. The majority of these efforts have been undertaken to restore fisheries resources. In some cases, large sums of money are spent on a single species or group of species (Roni *et al.*, 2008). For example, hundreds of millions of dollars are spent annually in the Columbia River Basin; the Florida Everglades; the Missouri, Mississippi, and Sacramento rivers; the Louisiana Delta; Chesapeake Bay; and the Great Lakes. It is estimated that over US $1 billion is spent annually on various aquatic habitat rehabilitation activities in smaller catchments (Bernhardt *et al.*, 2005).

Naiman (2013) identifies four phases in the evolution of river conservation and restoration in the United States:

- Phase 1: a 'discovery' phase, or a period of exploration and understanding of how rivers function
- Phase 2: a 'conservation' phase, characterized by efforts to protect species and places
- Phase 3: a 'restoration' phase, aimed at re-establishing environmental functions and conditions
- Phase 4: an 'effective integration of actions' phase, where conservation and restoration measures are better integrated with broader social values and drivers.

The discovery phase challenges and refines the conceptualization of how rivers function as ecosystems. Seminal examples include:

- how river ecosystems change as they flow from headwaters to the sea (Vannote *et al.*, 1980)
- integration of the effects of large dams and reservoirs on river corridors (Standford and Ward, 1983)
- discovery of new dynamics in hyporheic zones (Stanford and Ward, 1988; Boulton *et al.*, 1998)
- incorporation of the roles of large animals in shaping streams (Naiman, 1987)
- realization of the importance of floods (Junk *et al.*, 1989; Poff *et al.*, 2010)
- seasonal flows
- riparian zones (Décamps, 1996; Naiman and Décamps, 1997)
- habitat mosaics (Stanford *et al.*, 2005)
- spatial dynamics of species and populations that have adapted to and prosper in continually changing habitats (Fausch *et al.*, 2002)
- emergence of large river perspectives on what sources of organic matter drive ecosystem characteristics (Thorp and Delong, 1994).

Aquatic ecologists recognized during this discovery phase that freshwater biota were poorly inventoried (Stiassny, 2002; Balian *et al.*, 2008), and that freshwater biota lost species faster than terrestrial or marine ecosystems (Sala *et al.*, 2000; MEA, 2005), and were facing mounting anthropogenic impacts (Naiman *et al.*, 1995; Strayer and Dudgeon, 2010). About the same time, it was realized that productive river fisheries are maintained by landscape processes (Naiman *et al.*, 1987; Bisson *et al.*, 2003; Hilborn *et al.*, 2003), that anthropogenic climate change is real and is influencing aquatic systems worldwide (Schindler *et al.*, 1997), and that freshwater biodiversity is in steep decline and not a theoretical or future problem but an ongoing and accelerating one (Dudgeon *et al.*, 2005.

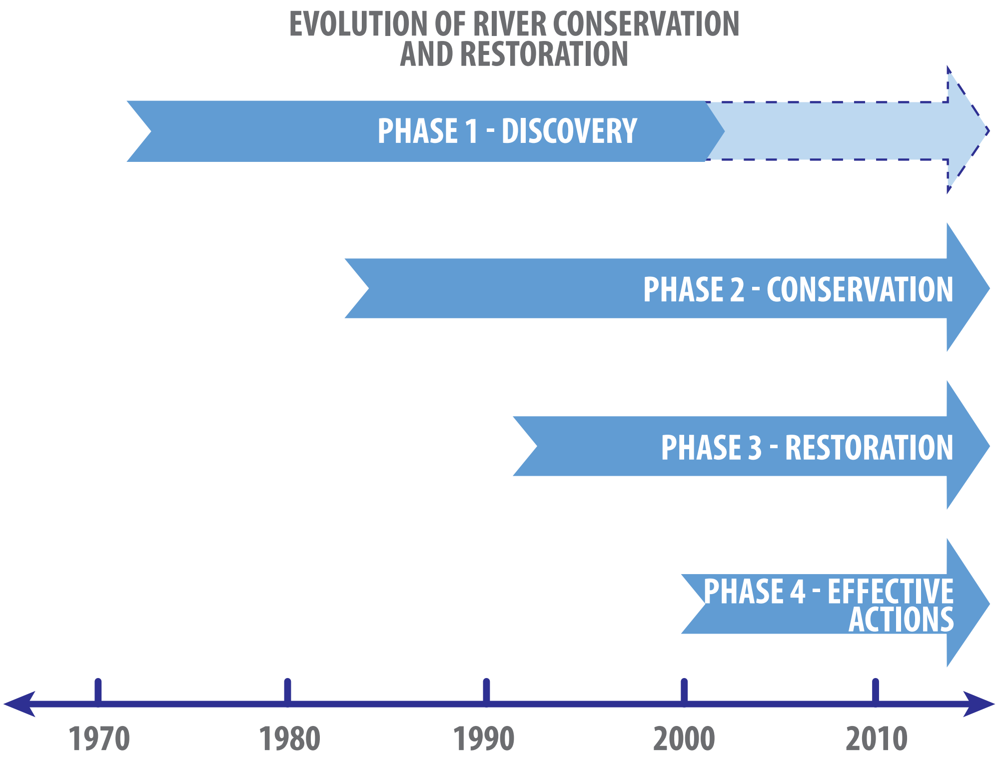
As human populations and economies continue to expand in North America, rivers are exploited for power generation, shipping and water extraction as well as modified for flood control and other purposes to the point where most rivers and floodplains are now physically and functionally altered (Poff *et al.*, 2007; Vörösmarty *et al.*, 2010).

In response to the improved understanding of rivers as ecologically dynamic yet dramatically altered by poorly informed human actions (Phase I), came the rises in conservation (Phase 2) (Kareiva and Marvier 2012;) and restoration efforts (Phase 3) (Roni, 2005). Unfortunately, while considerable knowledge was gained in the discovery phase, it has not been sufficient to make conservation and restoration generally successful in North America (Bernhardt *et al.*, 2005; Roni *et al.*, 2008). Early conservation efforts focused on legally designating endangered or threatened aquatic species for protection, buffering critical habitats by leasing water rights and riparian zones, establishing local conservation easements, identifying critical habitats or remaining strongholds, purchasing segments of streams and creating catchment councils and associations (Boon *et al.*, 2000). Nearly all conservation efforts have been directed at selected places and species of concern in critical but often isolated river or stream habitats. Likewise, river restoration has been, for the most part, focused on recreating structural attributes (e.g. channel form, minimum flows, pools and riparian cover) based on assumptions that ecosystem functions will follow (Good *et al.*, 2003; Humphries and Winemiller, 2009; Palmer and Filoso, 2009; Palmer 2010).

The need to bridge the gap between science and application, and science and people, marks the emergence of Phase 4 – effective integration of actions (Naiman, 2013). This phase emerged in the last decade and acknowledges the social-ecological complexity associated with river restoration (e.g. multiple owners, jurisdictions, interests, values, and public involvement). Contemporary activities seek solutions that balance the intertwined social and ecological issues, and these activities are advancing in important national and international programs (e.g. Naiman, 1992; Rogers, 2006; Rogers *et al.*, 2013).

All four phases in the evolution of river conservation and restoration continue today (Figure 2.7).

Figure 2.7. Four phases in the evolution of river conservation and restoration



Source: Naiman, 2013.

RIVER RESTORATION IN AUSTRALIA

Australia's rivers have been spared much of the industrial and urban pollution that has beset rivers in Europe, the United States, and Asia due to the nature of its economy and size and density of its population. In most instances, freshwater degradation in Australia has been linked to agriculture, including as a result of abstraction and clearing vegetation and associated catchment degradation. During the 1980s and 1990s, concerns grew over water quality in the Murray–Darling basin, the most significant basin in Australia for agricultural production. These concerns related to salinity levels due to high levels of dryland salinity across the basin, and high nutrient loads from fertilizers, which resulted in algal blooms. At the same time, over-allocation and over-abstraction of water for irrigation had significant impacts on river flows, affecting instream ecosystems, neighbouring floodplains, and the river estuary (see Connell, 2007). More recently, major concerns have been raised over the impact of agriculture and land use practices on the quality of water discharged into the Great Barrier Reef (QAO, 2015).

A number of measures have been implemented to address these issues, including a massive investment to improve river flows in the Murray–Darling basin. The federal government committed A $12.9 billion over ten years in water buybacks, infrastructure to improve water use efficiency and policy reforms. This includes A $3.1 billion to purchase water entitlements in the basin to be returned to the river for environmental purposes (DEWHA, 2008). Entitlements are being purchased under a voluntary, market-based programme.

Despite being a marine water body, the Great Barrier Reef has also been important to the evolution of river restoration practices in Australia. Poor water quality and the impact of high nutrient and sediment loads and pesticides in the river systems that drain into the reef are the most significant threats to the reef's health. In response, the Reef Water Quality Protection Plan (Queensland Government, 2013) was prepared with the objective of halting and reversing the decline in the quality of water entering the reef from the neighbouring catchments by 2020. The plan also has a target that by 2018 the total nitrogen and phosphorus loads and the amount of pesticides at the end of the reef catchments will be reduced by 50% and 60% respectively, and that there will be a minimum of 70% groundcover of dry tropical grazing land. The plan proposes that by 2018 there will be a 20% reduction in sediment load. Responsibility for implementing the plan is shared across a range of federal, state and local government bodies. Key actions include working in association with landowners to address the major sources of the pollutants and research into improved agricultural practice to reduce total pesticide and fertilizer inputs, and promoting and adopting best agricultural practice across the reef catchments. Voluntary industry codes of practice, such as those in the cotton, sugar, and beef industries, aimed at improving agricultural practice to reduce impacts on freshwater and related resources are also central to dealing with catchment degradation and associated water quality issues.

In addition to these major restoration initiatives, Australia also has considerable history in traditional riparian and catchment restoration projects in small and medium-sized catchments. These projects have primarily been led by local government, catchment management authorities, or community groups and have involved activities such as planting of riparian restoration, re-establishing instream habitat, and removal of invasive species, particularly invasive fish (Price *et al.*, 2009).

Approaches to river restoration have shifted significantly over time. For example, in Southeast Queensland, in response to growing community dissatisfaction with the state of the regions waterways, early efforts focused on addressing point source pollution, primarily through improved wastewater management (Bunn *et al.*, 2010). With this work predominately completed, diffuse pollution is considered the most significant threat to river health and restoration endeavours are now concentrated on improving land use practice and rehabilitating degraded parts of the riparian zone and upper catchments. At the same time, there has been significant progress in improving urban planning and design to support and enhance freshwater and freshwater-dependent ecosystems. This includes streetscape planning and design to achieve better stormwater management (Saxton, 2013).

RIVER RESTORATION IN SOUTH KOREA

Accelerated industrialization and urbanization since the 1960s have greatly altered river ecosystems in South Korea. Physical factors affecting river ecosystems include the construction of instream barriers; channelization through levee construction; dredging; gravel mining; floodplain reclamation; over-withdrawal of river water; and alteration of the watershed by deforestation and land use practices. Channelization of rivers is common. Water quality in South Korea's four major rivers is poor, and mid-sized and small streams, especially urban streams, are in worse condition. Water quality issues and flow diversions have profoundly altered river ecosystems in South Korea. These changes and associated problems have resulted in changes to the way that rivers are managed, including restoration efforts (Woo and Choi, 2013).

River management in South Korea – and the related river restoration – is regarded as having moved through five distinct phases since the start of major urbanization and industrialization in the 1960s:

1. managing 'natural' (i.e. relatively undisturbed) rivers
2. managing rivers to control disasters such as floods and droughts
3. exploitation, with significant development in floodplains, riparian zones, and even over the river channel itself, resulting in 'occupied rivers'.
4. restorative phase involving altering rivers to improve their amenity values ('park rivers')
5. restoration phase aimed at improving ecological values ('ecological rivers') (Woo, 2010).

South Korea's first restoration project was the Han River Project (1982–1986). The project was initiated by the Seoul Metropolitan Government and involved the floodplains along the Han River in Seoul being developed for a 'riparian city park' and the river was used for recreational boating. The approach has subsequently been adopted by a number of other Korean cities.

The most significant river restoration project undertaken in South Korea has been the 'Four Major Rivers Restoration Project', a multi-billion dollar project completed in 2011 at a total cost of approximately US $17.3 billion and aimed at modifying nearly 700 km of river channel. The project has been a major engineering endeavour aimed at improving water security, in terms of water quantity, water quality, and flood control, primarily through the construction of new dams and the removal of sediment (Shin and Chung, 2011; see Table 2.3).

Table 2.3. Summary of works and budget associated with Korean Four Major Rivers Restoration Project

Classification	Contents	Amount	Cost (£ billion)	Total cost (£ billion)
Main rivers	Sediment removal	520 million m^3	2.9	9.4
	Dams and embankments	16	3.5	
	Ecological restoration	537 km	1.2	
	Embankment reinforcement	377 km	0.5	
	Eco-friendly bike trail	1,206 km	1.0	
	Water quality improvement facilities	353	0.3	
Tributaries	Ecological restoration	392 km	0.5	2.9
	Embankment reinforcement	243 km	0.4	
	Eco-friendly bike trail	522 km	0.1	
	Water quality improvement facilities	928	1.9	

Source: Shin and Chung, 2011

The extent to which river restoration should focus primarily on beautification of rivers and increasing their human amenity (i.e. park rivers) versus returning rivers to a being functional ecosystems (creating ecological rivers) remains a point of on going debate in South Korea. Two different restoration models have emerged, one for each of these differing objectives – the Amenity Restoration Model and the Ecosystem Restoration Model (Woo and Kim, 2006).

RIVER RESTORATION IN CHINA

In a way, the history of 5,000 years of Chinese civilization is a history of river management. China is a country with frequent floods and droughts, and early river management was focused on engineering-based flood prevention and water supply, including creating levees, concreting river channels and constructing dams and weirs. While these measures helped protect against floods and increased water supply, a failure to recognize the ecosystem functions of rivers and a lack of measures to protect or restore river ecosystems resulted in destructive changes in the ecological balance. Over recent decades this approach has led to deteriorating river conditions and an associated ecological crisis.

With the development of China's modern economy and society, some of the negative effects of river engineering works have become more apparent. New management and restoration techniques are being considered based on a better understanding of the ecological roles of rivers and in the new millennium, river restoration has increasingly been the focus of policy makers and academics, with a variety of studies and practices emerging. River restoration in China does, however, remain in the early stages of development, and restoration approaches that can address river ecosystems as a whole remain elusive.

The period from 2000–2005 marked a nascent phase of river restoration in China. During that period, some Chinese scholars began to study and introduce international approaches to river restoration and to build local understanding of the science of river restoration. At the same time, the Chinese Government started to adopt a systematic approach to implementing river restoration, initially focused on building capacity and collating domestic experiences on restoring rivers.

Since 2005, river restoration has been evolving rapidly, seeing a shift from theoretical discussion and framework development to identifying and assessing methods, measures and techniques. Currently, river restoration programmes are targeted at key elements and functions of river ecosystems, such as restoration of riparian vegetation, river management from the perspective of landscape ecology and restoration of water quality through water pollution control. A major focus has been on restoration of urban rivers, with projects completed in more than 40 cities. Pilot projects have also focused on improving overall river management for ecological restoration. This approach has been adopted in a number of basins that have suffered from extreme ecological degradation, including in the Hei, Shiyang and Tarim river basins, all of which are located in the more arid north of the country.

The objectives of river restoration projects in China vary with location. In the north of the country, where water resources are scare, most restoration projects are focused on implementing environmental flows, restoring aquatic habitat, and generally improving river health. In the south, the focus is more on improving water quality and reducing water pollution.

China's river restoration efforts have been undertaken in catchments with a wide variety of sizes, ranging from the Hei River with a drainage basin over 30,000 km^2 to the Zhuan River (located in Beijing) with a drainage area of only several dozen square kilometres. Different restoration methods and techniques have been used in different types of catchment. For larger river basins, restoration is commonly incorporated as part of a river management plan aiming to restore elements of the river ecosystem and create a better balance between ecological protection and socio-economic development. For rivers with smaller catchments, techniques like dredging, riparian management and landscaping are used.

In addition to engineering techniques, responsible agencies recognize the importance of having key concepts and requirements for river restoration in government directives or industry standards. A number of government directives and standards are now in place, including:

- Guidelines on Protection and Restoration of Water Ecosystems (MWR, 2004)
- Technical Guidelines on Planning and Design of Urban Wetland Parks (trial), (Issued by the Ministry of Housing and Urban-Rural Development in 2005)
- General Planning Guidelines for National Wetland Parks (Issued by the State Forestry Administration in 2010)
- Technical Specifications for Ecological Environment Assessment (issued by the Ministry of Environmental Protection in 2006).
- Guidelines for aquatic ecological protection and restoration planning (Issued by MWR in 2015) (see Box 6).

In summary, river restoration in China is evolving and improving with new techniques and processes continuing to emerge. As part of this process, two important trends are evident in China's river restoration efforts: (i) a shift from issue-specific restoration to integrated solutions to restore river ecosystems more broadly; and (ii) the integration of river restoration into broader river management plans.

Box 6: Guidelines for river restoration planning in China

In 2015 the Chinese Ministry of Water Resources released new guidelines for river restoration planning. The Guidelines for aquatic ecological protection and restoration planning capture tasks related to current condition survey and assessment, overall planning for river restoration, ensuring minimum environmental water requirements, maintaining and improving water quality, river/lake landscape protection and restoration, protection of important habitats and biodiversity, protection and restoration of key eco-regions, and ecological monitoring of rivers and lakes.

The guidelines specify that the baseline assessment should include collection and assessment of basic information related to the basin, planning data, historical monitoring data about the natural and social environment, hydrologic condition, water resources availability, and the condition of the aquatic environment.

The planning process is required to consider the natural and socio-economic characteristics of the planning region, recognize constraints on the use of land and water resources, specify the guidelines and requirements for ecological protection and restoration of river and lake ecosystems, including establishing goals and actions for maintaining and restoring the lake/river eco-system functions.

Source: GIWP

RIVER RESTORATION IN EUROPE

Although there are records of attempts to reduce pollution and other anthropogenic impacts on rivers as far back as the sixteenth century, what would now be recognized as river restoration started in Europe in the 1980s. Early restoration projects focused on returning the form of the river (its sinuosity) rather than ecosystem processes, and bioengineering for bank stability. An important early driver for large-scale river health improvement stemmed from a desire to restore water quality through large-scale investment in wastewater treatment. European Union legislation has been particularly important since the 1990s, especially for addressing water quality problems. For instance, the Urban Waste Water Treatment (UWWT) Directive, which was adopted in 1991, obliged EU Member States to address pollution from domestic wastewater and certain types of industrial effluent. As well as provisions on planning, monitoring and information about wastewater treatment, the UWWT Directive required the collection and at least secondary treatment of wastewater in all towns with a population greater than 2,000 and stipulated that pre-authorisation would be needed for all discharges of urban wastewater, of discharges from the food-processing industry and of industrial discharges into urban wastewater collection systems. These requirements stimulated a significant investment in wastewater treatment in many EU Member States. In the UK alone, investments in enhanced treatment of wastewater between 1990 and 2015 have been estimated at £26.1 billion (approximately US $40 billion at 2015 exchange rates) (DEFRA, 2012).

Subsequently, river restoration projects have been further encouraged by other EU directives, including the 1992 Habitats Directive and the 2009 Birds Directive, which together require the establishment of a network of protected areas across Europe, called the Natura 2000 network. The Habitats Directive in particular requires features of the landscape that are of major importance for wild flora and fauna including rivers to be managed. The 2007 EU Floods Directive is also significant because it requires EU Member States to take action to mitigate flood risk, including by implementing natural flood management measures that river restoration can contribute to.

Perhaps most importantly, the 2000 EU Water Framework Directive (WFD) states that EU Member States must ensure that, subject to some defined exceptions, all water bodies (including rivers) must attain 'Good Ecological Status' by 2027 at the latest. The ecological status of a water body is assessed in relation to the quality of its biological community (including fish and invertebrate biodiversity), its hydrological characteristics and its chemical characteristics. EU Member States are also required to prepare river basin management plans on a transboundary basis, if necessary, which set out programmes of measures for ensuring that water bodies attain Good Ecological Status and that their status does not deteriorate. These plans are renewable on a rolling, six-year basis with the first period covering 2009–2015, the second 2015–2021, and so on. Another important feature of the WFD is its emphasis on public participation during the design and implementation of river basin management plans.

Since the advent of the WFD, river restoration in Europe has gained momentum. This is not surprising given that analysis by the European Environment Agency of the first set of river basin management plans showed that less than half the surface water bodies in the EU would attain Good Ecological Status by 2015 (EEA, 2012). The European Centre for River Restoration's RiverWiki documents 881 river restoration projects from 31 countries.[5] Although approaches to river restoration vary, the emphasis in the WFD on more comprehensive assessments of the ecological status of rivers has shifted the focus of restoration initiatives so that many are now more holistic in nature and less focused on single species (Smith *et al.*, 2014).

Some of the most significant river restoration cases from Europe are described below.

The Rhine River was a free-flowing system until 100 years ago when the mainstream was altered into the most important shipping canal in Europe to transport goods. Regulation measures included channelling the mainstream; constructing dams, weirs, sluices, dikes; and closing estuarine river mouths. The

5. https://restorerivers.eu/wiki/index.php?title=Main_Page accessed 20 July 2015

combined effect of these measures and other human activities, such as pollution, was a drastic decline in aquatic species.

In 1963, the states bordering the Rhine River developed the Convention of the International Commission for the Protection of the Rhine (ICPR) in response to deteriorating water quality. The participants in this commission are Switzerland, France, the Netherlands, Germany, Luxembourg, and the European Union since 1976 (Van Dijk *et al.*, 1995). Agreements on emission reductions, oxygen concentration improvement, organic compounds and heavy metal loads of the Rhine River were reached. However, the river was declared ecologically dead in the early 1970s when an acute mercury pollution wave led to massive mortality among aquatic species. This pollution wave led to a chronic problem due to bioaccumulation in the food chain (Carbiener *et al.*, 1990).

During the early 1980s, decreases in effluent discharges and improvements in wastewater treatment along the Rhine and its tributaries reduced pollution levels (Lelek *et al.*, 1990), resulting in a slight recovery of the biological communities. In November 1986, another heavy pollution wave called the Sandoz Accident occurred after a fire in a chemicals warehouse in Basle, Switzerland. In response to the Sandoz Accident, the ICPR developed the Rhine Action Program for the ecological restoration of the river.

More recently, the ICPR, and other stakeholders in the basin have successfully implemented urban wastewater management strategies and dramatically improved the water quality of the Rhine. In the past 15 years, adopting new, integrated policies has restored a substantial area of floodplains in the densely populated Rhine delta. In fact, the River Rhine received the first International River Foundation European Riverprize in September 2013 and the international RiverPrize in 2014 for remarkable achievements in integrated river basin management following a 50-year legacy of river degradation.

Historical attempts at restoration of the Danube River began in the 1940s with nature reserves designated along the river. Since then, restoration has been undertaken across much of the 2,800 km length of the Danube and its tributaries. However, until relatively recent agreements, including the 1994 Convention for the Protection of the Danube River and the WFD, there had been little coordination of activities at a basin level. As a result of improved co-ordination, modern restoration has involved a combination of large-scale, strategic, multi-project, cross-border restoration projects such as the Lower Danube Green Corridor and the Danube-Mura-Drava UNESCO Biosphere Reserve; and smaller, localised projects such as those in the Isar and Wien rivers (tributaries of the Danube flowing through Munich and Vienna respectively). Restoration has been instigated in response to a variety of issues including legislation and international conventions, concerns about urban amenity, biodiversity restoration and community lobbying. For example, the Danube National Park in Austria was designated and restored as a result of public protests at a planned dam construction on the site.

The River Thames begins in the Cotswold Hills, England, and flows west to central London and into the North Sea. At 294 km in length, the Thames is the second longest river in the UK. Its 16,133 km2 catchment is home to 13 million people and the river has been heavily degraded through hundreds of years of industrial and anthropogenic pollution. A number of milestones have marked this degradation: the Great Stink of 1858 forced politicians out of parliament, but ultimately led to reform of the city's sewers; the 1953 floods, which resulted in the death of 307 people, led to improved flood planning; and the 1957 declaration that the Thames was biologically dead led to a revaluation of the Thames as an important ecosystem (Francis *et al.*, 2008).

These events have cumulatively led to a multi-billion pound investment that has resulted in the River Thames being regarded today as one of the cleanest, heavily urbanized rivers in the world and it has been claimed to now support the widest biodiversity of any estuary in Europe (Lavery and Donovan, 2005). At the same time, the number of rivers in the Thames catchment classified as having water quality that is 'very good' has risen from 53% in 1990 to 80% in 2008 (Francis *et al.*, 2008). According to the more stringent assessment of river health required by the EU Water Framework Directive, there are significant restoration challenges still to be met in the Thames basin. An interim classification of the 398 riverine water bodies in the basin concluded that only 83 had attained Good Ecological Status as required by the WFD. As at 2014, most of the remaining 237 water bodies were classified as having Moderate Ecological Status, 61 were classified as having Poor Ecological Status and 16 as having Bad Ecological Status (Environment Agency, 2014).

The restoration of the River Mersey in the north-west of England is, in many ways, demonstrative of the history of river restoration in the UK (Batey, 2013). In the 19th Century, the north-west of England became one of the world's first industrialized regions. Urban areas expanded due to rapid industrial growth. Domestic sewerage systems were based on untreated disposal directly into rivers and the sea. The manufacturing industry established along the region's rivers and new canal system, which served as the major conduits for removing and transporting industrial waste. By the second half of that century, the River Mersey, and its major tributary, the Irwell, which in 1721 had supported fish as a commercial industry, had become so grossly polluted that a Royal Commission was appointed to report on the problem. However, little priority was attached to addressing these issues by the municipal authorities and, as late as the 1980s, the Mersey was the most polluted estuary and river system in the UK (Jones, 2000). Throughout the 20th century, progressive changes to legislation and institutions, including the formation of ten Regional Water Authorities across the UK in 1974 (including the North West Water Authority which served the Mersey Basin), brought about improvements to the river's health. Even so, towards the end of the century the region's waterways remained among the most polluted in the world, and industrial decline was manifested in dereliction, poor housing and growing social problems.

The poor state of the environment was particularly difficult in and around the region's watercourses. By the early 1980s, rivers and canals had become a serious constraint to urban regeneration and economic revival. After 150 years of pollution, a 25-year multi-billion pound, government-sponsored 'clean-up' campaign was implemented in 1985, to clean up the Mersey and its tributaries. The project was a pioneer in cross-sector (public–private–voluntary) partnerships and, in the period it was active (1985–2010), made significant progress in improving water quality, promoting waterside regeneration, and engaging stakeholders in the region (Batey, 2013).

RIVER RESTORATION IN SINGAPORE

Since Singapore's political independence from Malaysia in 1965 (and even before), water security has been an issue for an island state with limited freshwater supplies. Water security, and particularly sufficient high-quality water for consumptive purposes, has been the major driver behind river restoration efforts.

The Singapore River was the heart of the town during British colonisation of Singapore (Dobbs, 2003). By the time Singapore gained independence, the river had become heavily polluted, prompting concern for lost development opportunities (Chou, 1998). In 1977, the government officially began a large-scale, 10-year project to clean up the Singapore River (along with the Kallang basin), with the goal of bringing thriving aquatic life back to the river (Chou, 1998). The sources of pollution along the riverbanks were identified, including pig and duck farms, squatters, street hawkers, industries, and vegetable wholesale activities, from which garbage, sewage and other waste were dumped directly into the river. With strong political will, these sources were removed, garbage cleared, and the riverbed dredged. The subsequent monitoring indicated that the river had become significantly cleaner and aquatic life had returned. The clean up allowed for intensive business and residential redevelopment along the waterfront, which is now a major tourist attraction of Singapore.

The clean-up project is significant for Singapore's water resource management for two reasons. Firstly, it marks the start of the separation between drainage and sewer systems, which enables Singapore to harvest stormwater at a large scale (Khoo, 2009). Secondly, the clean-up project highlighted the multiple values of a clean waterway, including socioeconomic benefits (Chou, 1998). The transformation of the Singapore River has inspired many subsequent efforts of waterway rejuvenation, with clean and aesthetically pleasing waterways seen as a positive feature of the living environment (Malone-Lee and Kushwaha, 2009).

More recently, the ABC Waters Programme, launched in 2006 by Singapore's national water authority Public Utilities Boards (PUB, 2008), aims to guide sustainable stormwater management and channel enhancement projects across Singapore. In the past decades, the urge for water security and flood control has led to heavy channelization of most of the streams and rivers in Singapore, with several larger rivers dammed at their mouths. Drains, canals and reservoirs have dominated the waterscape. Despite the proximity to residential and commercial areas, these waters are largely external to the everyday life of people, as they have been managed solely for rainwater collection and storage, and for drainage efficiency for flood control.

The ABC Waters Programme is transforming the utilitarian drains, canals and reservoirs throughout Singapore into 'beautiful and clean streams, rivers and lakes with postcard-pretty community spaces for all to enjoy' (PUB, 2011, p.4). The programme aims to foster a sense of ownership by better integrating the reservoirs and waterways with the urban landscape (PUB, 2008). It also seeks to simultaneously improve the water quality, physical appearance, recreational value, and biodiversity of the waters. While targeting waterways and reservoirs, the ABC Waters Programme also addresses the impacts of storm water runoff generated from the urbanized catchment.

While water security remains the main driver for the ABC Waters Programme, the aspiration for a higher quality of urban life also plays an important role. Singapore's authorities believe that a cleaner and greener living environment would increase the city's competiveness and attract foreign investment to fuel economic growth (Tan *et al.*, 2009). The transformation of the Singapore River from a heavily polluted area into a fashionable neighbourhood played a key role to inspire such notion that clean waters lead to higher quality of living (Malone-Lee and Kushwaha, 2009).

2.5. Emerging challenges

River restoration is now being undertaken in a context that is increasingly complex and uncertain. This is creating challenges for traditional river restoration methods. Some of the emerging issues and common challenges are outlined below.

1. Returning rivers to a natural state is not feasible in most situations

Many early river restoration initiatives had a goal of returning rivers to a 'pre-development' or 'natural' state. Accordingly, many of the river restoration approaches and guidelines that have developed internationally have this goal in mind, with restoration targets based on historical conditions or by referencing similar (but undisturbed) rivers. The degree of change in river basins around the world means that, in many cases, returning rivers to a pre-development condition is now physically or economically impractical and would require unacceptable limitations on current and future human activities. Further, in areas where rivers have been altered by human development for centuries, such as in China, the concept of a river's 'pre-development' condition is almost meaningless given the extent and duration of human-induced alterations. As a consequence, water resource managers have needed to change the way they approach restoration, particularly in setting restoration targets.

2. Balancing the multiple roles of a river

Historically, many river restoration projects were implemented in response to a single driver, and with a primary outcome in mind – most commonly improved water quality. In heavily developed basins, with a range of competing users, river restoration is now often required to achieve multiple and, at times, conflicting, objectives (Palmer *et al.*, 2014). For instance, restoration goals may concurrently include improved water quality, enhanced amenity to support urban development or recreational activities, flood protection, promoting biodiversity, and improved navigation. These concurrent goals require balancing the natural functions of the river with specific human needs, and can require trade-offs in the planning process. They also require agreement with a range of stakeholders about the trade-offs when setting priorities and objectives.

3. Complexity and scale

Increasingly, it has become apparent that many restoration projects have failed as a result of tackling issues at the wrong spatial scale (Roni *et al.*, 2002; Palmer and Filoso, 2009). Notably, where the drivers of river degradation are at the basin scale, responses need to be designed accordingly, and local restoration projects alone are unlikely to be successful. Operating at a larger scale requires engaging with a broader range of stakeholders and linking to a wider range of planning and management instruments, some of which may sit outside the traditional water management processes and institutions (Rieman *et al.*, 2015). At the same time, budget, capacity and institutional constraints inevitably limit the scope of potential responses, particularly in the face of the large, complex, and widespread problems that impact on river basins.

Spatial disconnect between the causes and consequences of poor river health can present particular challenges. Where river degradation is a result of activities at the basin-level, the capacity of local groups to address local problems diminishes. Local governments or community groups are unlikely to have the resources, capacity, or institutional mandate to deal with problems that originate beyond their jurisdiction. This implies the need for different institutional and funding models to support river restoration.

4. Increasing uncertainty over future conditions

Restoration projects need to result in river ecosystems that are resilient to future stresses and risks, not just for historic conditions. For example, efforts to improve water quality need to consider any changes in the basin that will affect the inputs and processes that drive water chemistry and water quality outcomes. The gross uncertainty over the future of river basins makes this challenging. Among other factors, there is uncertainty relating to changes in climate, land use, population growth, and urban development. Restoration also needs to allow for shifts in human values and belief systems.

5. Ensuring the sustainability of river restoration

Ensuring that the benefits of river restoration are enduring is challenging with multiple dimensions. Firstly, it requires financial sustainability. Restoration projects are seldom maintenance-free, and funds may be required for ongoing management costs. Secondly, sustainability requires that future activities within the basin do not undermine the restoration gains. This requires that restoration activities be undertaken with a view to the likely future state of the basin (e.g. future development), as well as ensuring appropriate planning, regulatory and monitoring systems are in place. Thirdly, sustainability requires that a river ecosystem have the adaptive capacity to maintain its restored condition; that is, to be self-sustaining, ideally by maintaining a dynamic equilibrium with minimal further interventions.

6. Scientific support for river restoration

The scale and complexity of river management and restoration issues is challenging the capacity of our scientific understanding of rivers to identify when and what action is necessary to best address declining river health. Equally, scientists are being required to demonstrate, with a high degree of certainty, the benefits that can be expected from the significant investment of public funds (see for example QAO, 2015). While restoration science has advanced significantly in recent decades significant challenges remain to ensure our understanding of river ecosystem function improves, and is appropriately applied by river managers. The divide between restoration science and practice is seen by many as a cause for concern and as a factor that has contributed to failure and inefficiency in restoration interventions (Wyborn *et al.*, 2012; Guillozet *et al.*, 2014). It is also apparent that a number of core ecological principles have often not been appropriately used in restoration efforts, while at the same time restoration practices in common use should be subject to a greater level of scientific rigour (Palmer, 2008).

In addition, political and other factors can drive management responses that are not supported by the underlying science. For example, improving the amenity values of rivers has increasingly become a driver for river restoration. Focusing on this driver can lead to restoration approaches that focus on superficial elements of the river system – such as landscape gardening – and ignore the underlying natural river processes (Woo and Choi, 2013).

In setting out a framework for a strategic approach to river restoration, Chapter 3 considers approaches to respond to these and other challenges.

CHAPTER 3
FRAMEWORK FOR STRATEGIC RIVER RESTORATION

OVERVIEW AND KEY MESSAGES

This chapter sets out a conceptual framework for strategic river restoration. It is followed by a description of how restoration strategies and plans relate to one another and other planning instruments. The chapter concludes with a discussion of the key dimensions of river restoration, including spatial, temporal, and thematic aspects. The key messages from the chapter are:

- Increasingly, ad hoc or small-scale river restoration interventions are unlikely to be successful. Rather, the dynamic and complex nature of river ecosystems requires a strategic approach to river restoration. The approach needs to be systems-based, responding to underlying drivers of degradation, and balancing trade-offs within the basin.
- In most cases, coordinated delivery of planning, implementation and monitoring of restoration activities is required on a basin or regional scale with local-scale delivery capabilities.
- Restoration strategies need to identify and respond to the links between external drivers, catchment processes, river health and the provision of ecosystem services, and societal priorities.
- Restoration strategies should reflect the priorities of local communities while at the same time ensuring broad consistency with strategic objectives.
- River restoration can be supported by a combination of policies, strategies, and project-level plans. These different instruments need to be aligned and to develop synergies with one another, as well as with other regulatory and planning instruments such has river basin, development, and conservation plans.

3.1. Considerations and rationale for a strategic approach

River ecosystems are dynamic systems. The structures and processes supported and maintained by healthy rivers result in a continual development or evolution of the basin (Fischenich, 2006). Natural riverine processes can result in changes to the physical, chemical or ecological make up of the river. Changes can be the result of individual events, like a flood, or as a consequence of tectonic movement over thousands or millions of years. The large fluctuations in river flow between droughts and floods, as well as the range of flows in between, all affect the river's physical, chemical and ecological make up. While natural processes have resulted in the evolution of river systems for millennia, increasingly, anthropogenic factors, whether incidentally or by design, are also having a major influence on river system structure and function (see section 1.2). At the same time we are seeing an evolution and escalation of the demands for the services that rivers provide to society.

The complex, dynamic and inter-related nature of river and human systems mean that ad hoc measures are unlikely to respond to the challenges of basin-scale river management and restoration (see section 2.5). Indeed, evidence increasingly suggests that many past river restoration efforts have failed due to being undertaken at the wrong spatial or time scale (Roni *et al.*, 2002), addressing the wrong problems, or implementing the wrong measures (González del Tánago *et al.*, 2012). Furthermore, there is limited monitoring or assessment of restoration outcomes to support assessments of what has worked and what has not (Bernhardt *et al.*, 2005).

Addressing these and related issues requires a more strategic approach to planning and implementing restoration activities, which requires three things.

Firstly, it necessitates a systems-based approach. Understanding both the physical river system and the socio-economic, political and cultural aspects of the system are equally important to successful river restoration. The restoration process needs to:

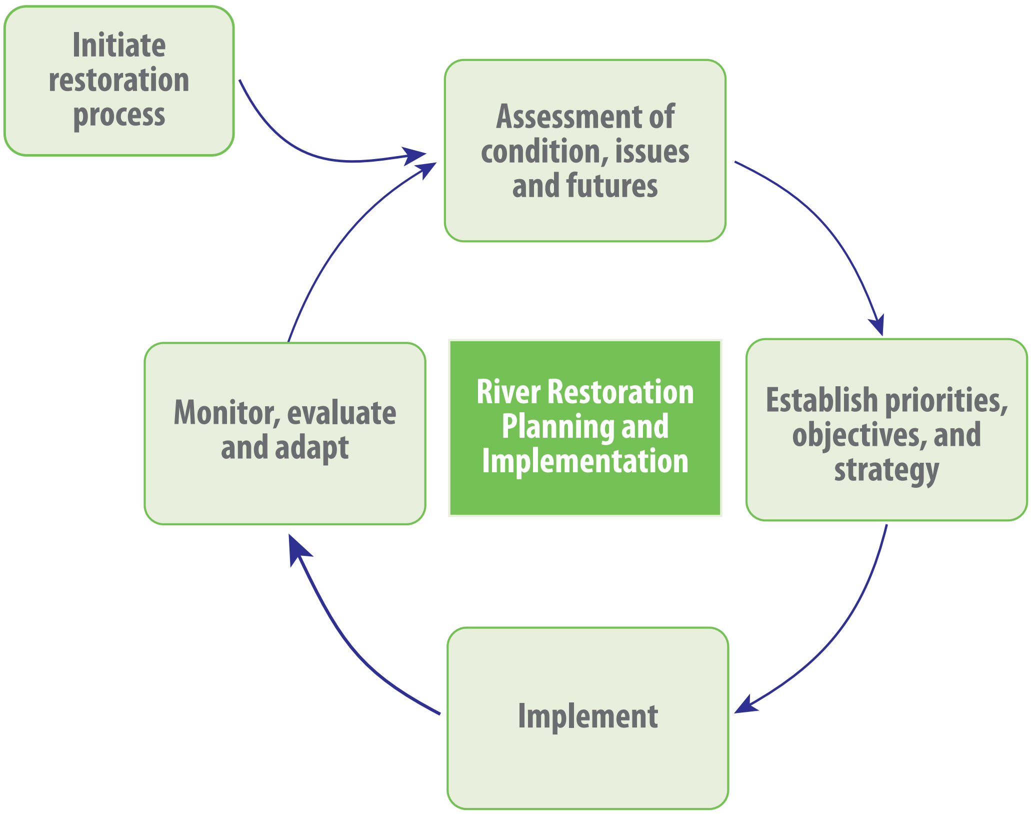
- work with the dynamic nature of the river ecosystem and the multiple basin-level processes that drive system function and change it over time
- respond to the underlying drivers of the restoration: interventions need to be relevant to both the causes of ecosystem degradation (e.g. land use in the upper catchment), as well as the motivations for addressing that degradation (e.g. demands for improved water quality)
- align with broader development plans and water resource plans, to ensure both that restoration measures will support development objectives and that current or future developments do not undermine the restoration measures and the provision of ecosystem services over time.

Secondly, achieving strategic outcomes requires that the restoration process strike an appropriate balance between human and freshwater systems. River ecosystems are the source of limited, but potentially renewable, natural resources, and their capacity to provide different services to society varies depending on the demands placed on them and the way they are managed. This implies a greater role for river restoration planning in balancing trade-offs, including:

- Balancing human demands and those of the natural environment. For example, to determine which natural functions and processes should be maintained, which regions protected or restored, and those areas where development will be prioritized.
- Balancing the different human demands on a river system. Agriculture, flood management, and hydropower production, for example, all have different and, at times, conflicting needs of the services provided by a river. Even within the same group of users, conflicts can occur. Water resources management needs to prioritize between these uses, and those priorities need to be considered and supported by the restoration process.
- Balancing different river functions. River restoration needs to recognize the different functions that a river performs and to determine which are to be prioritized. This also requires recognition that a river will perform different functions in different geographic regions within (and outside) the basin.

Finally, strategic river restoration requires an adaptive approach. Restoration strategies are inevitably developed in the absence of perfect information about the condition of the target river, and how it will respond to different interventions. Restoration relies on assumptions about how river function will change as a result of implementing the proposed restoration measures. Societal demands are also likely to evolve. However, none of these outcomes are certain. This uncertainty requires that, at their core, river restoration strategies have an adaptive management approach. Central to the notion of adaptive management is the idea of an ongoing process of planning, implementation, monitoring and adaptation (see Figure 3.1). This should provide a mechanism for testing the assumptions that underpin the restoration strategy, and for adjusting that strategy where evidence suggests that a different approach is likely to be more effective, or where new objectives are identified. Monitoring and adaptive management are discussed in detail in Chapter 5.

Figure 3.1. The adaptive nature of developing and implementing a river restoration strategy or plan



3.2. Conceptual framework for strategic river restoration

This section presents a framework for strategic river restoration (see Figure 3.2). The framework identifies the conceptual linkages between physical elements of a river ecosystem, the demands placed on it by human activities, and the considerations involved in determining the most appropriate restoration responses. The framework is designed to address to the challenges set out in section 2.5 and is a prelude to the restoration planning process described in section 3.8.

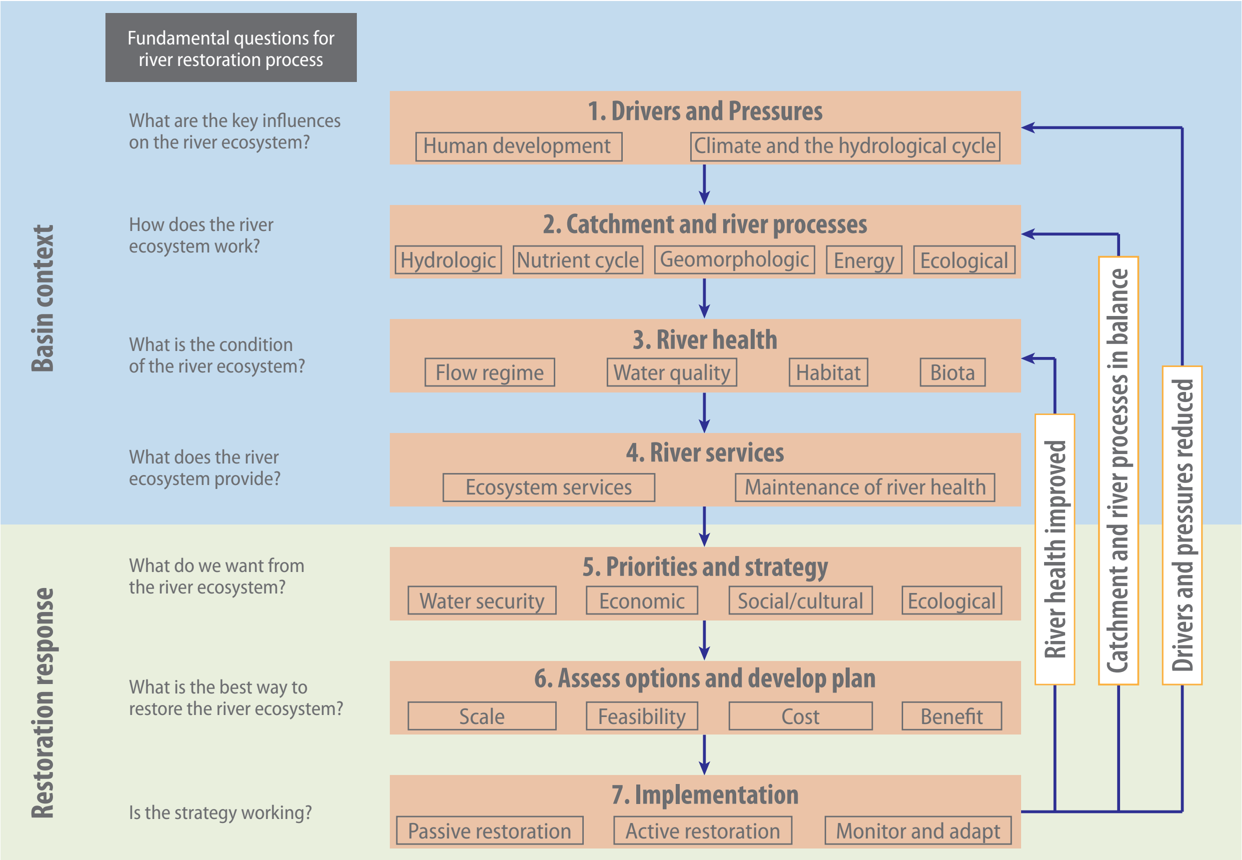
The framework consists of seven components. The first four components relate to the basin context. These components are primarily addressed in the planning process through the situation assessment (see section 4.2). The last three components relate to the restoration response, which involves developing and implementing a river restoration strategy (see section 4.3). For each component, the framework identifies a fundamental question. These are the core questions that need to be considered in developing a strategic approach to river restoration.

BASIN CONTEXT

The first component of the framework relates to external drivers. These are the factors that influence the river's natural processes and the societal needs that impact on it. External drivers include human development, such as agriculture, urbanisation, or other land use change, which can result in physical changes within the system. Climate change is also an external driver and links to both human development and the hydrological cycle. It is important to know how these drivers are likely to evolve over time, or what new drivers are expected to emerge. The key question here is: What are the key influences on the river ecosystem?

The second component relates to the catchment processes that influence the condition and function of the river ecosystem. Catchment processes include hydrologic processes, nutrient cycling, geomorphological process such as the erosion of the landscape and the movement of sediment, the movement of energy through the basin, and biological processes. Restoration needs to be undertaken with an understanding of how these processes drive and/or constitute the river ecosystem, how they interact with one another, and the implications of changes to those processes, ultimately with a view to establishing an appropriate balance between the processes The key question here is: How does the river ecosystem work?

Figure 3.2. River restoration conceptual framework



River restoration requires an understanding of the elements that make up the river ecosystem that together constitute river health (component 3). This understanding forms the baseline for decision-making, setting targeted and measurable objectives and monitoring outcomes. River health can be considered in terms of the flow regime, water quality, the physical form (such as the river channel and floodplains, which create the habitat), and the biota (see section 1.1 and Figure 1.3). As well as understanding river health at a point in time, it can be critical to identify trends in river health such changes in water quality or in biota; how that is likely to affect other aspects of the river system; and how river health is expected to change into the future. The key question here is: What is the composition and status of the river ecosystem?

Central to the concept of strategic river restoration is recognition of river services – the benefits that rivers provide for people and nature (component 4). Understanding river services involves understanding the role of the river, both in the natural environment and in supporting human society. Understanding the capacity of a river to provide ecosystem services, as well as its role in maintaining ecological health, is essential to support decision making. With this information it is possible to consider the benefits derived from the river, who benefits, what benefits have been lost or are threatened as a result of changes within the basin, and what is the potential for improved services in the event that river health and related function is improved. The key question here is: What does the river ecosystem provide?

RESTORATION RESPONSE

The context of the basin should inform the decision-making process around the river restoration response. Firstly, understanding the basin context allows for decisions to be made on priorities and strategies: determining to what extent the restoration process should be targeted towards objectives and outcomes related to conservation and protection, economic development, social and cultural benefits, and water security (component 5). These decisions should be informed by a combination of environmental, social and developmental objectives and by the scope for the river system to meet those needs, based on the existing condition of the river system, as well as current or future drivers of change. The key question here is: What do we want from the river ecosystem?

Prioritizing objectives is fundamentally a strategic issue and involves at least some political judgements. In contrast, assessing options and planning their implementation is primarily a technical process, relying on various tools (in turn predicated on biophysical and social sciences) to identify the best approach for achieving the strategic objectives for the basin (component 6). The costs and benefits associated with different restoration strategies need to be considered, alongside feasible measures, the level of stakeholder support and the appropriate scale to undertake the restoration. The key question here is: What is the best way to restore the river system?

The final component of the framework (component 7) relates to implementation. As well as the actions that give effect to the restoration strategy, this component incorporates the adaptive management aspects of river restoration. Restoration measures and their impacts need to be monitored and evaluated to determine whether the assumptions around how the river ecosystem would respond were correct, or whether changes to the approach need to be made. The key question here is: Is the strategy working?

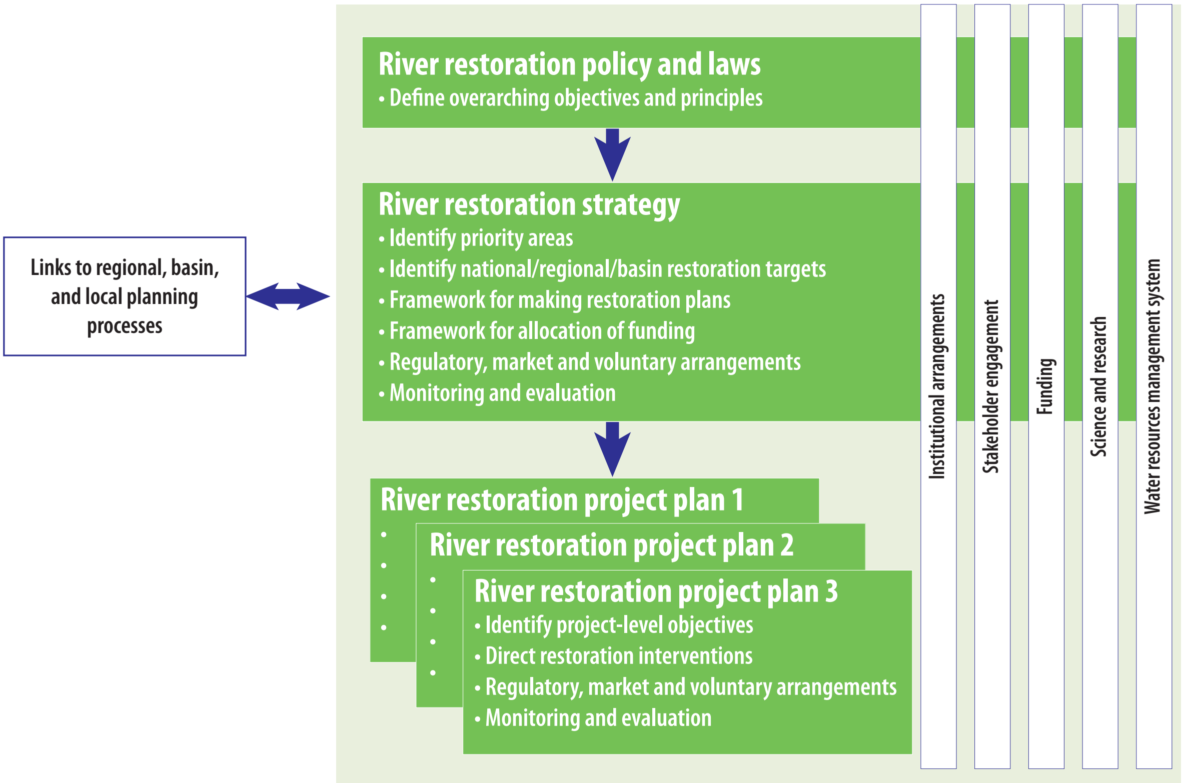
3.3. Planning hierarchy

River restoration can require coordination at numerous spatial and administrative scales, including at the national, basin, river, or reach level. As such, plans and other instruments relevant to river restoration can include:

1. National or regional policies or laws. For example, laws or policies these may define overarching objectives for river health outcomes, such as water quality targets, or objectives related to protecting or restoring important ecological assets. Policies and laws related to restoration are discussed in more detail in section 7.2.
2. National, basin, or regional river restoration strategies. Strategies might identify priority areas and high-level goals for restoration and set restoration targets for either inputs or outcomes. These strategies can provide a framework for decision making and allocating funds at the local or project level. This could also be considered the 'programme level' for restoration responses.
3. River restoration project plans. These plans define the objectives and actions to be taken as part of a particular intervention. A river restoration plan may target a particular area (e.g. a reach-level riparian restoration project) or a particular issue (e.g. improving river flow).

These three categories can be presented as a top-down hierarchical structure, with national policies and laws informing the restoration strategy, which in turn guides project-level restoration plans (Figure 3.3).

Figure 3.3. River restoration planning hierarchy, showing linkages between restoration policy, restoration strategy, and restoration project plans



In practice, many different approaches can exist. River restoration strategies are seldom developed on a blank canvas – rather, strategies are often required to fit around an existing suite of laws, policies, plans, and projects. As such, restoration planning can occur from the top-down, for example where national policies are already in place (e.g. the Spain National River Restoration Strategy; Box 7), or bottom up, where local efforts have preceded coordinated action at a higher level and where national policies or strategies may be retrofitted to align with approaches that have already been adopted on the ground (e.g. the Puget Sound Salmon Recovery Plan; Box 7). In practice, there may be an iterative approach involving both top-down and bottom-up components, as has been the case in the Danube River basin, for instance.

Box 7: International experience in aligning restoration plans

Spain

Spain as a member of the EU is committed to achieving the targets set by the EU Water Framework Directive (WFD) for improving the ecological status of its water bodies. The WFD is a key overarching policy that guides river restoration activities in the country. To guide promote, and support efforts to satisfy the WFD requirements, the Spanish Ministry of the Environment initiated a National Strategy for River Restoration in 2006 (see further Box 8). One of the goals of the strategy was to set, at a national level, principles and procedures to assist river basin agencies in applying the WFD and defining restoration measures to be included in river basin management plans.

Figure 3.4. Hierarchy of restoration instruments in Spain

Source: González del Tánago *et al.*, 2012

Columbia River, United States

Restoration of the Columbia River is coordinated via three levels of program organization: (i) a basin-wide level that contains the programme vision, scientific foundation, biological objectives, general strategies and implementation provisions that apply generally across the programme and are implemented throughout the basin; (ii) an ecological province level that divides the Columbia River Basin into 11 unique ecological areas, each representing a particular type of terrain and corresponding biological community; and (iii) a sub-basin level, with integrated plans that contain the specific objectives and measures for the 58 sub-basins and mainstem reaches of the Columbia, as well as a separate plan tying together the mainstem Columbia and Snake rivers and a plan for the Columbia River estuary. Completed in 2005 by Northwest Power and Conservation Council, the sub-basin plans identify priority restoration and protection strategies for habitat and fish and wildlife populations in the United States portion of the Columbia River system. Plans help guide the future implementation of the Council's Columbia River Basin Fish and Wildlife Program, which redirects ~US $250 million per year of electric revenues to protect, mitigate and enhance fish and wildlife affected by hydropower dams. Sub-basin plans integrate strategies and actions funded by others, thus ensuring that each plan serves the Council's purposes under the Northwest Power Act and also meets the legal requirements of the US Endangered Species Act and the US Clean Water Act.
Source: Naiman, 2013

Puget Sound, Washington State, US

Under state water resources law, the Washington State is divided into regions for water resource planning, known as Water Resource Inventory Areas (WRIAs). At the time of preparing the Puget Sound Salmon Recovery (PSSR) Plan, which was adopted in 2007, many of the WRIAs were already undertaking catchment-based recovery planning. The PSSR planning process recognized the importance of local knowledge and ownership of the recovery work, as well as the need for strategies that responded to the characteristics of the local sub-catchments. The PSSR Plan therefore incorporated the individual plans prepared by local sub-catchment recovery planning groups from across Puget Sound. While each catchment has developed its own strategy for salmon recovery, the PSSR plan identifies the top ten actions required for salmon that are found throughout the various sub-catchments.
Source: Batey, 2013

Southeast Queensland, Australia

The Southeast Queensland Natural Resource Management Plan 2009–2031, (SEQ NRM Plan) is the over arching non-statutory planning document for the region that sets measurable targets for the condition and extent of the environment and natural resources. Measurable regional targets were established for various themes, including water. River restoration is a management action in multiple documents that underpin the SEQ NRM Plan to achieve regional targets for water, including the SEQ Healthy Waterways Strategy (2007–2012). Under the strategy are specific plans, such as the Non-Urban Diffuse Source Pollution Management Action Plan, which aims to reduce non-urban diffuse pollutant loads by 50% of the by 2026.

Source: Saxton, 2013

Murray-Darling Basin, Australia

In Australia, the Murray–Darling Basin Plan sets 'sustainable diversion limits' for subcatchments across the basin. These limits establish the long-term average level of water abstractions for different parts of the basin that are to be achieved to meet ecological targets. In many parts of the basin the volume of water that may be taken under existing water entitlements held by consumptive water users (irrigators and others) exceeds the limits set by the basin plan. To give effect to the plan, the Australian Government developed the Water Recovery Strategy for the Murray–Darling Basin, which sets the proposed approach for reducing the volume of consumptive water entitlements and improving environmental flows. This includes investments in water use efficiency measures and buying back water entitlements from farmers and other users. The Murray–Darling Basin Plan provides the framework for guiding the Restoring the Balance buyback program for the location and volumes of water required for environmental purposes.

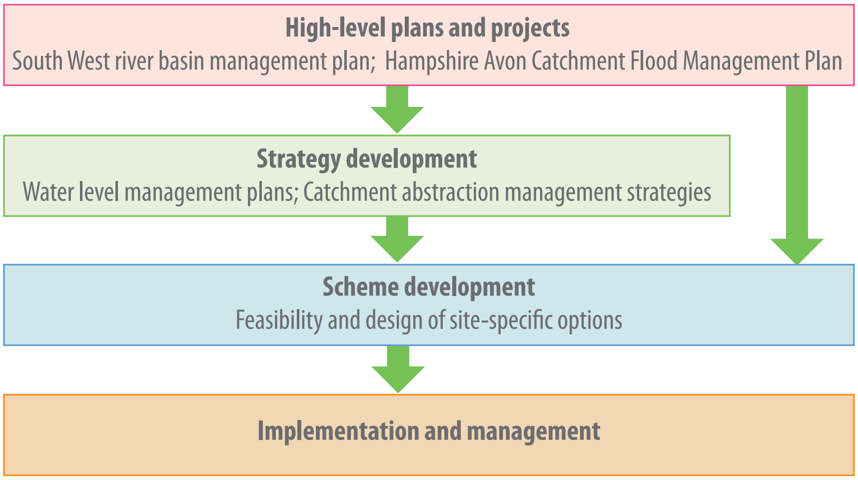
Source: Commonwealth of Australia, 2014

The Hampshire, Wiltshire and Dorset River Avon, United Kingdom

To support the restoration of the River Avon, UK, a strategic framework was developed by a partnership that included the Environment Agency, Natural England, Wessex Water (the local water utility) and a number of fishing and conservation trusts. The strategy set out a plan for the physical restoration of the 200 km river and its key tributaries. The restoration strategy recognized that it was one of a number of initiatives aimed at addressing issues in the river basin, with parallel projects to address issues related to flow, water quality, diffuse pollution and water level management. The role of the strategy, and where it fits within the broader hierarchy of plans and actions, is similar to other major restoration efforts (Figure 3.5).

Source: Halcrow and GeoData Institute, 2009

Figure 3.5. Strategic framework for restoration of the Avon River



Source: Adapted from Halcrow and GeoData Institute, 2009

CROSS-CUTTING ISSUES

In addition to the core restoration strategy and planning instruments, there are a number of crosscutting issues that need to be addressed in a coordinated way (Figure 3.3). These issues include:

- the water resources management system, to ensure alignment with other tools for managing the water resources in the basin
- science and research, to provide a scientific basis for assessing issues, risks, priorities, options for action, and monitoring and evaluating the effectiveness of actions, both from a physical and social science perspective
- funding for river restoration, to ensure resources are available to implement and maintain restoration measures
- stakeholder engagement, to provide inputs to the planning process including identifying priorities for restoration, and to promote support and compliance

- institutional arrangements, to ensure governance arrangements that support coordinated and consistent actions.

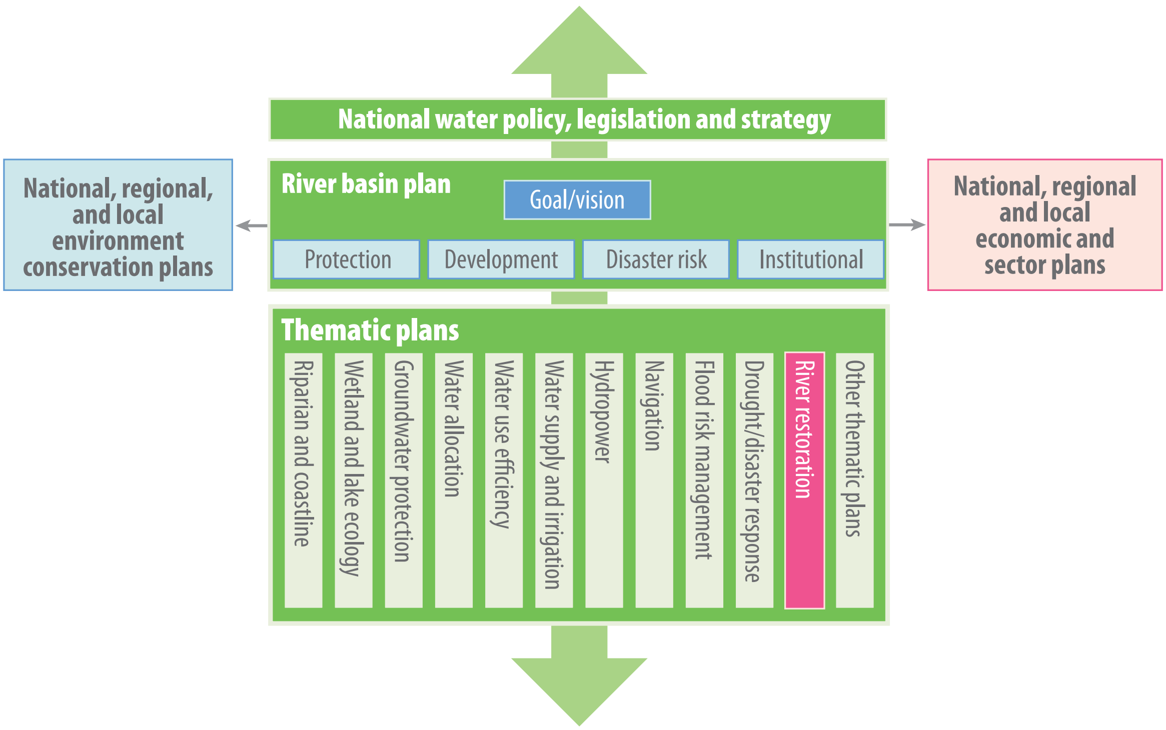
These elements and their role in the river restoration are considered in more detail in Chapter 7.

RIVER RESTORATION AND RIVER BASIN PLANS

Strategic river restoration requires that policies, strategies and plans be developed with a clear understanding of long-term development and conservation objectives and priorities. To this end, restoration planning needs to be informed by existing regional, basin, and local planning instruments. The basin plan is critical. Basin plans can help identify current and future activities within the basin, set basin-wide targets for the use and condition of water resources, and may provide linkages to development and conservation plans relevant to the basin. All of these factors should be considered in restoration planning.

River restoration strategies can be a mechanism for achieving the goals set out in a basin plan (see Figure 3.6). Under such a scenario, the restoration strategy can be one of a number of theme-based instruments established to coordinate different activities within the basin to achieve the overarching goal or vision. For example, the 2012 Murray–Darling Basin Plan establishes objectives and outcomes for the basin, while the basin's Water Recovery Strategy sets out the proposed approach to achieve the limits on water use and environmental flow objectives set by the plan (see Box 7).

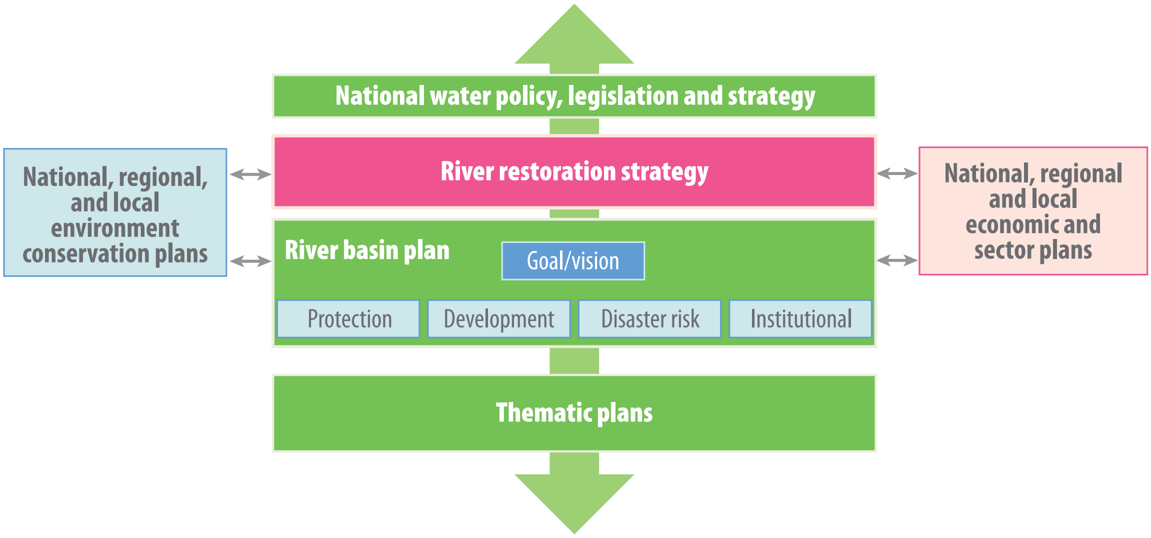
Figure 3.6. Interface between development and conservation plans, the river basin plan and thematic plans, showing river restoration as one of the thematic plans giving effect to the basin plan



Source: Adapted from Pegram et al., 2013

Alternatively, a restoration strategy may be superior to the basin plan, such as where a national restoration strategy is in place, in which case the basin plan may need to be developed or amended to meet the overarching restoration goal and objectives (Figure 3.7). This is the situation in Spain, for example, where the national restoration strategy defines principles, procedures and measures to be adopted in river basin management plans (see Box 7).

Figure 3.7. Interface between development and conservation plans, the river basin plan and thematic plans, showing the river restoration strategy as superior to the basin plan



RIVER RESTORATION AND OTHER WATER PLANS

River restoration strategies inevitably overlap with other water resources management plans – plans that have the potential to either support or undermine restoration efforts. Equally, restoration measures can improve or hinder outcomes under those other plans. There is the potential both for conflicts and synergies between restoration plans and other water resources management plans. This highlights that substantial effort may be needed from river restoration planners and those leading other planning processes to ensure that thematic plans are sufficiently, if not perfectly, aligned. In summary, river restoration strategies should:

- recognize the limitations on restoration potential imposed by other thematic plans
- support the objectives set by other thematic plans where possible
- drive changes to other thematic plans to support restoration objectives.

These risks and opportunities need to be considered as part of the planning process, as well as during implementation. Some of the key linkages are described below and shown in Figure 3.8.

Basin water allocation plans determine how much water is available to different users within a river basin. Allocation plans have a major impact on the flow regime including, either explicitly or implicitly, determining the water set aside for environmental flows (Speed *et al.*, 2013). Restoration measures may be limited in their capacity to improve river health where flow is the limiting factor to river health. In these cases, restoration strategies need to either:

- recognize the limits of what is feasible (e.g. in terms of river health) given existing water allocations and constraints on flows
- provide a mechanism for adjusting water allocations to improve environmental flows, for example through buying back of existing water entitlements or linking to changes to water allocation or dam operation rules.

Water quality protection plans aim to ensure that the water within a river system is fit for purpose: such as for human consumption, for irrigation or to achieve ecological objectives. As a key component of river health, improving water quality is often an objective of restoration projects. At the same time, many other restoration objectives may be unsuccessful where water quality is poor. As for water allocation issues, this means that restoration strategies and plans need to either:

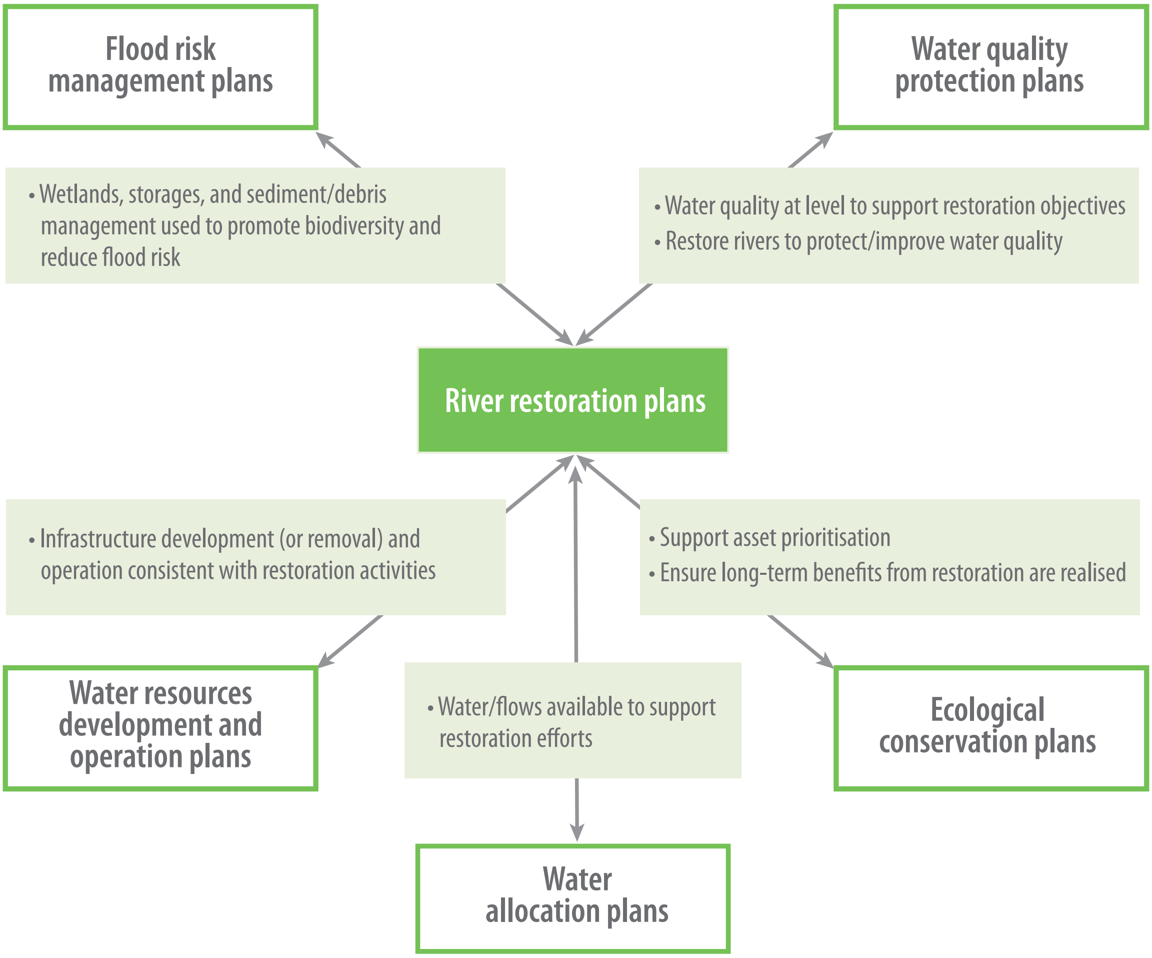
- recognize the target water quality for different parts of the basin and implications for restoration objectives, for example where water quality is expected to be relatively poor, to ensure that any restoration measures will not be undermined by the poor water quality
- adjust water quality objectives (and related actions) to align with broader restoration goals, for example through amendments to the relevant water quality protection plan.

Restoration measures also offer the potential to improve water quality and contribute to achieving the objectives set by water quality protection plans (Pegram *et al.*, 2013).

Flood risk management (FRM) plans should aim to manage the whole of the flooding system in an integrated way. FRM plans and related strategies can interact with restoration efforts in various ways. Strategies could involve changes to the flow regime or the construction of infrastructure – such as dams or levees – which could impact on proposed restoration sites or objectives. At the same time, some restoration measures, such as those related to the conservation of upland catchments, wetlands or floodplains, also contribute to reducing flood risk (Sayers *et al.*, 2013).

Ecological conservation plans can closely align to restoration plans, but are not necessarily the same thing. Restoration plans can contribute towards achieving biodiversity or related outcomes that are established by a conservation plan. At the same time, conservation plans can be crucial for protecting the benefits from restoration efforts by limiting activities within a conservation zone. This can provide a refuge for threatened species, support re-colonisation, and generally limit the extent of aquatic and riparian degradation and thus reduce the need for future restoration.

Figure 3.8. Linkages between river restoration plans or strategies and other thematic plans



3.4. The different dimensions of river restoration

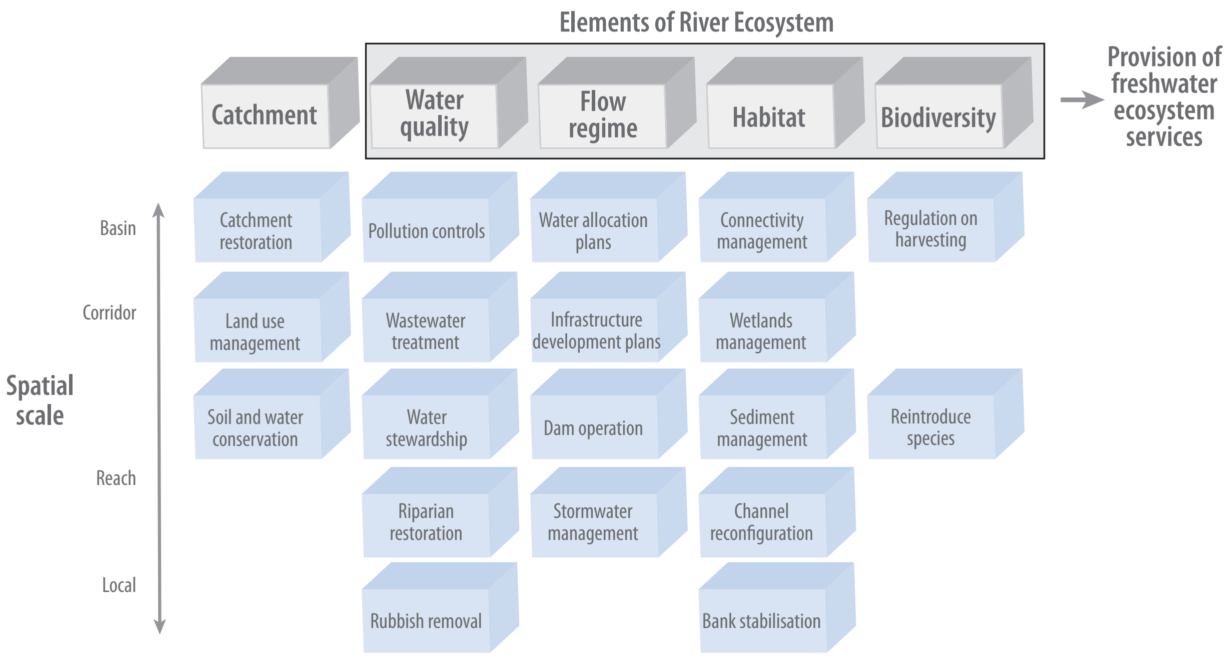
River restoration needs to be considered in terms of three dimensions:

1. spatial scale: where within the basin different restoration measures are undertaken
2. time scale: when different measures should be implemented, as well as the timeframe for responses, i.e. improvements in river health
3. range of measures: the different types of activities that can be undertaken to achieve restoration objectives.

Deciding how these three dimensions should be addressed for a particular river restoration strategy is at the core of the planning process – a restoration plan should elaborate the actions that should be taken, when, and at what spatial scale. The actions will depend on a combination of factors, including the nature of the problems in the river basin, what the restoration strategy is trying to achieve, and practical considerations such as the financial and technical resources available.

Figure 3.9 shows examples of restoration measures targeting different elements of the river basin, and undertaken at different spatial scales. Measures will also be undertaken at different temporal scales. The figure is only indicative, and measures may be undertaken at a multiple scales depending on the situation, or to achieve multiple outcomes in terms of river health and ecosystem function.

Figure 3.9. Relationship between the elements of a river ecosystem, different restoration measures, and the spatial scale at which interventions are made



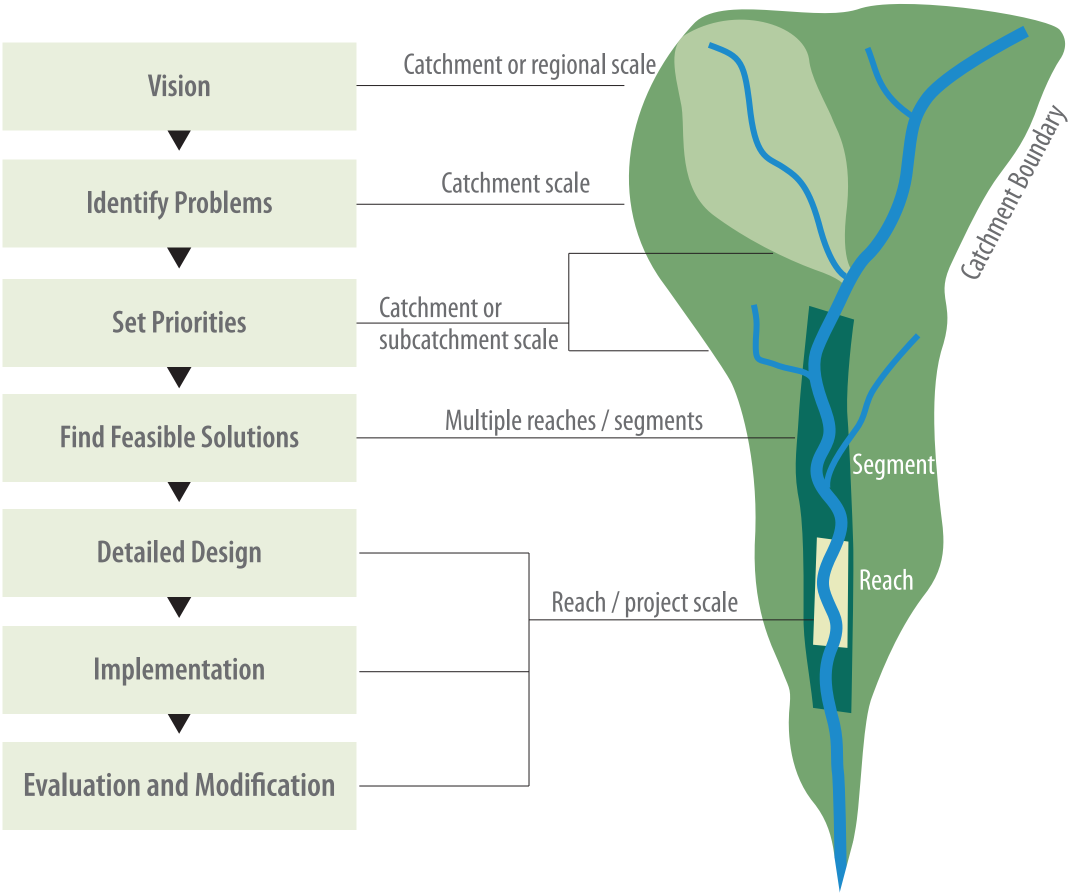
3.5. Spatial scale

Spatial scale is important in river restoration for a number of reasons. Firstly, it is important because of its ecological significance. Different ecosystem processes can occur at the regional or landscape scale, or at a basin, river corridor, reach, or local scale. Understanding the scale at which different processes occur helps inform the most appropriate response.

Secondly, spatial scale is important because of its political dimension. Where rivers cross administrative boundaries, restoration objectives and actions need to link to other planning instruments at the appropriate scale. Administrative boundaries may also limit the extent to which a planning agency has a mandate to undertake restoration activities.

Finally, spatial scale is relevant because different steps in formulating and implementing river restoration strategies and plans will necessarily need to take place at different scales. For example, the process of setting a vision and identifying problems might need to take place at the basin scale. Based on this, priorities might be set at a sub-catchment scale, and ultimately restoration projects designed and implemented at the reach level or at an individual location (see Figure 3.10). Some restoration interventions may need to be implemented across scales. Therefore, a particular river reach might be identified as a problem area by catchment scale analysis; more detailed analysis might then be required at a local scale to understand the drivers of degradation (i.e. the specific causes of the problems) and the options for restoration action within that reach.

Figure 3.10. Spatial scale relevant to different steps in the restoration planning process



Source: Rutherfurd et al., 2000.

River basins are now widely acknowledged as the optimal planning scale for freshwater ecosystems (Kersher, 1997; Alexander & Allan, 2007). However, restoration planning is not always possible or indeed necessary at this scale, depending on the legal and political context, and the nature of the ecological challenges to be addressed. It is also relevant to distinguish between the scale of planning and the scale of Implementation (Hermoso *et al.*, 2012). While it may be preferable (where feasible) to plan at the basin level, this does not mean implementation is necessarily required at that same scale (i.e. at a basin-scale). Rather, whole-of-basin processes need to be considered in the planning process, but an optimal response may involve only implementing responses in selected areas.

Different types of interventions will also take place at different spatial scales. Efforts to restore flows might involve changes to basin-level water allocation, for example via a water allocation plan. Alternatively, more localised flow management issues might be addressed by changes to operational rules for a reservoir or hydropower plant. Likewise, management of pollutant loads might involve whole-of-basin regulatory measures or, alternatively, local action to address specific discharges by a particular user (see Figure 3.9).

It is important to note that the same activity will have different impacts on the basin depending on where it is undertaken. For example, the ecological benefits of removing a dam to enable fish passage are likely to be significantly greater if the dam is located near the river mouth, compared with one in the upper catchment (Gilvear *et al.*, 2013).

3.6. Time scale

Evidence suggests that many river restoration projects fall short of their objectives as a result of failure to focus on the appropriate time scale, including the failure to recognize the long timeframes required to achieve effective restoration (Hilderbrand *et al.*, 2005).

As with the spatial scale, the time scale is relevant to river restoration for a number of reasons. The first relates to the natural evolution of river systems. Rivers naturally undergo a process of evolution over hundreds and thousands of years. It is important to recognize the history of a river and the way the river has evolved over time.

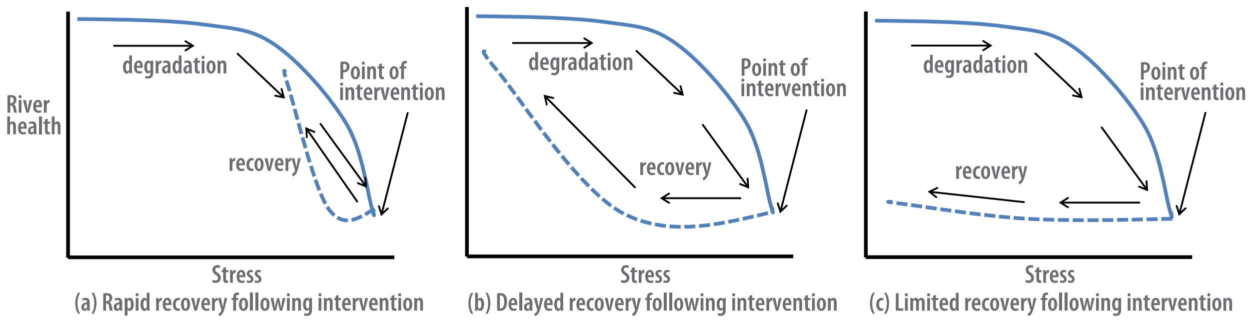
Secondly, the time scale is important from the perspective that rivers experience natural variability on a seasonal or annual basis. In particular, stream flows will alter a result of natural variations in rainfall and runoff. River restoration needs to account for and support that natural variation. Restoring rivers to a static condition is unlikely to be successful.

Thirdly, the time scale needs to be considered in terms of sequencing responses. It is seldom possible to undertake all restoration measures at a single point in time, due to practical, financial or resourcing constraints. More commonly, restoration programmes may be undertaken over years, or even decades. The restoration planning process needs to consider which activities should be taken and when. It is relevant to consider:

- Time critical interventions: for example, where actions are required to stop rapid on going or irreversible degradation or actions that can only be implemented during particular seasons, e.g. if low flow conditions are required.
- Ecological significance of sequencing: for example, there may be little point in reintroducing a native fish species if the water quality or habitat are not yet able to support that species. Improving water quality or habitat should be the first priority.
- Project management considerations: such as the most efficient sequencing of activities from a project implementation perspective. For example, if one (high priority) task is planned for a particular location, it may be more efficient to complete other future tasks planned for the location at the same time.

Fourthly, time scale is relevant when setting objectives. It is necessary to consider recovery rates, and what timeframe is realistic for river health to improve after restoration works are completed and/or stressors are removed. In this regard, (i) recovery rates are not necessarily linear and can vary significantly depending on the situation (see Figure 3.11) and (ii) the long timeframes necessary to achieve full recovery should not be underestimated. Ecological restoration is often trying to achieve in a matter of years what takes decades or centuries under natural conditions (Hilderbrand *et al.*, 2005). This can be important for considering which activities can demonstrate a level of success in the short term, which can be important for maintaining the political and local support for the restoration work.

Figure 3.11. Trajectories of degradation and restoration, showing changes in river health as stresses increase and then are alleviated by restoration measures. The arrows demonstrate change over time



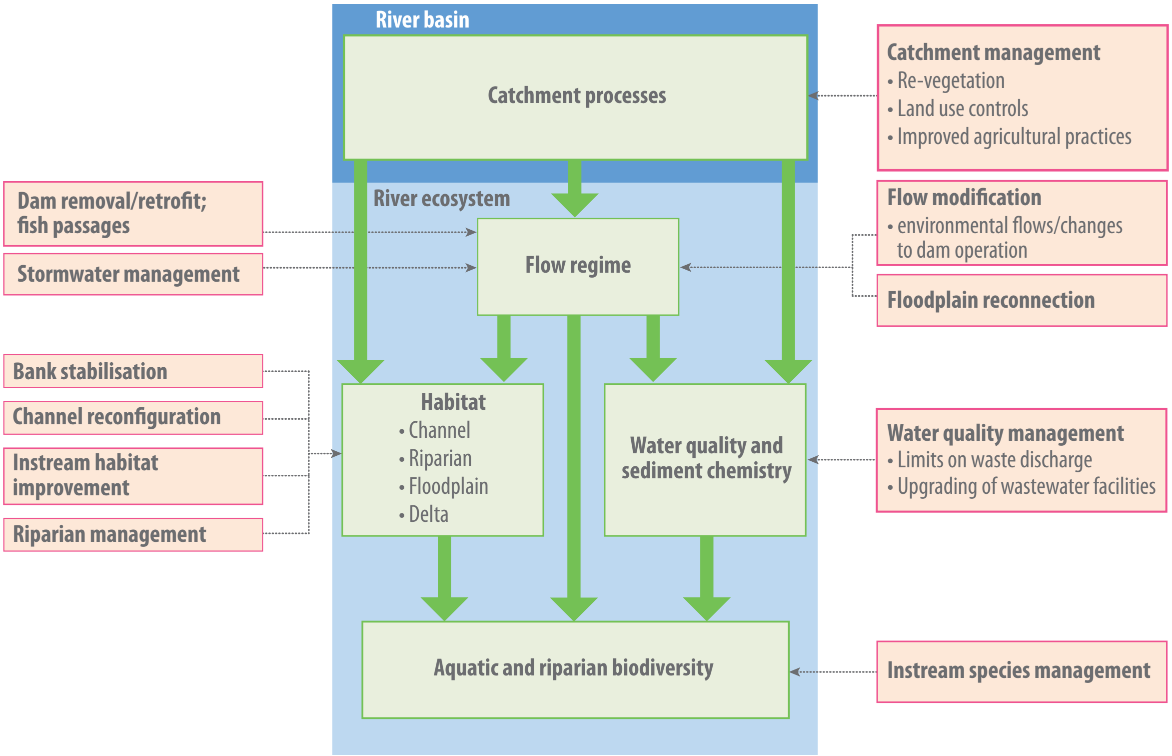
Source: Adapted from Saar, 2002

3.7. Measures for river restoration

There is a wide range of measures that can assist with improving river health. Measures may focus directly on any one or more of the elements of the river ecosystem, while recognising that there will implications for other parts of the system. While the ultimate goal of a river restoration project might be to improve water quality or to restore riverine biodiversity, the restoration measures might target other aspects of the river ecosystem or surrounding river basin – such as the riparian zone, the flow regime, or the catchment – with a view to achieving that goal.

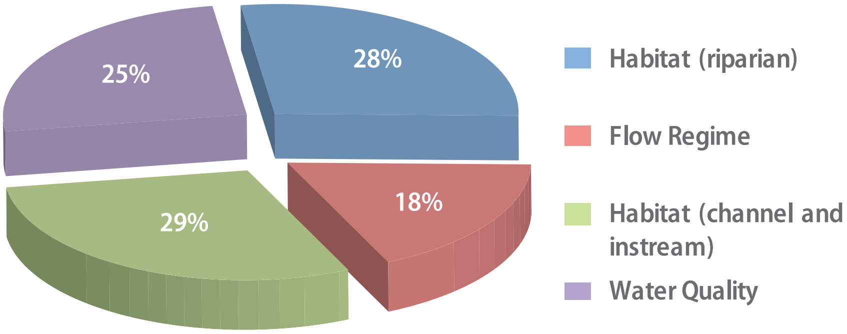
Strategic river restoration planning requires consideration of how these measures are nested within the broader strategy, including the appropriate scale for addressing different issues, and the way that one measure may support or hinder other measures.

Figure 3.12. Schematic showing relationship between different measures for river restoration and the elements of a river ecosystem



Based on data for projects in the US, the EU and Australia, restoration projects are roughly split between those focused on improving water quality, riparian restoration, altering the flow regime, and changing the instream habitat, including re-shaping the river channel. Figure 3.13 shows a breakdown of different measures based on data from the US, the EU, and Australia for approximately 48,000 restoration projects. This breakdown does not include projects in the broader river catchment (i.e. outside of the river corridor), although such activities can of course have significant impacts on catchment processes, including catchment hydrology and the sediment and other materials entering the river corridor. It is relevant to note that the split between different elements of the river ecosystem is not always clear-cut and many projects inevitably involve activities that will affect multiple aspects of the river ecosystem.

Figure 3.13. Breakdown of restoration projects based on the element of the river ecosystem that is most directly targeted by the project



Source: Based on data from Bernhardt et al. (2005); Brooks and Lake (2007), the UK River Restoration National River Restoration Inventory (www.therrc.co.uk/river-restoration) and the EU RiverWiki (https://restorerivers.eu/wiki/index.php?title=Main_Page).

These broad categories capture a range of measures. Changes to the flow regime may focus on improving connectivity (e.g. retrofitting fish passages, removal of barriers) or on increasing flows or altering the timing of flows (caps on abstractions, introduction of environmental flows). Improving riverine habitat may involve improved bank stability, altering the geomorphology (such as by re-introducing meanders), or the creation of instream habitat (such as the introduction of logs or vegetation).

There are various ways that measures for undertaking river restoration can be grouped. The typology of different river restoration measures in Table 3.1 is based on the categories developed as part of an assessment of restoration projects in the US (Bernhardt *et al.*, 2005; see Table 3.1). Those categories are split between the different elements of the river system (catchment, flow regime, habitat, water quality, biodiversity), based on which element the measure is primarily used to address. The table describes what the measure is typically used to achieve, and includes examples of both passive (e.g. policy or regulatory-based approaches) and active restoration (direct interventions to modify the river ecosystem). Chapter 10 includes a more detailed description of each of the restoration measures, references for detailed technical guidelines, and case study examples.

Table 3.1. Typology of river restoration measures

Element of river ecosystem	River restoration measure	Used in river restoration to:	Examples of different measures	
			Active restoration	Passive restoration
Catchment	Catchment management	Alter the water, sediment, and other matter that enters the river channel	Revegetation of the catchment Rehabilitation of gullies/high-erosion zones Land and water conservation	Land use planning/regulatory controls on land use, vegetation clearing Promotion (compulsory or voluntary) of agricultural best management practice
Flow Regime	Flow modification	Change the volume, timing, frequency, and duration of flows	Buy back of water entitlements and actively managing the water for improved environmental outcomes Removal/re-engineering of floodplain drainage	Mandating release of e-flows for hydropower/dam operators Restrictions on abstraction of water by water users
	Stormwater management	Alter the flow pattern of water running off from urban areas, e.g. altering flood peak	Construction of ponds, wetlands, flood retention basins, or other flow regulators in urban areas Removal/reduction of impervious surfaces in the urban catchment	Urban development and design requirements
	Dam removal/ retrofit	Improve flows and ecological outcomes, including improving the movement of sediment and fish	Removal of redundant dams or weirs Retrofitting of fish passages to existing dams or weirs	Regulatory requirements on dam operators
	Floodplain reconnection	Reduce flood risk by increasing the capacity of the river system to store and release floodwaters Allow for the movement biota, sediment, and other matter between the channel and floodplain Increase assimilation of pollutants and groundwater recharge	Removal of levee banks Construction of infrastructure (e.g. choke points) to increase frequency of flooding	Mandating release of e-flows for hydropower/dam operators Restrictions on abstraction of water by water users
Habitat (riparian)	Riparian management	Alter the water, sediment, and other matter that enters the river channel; provide habitat; alter water temperature through shading; support migration along the river corridor	Revegetation of riparian zone Removal of invasive plants	Exclusion of cattle and other invasive species Regulatory restrictions on clearing of riparian vegetation
	Land acquisition	Acquire riparian lands to control land use and/or allow for restoration works	Purchase of land in sensitive/high-value areas	
Habitat (instream)	Instream habitat improvement	Promote or create habitat that supports biodiversity	Creation of habitat via introduction of logs/snags; planting of instream vegetation	Restrictions on mining and other extractive activities within the river channel
	Bank stabilization	Reduce erosion/slumping of bank material into the river	Strengthening/reshaping of river bank Planting of vegetation directly on the river bank	Restrictions on activities on the river bank
	Channel reconfiguration	Altering the channel plan form or the longitudinal profile, thus increasing hydraulic diversity and habitat heterogeneity and decreasing channel slope	Daylighting (opening of pipes/removal of coverings) Re-meandering of river channel	
Water Quality	Water quality management	Protect or improve water quality, including chemical composition and particulate load	Construction or upgrade of wastewater facilities Capture of urban litter and sediment Mine remediation Wetland restoration	Changes to dam release operations to manage water temperature Regulatory requirements on management/ discharge of pollutants
Biodiversity	Instream species management	Protect or improve number/diversity of important species	Stocking/re-introduction of species	Controls on harvesting/removal of species Establish conservation zones
Other	Aesthetics/ recreation/ education	Increase community value, such as by improving appearance, access, or knowledge	Creation of riparian parks, walkways, and river access points Education facilities	

3.8. The Golden Rules of River Restoration

Based on international experience, a number of key principles are emerging that can help guide river restoration efforts. These principles are described here as eight golden rules. The rules are designed to respond to the challenges to river restoration identified earlier in the book. The rules are based on the international experiences set out in this book, and also draw on similar rules or principles put forward by others (e.g. Palmer *et al.*, 2005; Beechie *et al.*, 2010).

1. **Identify, understand, and work with the catchment and riverine processes.** Understanding the complex physical, chemical, and biological processes that drive river health is critical to understanding the causes of declines in river health, the loss of ecosystem services, and for identifying the most effective and efficient restoration measures. Such an understanding is also vital to ensure that the potential benefits of a healthy river system and associated ecosystem services are fully recognized. Restoration projects that work with, rather than against, natural processes are more likely to be self-sustaining.
2. **Link to socio-economic values and integrate with broader planning and development activities.** A strategic river restoration plan should recognize, incorporate and involve all of the existing strategies that affect the river, or are affected by it, to identify achievable objectives. Restoration objectives need to be consistent with objectives related to urban and industrial development, flood mitigation and water supply, with restoration sites selected and activities designed accordingly. Planning should reflect the priorities of different types of community while at the same time ensuring broad consistency with strategic objectives. This includes balancing trade-offs between human needs and the environment, between different people, sectors, and locations, and between different river functions. Restoration objectives and water resources regulatory arrangements need to align to ensure the long-term success of restoration projects and to protect river health improvements into the future.
3. **Restore ecosystem structure and function by working at the appropriate scale to address limiting factors to river health.** River health will be affected by a multitude of factors and processes from across its catchment. Restoration work undertaken at a local scale will have limited effect if the key factors that are influencing river health are located outside the restoration site; rather, restoration measures need to respond to those factors that are limiting river health wherever they may be. In most cases, coordinated delivery of planning, implementation and monitoring of restoration activities is required on a regional scale with local scale delivery capabilities. If it is too difficult to address catchment scale issues, judgement will be needed about the effort to be spent on local restoration interventions.
4. **Set clear, achievable and measurable goals.** Goals (and objectives) should be framed as much as possible in terms of measurable changes to ecosystem function, the provision of ecosystem services and, where feasible, socio-economic factors. Restoration planning and funding arrangements need to recognize that reversing the impacts of decades of human disturbance can take many years. At the same time, shorter-term projects can be important to demonstrate the benefits of the work to those funding it and provide motivation to those implementing.
5. **Build resilience to future change.** Rivers need to be restored with an eye to the future, not just the past. Planning and implementation needs to consider likely changes in the landscape over time and the implications that will have on the river system, including include changes to climate, land use, hydrology, pollutant loads, and development within the river corridor. Given the gross uncertainty over future conditions, river restoration should aim to establish river structure and function that will provide resilience to a range of scenarios.
6. **Ensure the sustainability of restoration outcomes.** The dynamic nature of river systems creates a particular challenge in ensuring that the gains realised from river restoration are not short-lived. River restoration strategies should be planned, implemented, and managed with a view to achieving outcomes that are sustained over the long term. Self-sustaining ecosystems should be established, which will require minimum interventions in the future, ensuring there is a sustainable financing mechanism available to meet any ongoing costs, and ensuring that regulatory measures are in place to protect benefits realised from river restoration and prevent them from being undermined by activities within the basin, including future development.
7. **Involve all relevant stakeholders.** An integrated approach, addressing land and water issues, and involving inter-agency and community collaboration, is likely to achieve the best results for river restoration. Coordinating the actions and objectives of different government agencies will provide the most effective and efficient approach to achieving restoration objectives. At the same time, the grassroots nature of river restoration has made the involvement of landowners, other citizens, and community groups a fundamental element of many projects. Restoration projects also offer the opportunity to reconnect people and rivers, which can result in benefits that endure beyond project completion. The restoration process should also provide opportunities for continued learning and to ensure that stakeholders develop the capacity to respond to ongoing challenges related to river management.

8. **Monitor, evaluate, adapt and provide evidence of restoration outcomes.** Monitoring against defined and measurable objectives is critical as a means of guiding adaptive management. Monitoring programs should validate (or disprove) the scientific assumptions that underpin the restoration strategy and should provide evidence as to whether restoration projects have been successful in terms of restoring ecosystem structure and function, ecosystem services and socio-economic benefits. An appropriate scale of monitoring that will detect the impacts of restoration over a relevant timeframe is required and should continue long after the restoration actions have been 'completed'.

CHAPTER 4
PROCESS AND PROCEDURES FOR RIVER RESTORATION

OVERVIEW AND KEY MESSAGES

This chapter describes the steps involved in planning and implementing river restoration. The chapter begins with a brief description of the key steps in the process. It then discusses some of those steps in detail, including the situation assessment and approaches to prioritizing and setting goals and objectives. The key messages from the chapter are:

- Restoration planning needs to be informed by a robust assessment of the current status of the river ecosystem, existing issues and threats, and the future scenarios.
- A restoration strategy should identify a long-term vision for the river basin, the desired outcome of the strategy over the planning horizon (goals), and specific, measurable targets to be achieved over the short to medium term (objectives). Goals and objectives should be framed, as much as possible, in terms of measurable changes to ecosystem function, the provision of ecosystem services, and socio-economic factors.
- Restoration strategies should aim to build resilience to future change. Rivers need to be restored with an eye to the future, not just the past, considering likely changes in the landscape over time and the implications that will have for the river ecosystem.
- Determining priorities for action requires an iterative process of considering priorities for the basin along with the effectiveness, efficiency, and sustainability of different restoration measures.

4.1. Overview of the river restoration planning process

A river restoration process may be initiated as a result of any of a number of factors: there may be a political directive or a legislative obligation for the relevant government agency to undertake a restoration process; in the case of a community-based organization or other NGO, the process may be started as a result of an internal decision of the organization. Once initiated, the restoration process will typically involve the following steps (Figure 4.1):

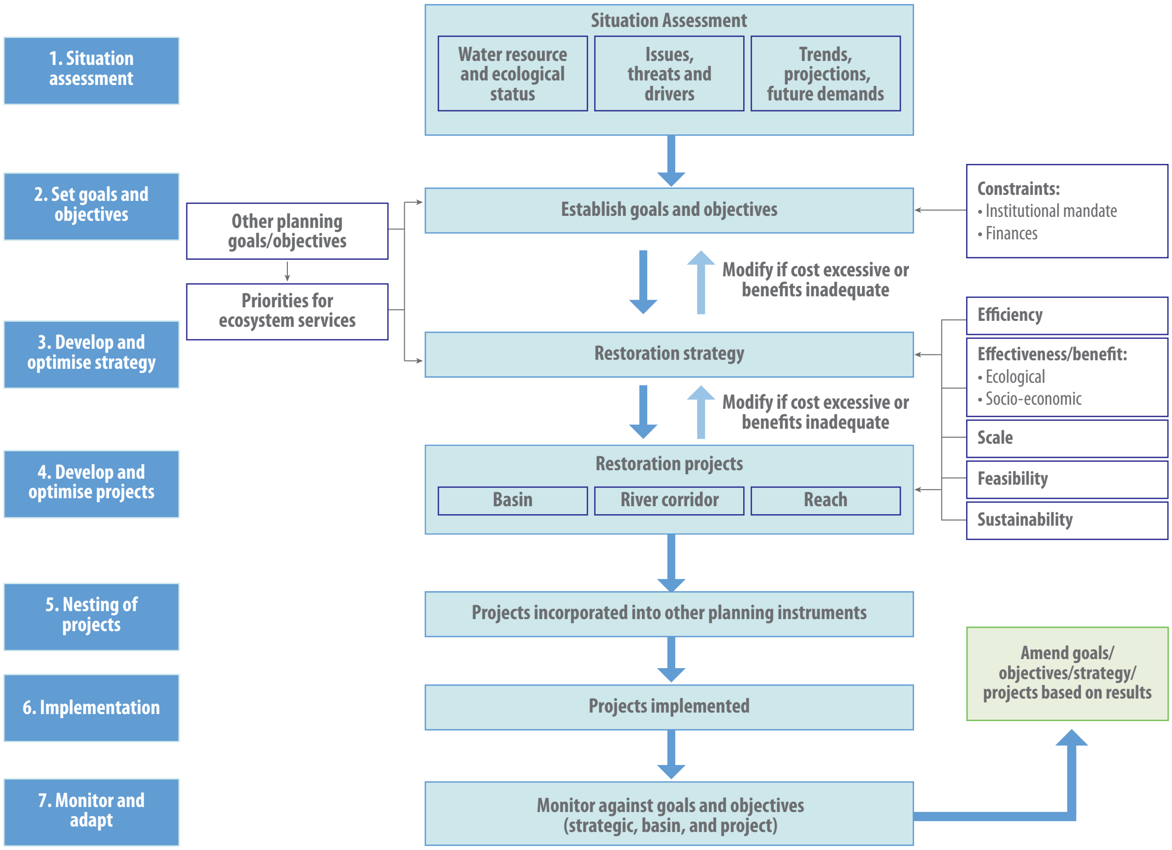
1. **Situation assessment.** This involves undertaking a baseline assessment of the river basin to provide the information necessary to support decision-making and the planning process more broadly. This should provide an understanding of the condition of the river system, its structure and function, identify causes of and threats to poor river health; and demands on and requirements for ecosystems services from the basin. This step is discussed further in section 4.2 and Chapter 8.
2. **Establish overarching goals and quantifiable objectives.** These goals and objectives should define the basis for the restoration work, and guide all steps in process, by describing what it the restoration work aims to achieve, and

the basis for assessing progress towards that goal. This step is discussed further in section 4.3.

3. **Develop and optimse the restoration strategy.** This step is designed to determine the overall approach to achieving the restoration goals and objectives. The approach may include deciding which elements of the river system that are most important for restoration, such as by prioritizing geographic regions, river assets and ecosystem functions. The process of developing the strategy is discussed further in section 4.3
4. **Develop and optimise individual restoration projects.** Individual projects need to be identified to help achieve the overarching goal and objectives. These projects may include actions at the basin, corridor or reach scale. Section 3.7 and Chapter 11 set out the most common river restoration measures used when implementing projects.
5. **Nesting of projects.** After potential restoration projects have been identified, they need to be aligned with each other and with other water resources management plans and (where relevant) develop plans and other planning instruments. This alignment may require adjustments to both other water resources management plans (to give effect to the restoration strategy) or to draft restoration project plans (to ensure consistency and alignment with other instruments). The planning hierarchy is discussed in section 3.3.
6. **Implementation.** Implementation involves undertaking activities in accordance with the restoration strategy and individual project plans. This book does not discuss this step in detail. There are various guidelines and manuals that set out the operational requirements for implementing river restoration projects (see Box 42).
7. **Monitor and adapt.** This step should determine the extent to which the restoration goals and objectives have been met, the effectiveness of restoration activities, and provide a mechanism for making adjustments to the restoration strategy and project plans as required. This step is discussed further in Chapter 5.

While these steps are shown here in linear fashion, in practice developing a restoration strategy and related plans is likely to be an iterative process. In particular, establishing goals and objectives, describing the restoration strategy, and designing specific restoration projects are each likely to require reconsideration of earlier steps, depending on the outcomes of latter parts of the process.

Figure 4.1. The steps in developing and implementing a river restoration strategy



Box 8: Developing the Spanish National River Restoration Strategy

In response to a series of threats to its freshwater ecosystems and to meet the country's obligations under the EU Water Framework Directive, the Spanish Ministry of the Environment initiated a National Strategy for River Restoration in 2006. Figure 4.2 shows the seven steps that were followed to implement the strategy. The first step involved setting goals, desired targets, and required actions. Technical guidelines were then developed and disseminated to obtain the necessary technical and social support. The next step involved identifying key problems, alternatives and constraints. Based on the situation assessment, a series of priorities and strategies were developed. Five main action lines were identified: education and training, conservation, restoration and rehabilitation, voluntary work, and documentation and research. A number of projects were subsequently implemented under these action lines, including 13 projects in the area of restoration and rehabilitation, with further projects still on going. Work remains ongoing in developing criteria for assessing the success of restoration projects and the strategy as a whole.

Figure 4.2. Steps in developing the Spanish River Restoration Strategy

Source: González del Tánago *et al.*, 2012

4.2. Situation assessment

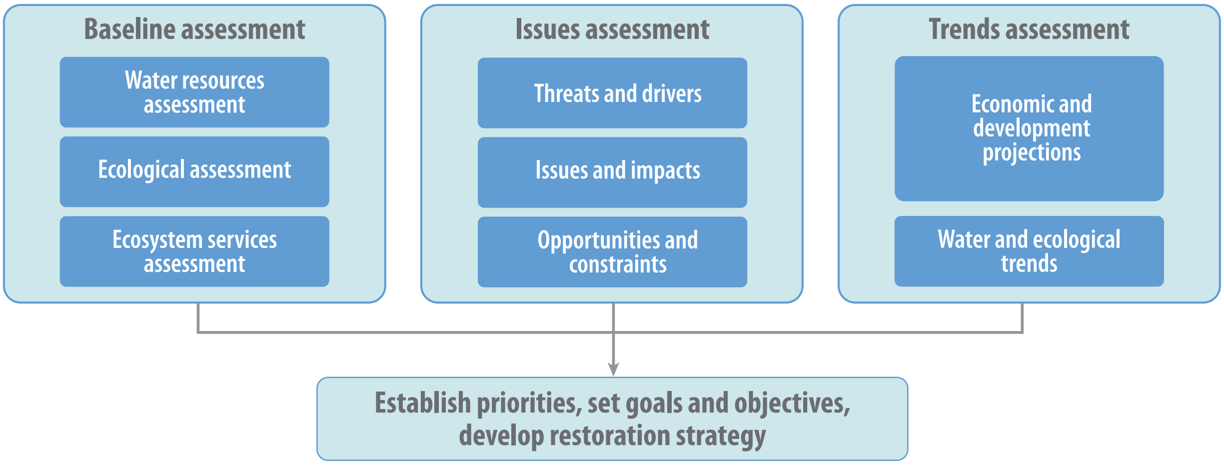
Preparing a river restoration strategy requires a range of information to be available to decision-makers and stakeholders to help them understand the issues, assess the options and formulate a response. This means having the information to respond to a number of the core questions for the river restoration process set out in the restoration framework (see section 3.1 and Figure 3.2), notably:

- What are the key influences on the river ecosystem?
- How does the river ecosystem work?
- What is the current condition of the river ecosystem?
- What does river ecosystem provide, and to whom?

The situation assessment should be designed to provide this information and can be considered in terms of three parts: a baseline assessment, an issues assessment, and a trends assessment (see Figure 4.3). Monitoring approaches to support these sorts of assessments are discussed in detail in section 5.3.1.

Approaches to assessing river systems, and projecting future conditions, are the subject of a large number of technical books and guidelines (see Box 42). Chapter 8 includes an overview of approaches for assessing river health, which will form part of the situation assessment. The following sections describe some of the key aspects of such approaches.

Figure 4.3. Undertaking a situation assessment to inform river restoration planning



BASELINE ASSESSMENT

The baseline assessment should provide an understanding of both the current status of the river ecosystem, as well as how that system works. This understanding should consider both the ecological situation, the availability of water resources, and human dependency on the river ecosystem (i.e. the ecosystem services it provides).

Understanding the key ecosystem functions, including different processes within the river basin is particularly important for effective river restoration. The role different functions play in contributing towards river health and the provision of ecosystem services need to be identified. Such an understanding can provide a scientific basis for restoration decisions, for example by:

- allowing for targeted responses that address causes of the loss of system functionality
- supporting the prediction and quantification of short and long-term effects of restoration
- allowing for evaluation of ecosystem interdependencies and the assessment of cumulative impacts
- allowing for an assessment of thresholds beyond which ecosystem function is likely to collapse or materially alter (Fischenich, 2006).

The function-based approach to river restoration developed by the US EPA supports this approach to decision-making (Box 9).

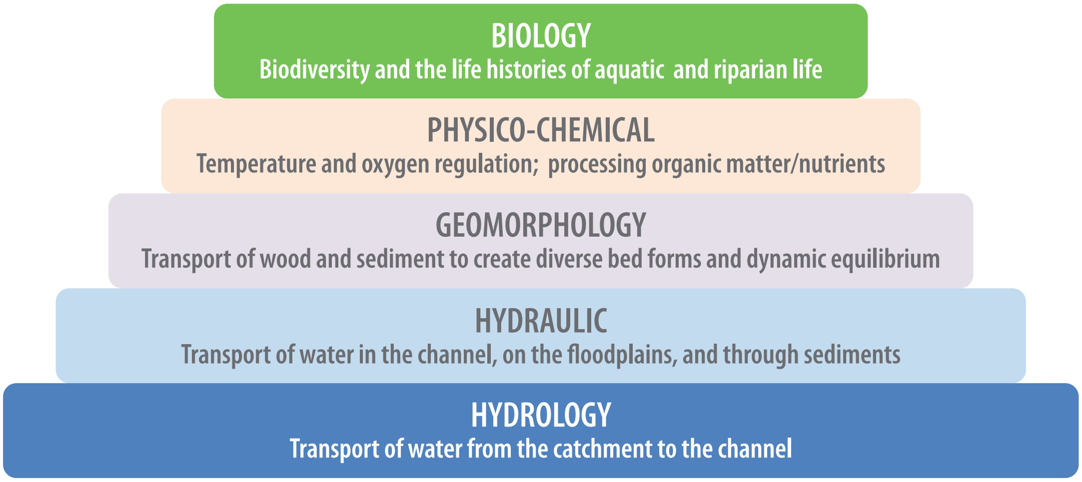
Identifying how a river ecosystem functions allows planners to better understand how an ecosystem is likely to respond to human interventions. This is central to the process of setting objectives and prioritizing actions. Given the complexity of river systems, the nature of the responses can be varied, as well as challenging to predict. Depending on the nature of the original disturbance, the level of degradation, and the type of intervention, the river health of a degraded river system may quickly improve, may take time to improve, or may not recover at all (see Figure 3.11). Understanding the likely response of a system to interventions is thus critical in guiding:

- when to intervene – for example, early intervention may be far more cost effective, or there may be thresholds beyond which irreparable damage is done
- where to intervene – for example, to allow the prioritisation of restoration efforts to assess the costs and benefits of different options
- what to expect from the intervention – for example, to allow for realistic targets for improving river health or restoring ecosystem services.

Box 9: A function-based approach to river restoration

The US Environment Protection Agency has developed a function-based framework for developing and assessing river restoration projects. The framework breaks down stream function into a hierarchy of five categories. High-level functions are supported by lower-level functions. Level 1 (hydrology) underpins all other functions, whereas level 5 (biology) depends on all other functions (see Figure 4.4). A primary goal of the framework is to help those undertaking restoration activities to understand that stream functions are interrelated and generally build on each other in a specific order. Functions should be addressed in the order shown. For example, reintroducing a species of fish (level 5), is unlikely to be successful if limitations related to supporting functions – such as hydrology (e.g. sufficient flows), geomorphology (e.g. habitat), and physico-chemical (e.g. water quality) – have not first been addressed. The framework also aims to place reach-scale restoration projects into the basin context and highlight that site selection is as important as the reach-level intervention itself.

Figure 4.4. Stream functions pyramid framework



Source: Adapted from Harman *et al.*, 2012

ISSUES ASSESSMENT

The issues assessment should identify:

- Threats and drivers: those factors that are affecting or threatening the condition of the river ecosystem. This should include any activities or processes that may affect the river's key ecosystem functions (see Figure 1.1), for example.
  - factors affecting the capacity of the river to act as a conduit, such as barriers to lateral or longitudinal connectivity, or changes to the river channel that affect it's ability to transport flood waters
  - factors affecting the capacity of the river to act as a barrier or filter, such as the loss of riparian vegetation
  - factors affecting the capacity of the river to act as a source and a sink, such as pollution, which limits the ability of the river to assimilate waste and to provide clean drinking water supplies
  - factors that reduce the habitat provided by the river, such as mining or clearing of instream vegetation.
- Issues and impacts: what are the challenges within the basin, and what are the consequences for both the river ecosystem and for those communities that rely on the river for the provision of ecosystem services? This should include identifying the limiting factors to improved river health (see Box 10).
- Opportunities and constraints: river restoration planning needs to consider where there is potential for restoration to support or benefit from other water-related activities within the basin (e.g. under other thematic plans – see Figure 3.8), and the potential for synergies. The planning process also needs to recognize any constraints on future restoration activities – these may include legal, physical, practical, political, or financial constraints.

Box 10: Identifying barriers to improved river health in the Spanish restoration strategy

The situation assessment undertaken as part of the Spanish National River Restoration Strategy identified the key challenges for improving environmental conditions in line with the requirements of the EU Water Framework Directive. A series of working groups were established to assist with this process. These groups prepared detailed reports on the main problems and constraints related to river health in Spain. The six challenges identified by the planning process, in order of significance were:

1. Excessive water withdrawal in rivers and in some aquifers
2. Pollution from urban or industrial sources
3. Diffuse pollution from agriculture
4. Degradation of fluvial and riparian landscape (inappropriate land use)
5. Degradation or drying of wetlands (inappropriate land use)
6. Invasion of exotic species

In addition, the working groups also identified relevant administrative and management issues. These included lack of technical knowledge and capacity; limited cooperation between relevant agencies; the failure by development planning to account for structural water deficits and pollution issues; limited social awareness; and lack of long-term studies to assess the cumulative impacts of activities within the basin.

These factors informed the development of priorities and strategies for river restoration at the national scale.

Source: González del Tánago *et al.*, 2012

TRENDS ASSESSMENT

Rivers need to be restored to provide for, and be resilient to, future conditions. Restoration planning therefore needs to be informed by a vision of the future, as well as an understanding of the present. This allows river restoration to consider both:

- Future demands: what ecosystem services will be required from the river basin in the future? What water supply will be required? Will urbanisation alter the flood risk in the basin, and thus the need for greater flood attenuation?
- Future pressures: how are the drivers of river health likely to alter over time? What might land use in the basin look like? Is there likely to be significant vegetation clearing? What pollution loads can be expected? Is the climate expected to change, and how might this affect the hydrology of the basin?

The trends assessment needs to consider economic and developmental factors (how human communities and actions in the basin are likely to change); water and ecological factors (what changes can be expected to the structure and function of the river itself); and social factors (what people want the future river-scape to look like).

Development and conservation plans will typically provide a guide to anticipated future conditions and requirements in the basin. The situation assessment provides one avenue for integrating future development plans in the basin into the restoration planning process.

Understanding trends in the basin, including how river condition and use has altered over time, can be an important basis for informing projections of future condition and demands. As such, the 'futures' assessment can involve an element of looking backwards.

In addressing the future, water resources planning, including restoration planning, is increasingly focused on addressing the challenge of uncertainty about the future and the need for flexibility, rather than trying to plan deterministically for one or more probable futures. This is driven by two key sources of uncertainty: (i) rapid and unprecedented social, economic, and demographic change; and (ii) climate change (Pegram *et al.*, 2012). These factors drive not only the collation of information as part of the situation assessment, but also imply the need for planning mechanisms that are more flexible and more robust to a range for future scenarios. This includes the approach to setting goals for a basin, and in setting the restoration strategy.

Box 11: Alternative futures assessment for the Willamette River Basin, Oregon, United States

The Willamette River Basin covers approximately 30,000 km^2 and is located in the north-west of the US in the state of Oregon. An alternative futures analysis was undertaken to inform discussions on the development of a vision for the basin's future and a basin-wide restoration strategy. This type of analysis aims to assist with developing a shared vision among stakeholders by (i) clarifying differences of opinions, by requiring stakeholders to specify their individual goals and priorities in the form of assumptions for a specific future scenario, (ii) presenting the implications of stakeholder goals and priorities for the river system, (iii) demonstrating the changes in land and water use that would be required to achieve particular future scenarios and (iv) assessing the socio-economic and ecological implications of different scenarios.

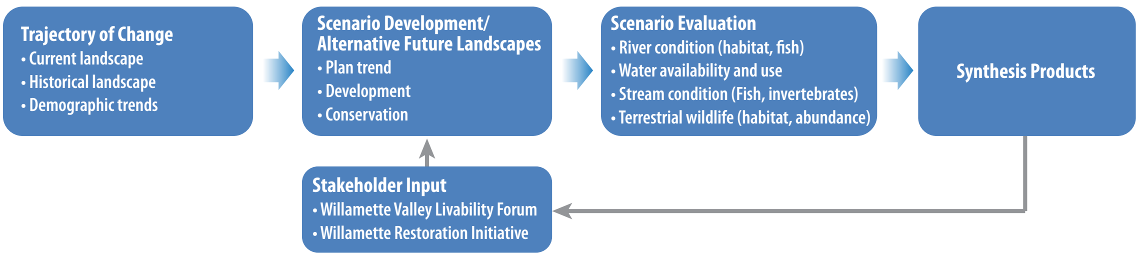
Based on the current situation in the basin, historic trends, and the current trajectory of key indicators in the basin (e.g. demographics), three alternative futures were developed. The scenarios were:

- Plan Trend 2050 – the expected future landscape in 2050 if current policies related to land and water development and use are maintained
- Development 2050 – a loosening of development controls
- Conservation 2050 – a greater emphasis on ecosystem protection and restoration.

The objective was not to predict the future, but to assess the sensitivity of key indicators to alternative land and water use policies. Each scenario was evaluated with respect to four resource endpoints of concern:

- Water availability – demands for surface water for consumptive and ecological purposes and the extent to which demands can be satisfied by supplies in the basin
- The Willamette River – channel structure, riparian vegetation, and fish community richness in the mainstem
- Ecological condition of streams – habitat and biological communities in second to fourth-order streams in the basin
- Terrestrial wildlife – habitat for terrestrial wildlife in the basin, and the abundance and distribution of selected birds and mammals.

Figure 4.5. The process of assessing alternative futures in the Willamette River



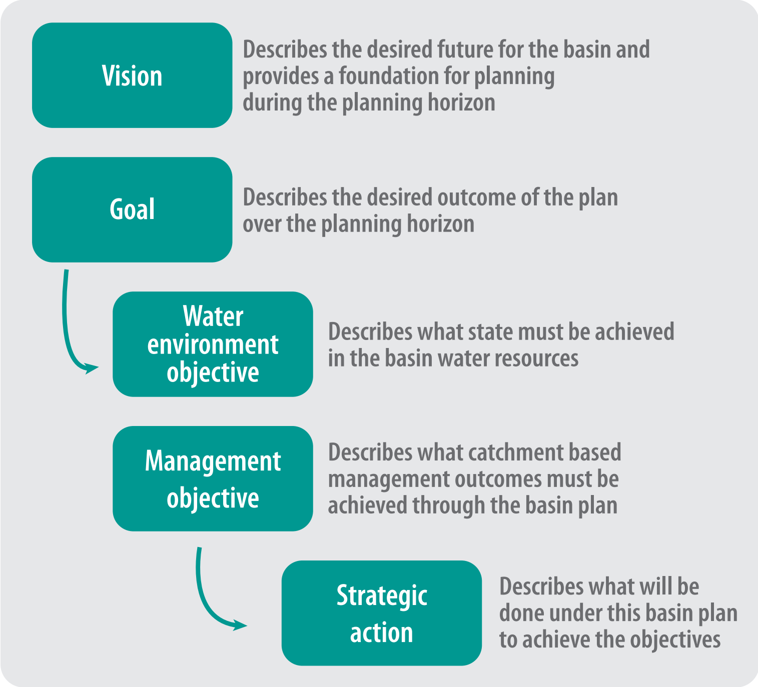
Source: Adapted from Baker *et al.*, 2004

4.3. Goals, objectives and developing the strategy

As with all planning exercises, one of the most critical steps in restoration planning is deciding what the restoration strategy is designed to achieve. This book uses the following terminology:

- Vision refers to a long-term desired future state of the river basin
- Goal refers to the desired outcome of the plan over the planning horizon
- Objectives refer to specific, measurable targets to be achieved, usually over the short to medium term (see Figure 4.6).

Figure 4.6. Hierarchy of vision, goal, objectives, and actions under a basin plan



Source: Pegram et al., 2012

Box 12: Vision, targets, outcomes, and actions in the Southeast Healthy Waterways Strategy and the Columbia River Restoration Programme

The SEQ Healthy Waterways Strategy (2007–2012) identifies a vision for the region's waterways and catchments. The vision is that:

By 2026, our waterways and catchments will be healthy ecosystems supporting the livelihoods and lifestyles of people in South East Queensland, and will be managed through collaboration between community, government and industry.

The strategy also identifies a series of resource condition targets (which relate to healthy ecosystems) and community targets (which relate to supporting livelihoods and lifestyles) that need to be achieved if the vision is to be realised. For example, the strategy has targets[6] that include:

- in 2026, 100% of SEQ waterways classified in 2007 as disturbed achieve their scheduled water quality objectives
- by 2026, the community would be more capable and active than in 2008 in positively influencing natural resource management outcomes.

The strategy then identifies five management action outcomes, which are required to achieve the resource condition targets. The management action outcomes[7] include:

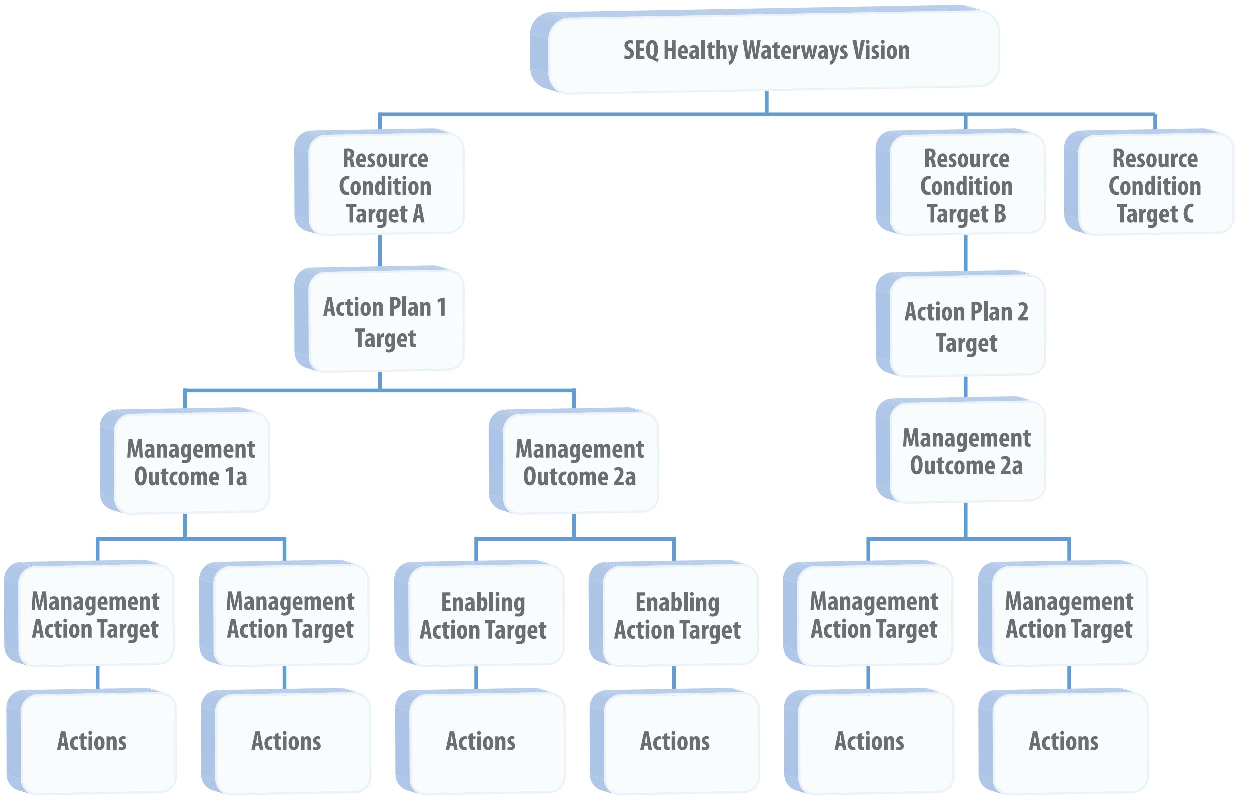
- 100% dry weather reuse of point source discharges (delivering removal of nutrient loads from the system)
- 100% water sustainable urban design (WSUD) performance standards in all new development adopted
- 50% reduction of diffuse loads in priority catchments through riparian restoration and instream rehabilitation and best management practices.

The strategy itself consists primarily of 12 action plans. These include a combination of:

- issue-based action plans (e.g. point source pollution management, water sensitive urban design, non-urban diffuse source pollution management)
- area-focused action plans (targeting specific catchments or regions)
- enabling action plans (e.g. a communication and education plan; an ecosystem health monitoring plan).

6. These are equivalent to 'goals' in the terminology used in this book.
7. These are equivalent to 'objectives' in the terminology used in this book.

Figure 4.7. Hierarchy of vision, targets, plans, outcomes, and actions in the Southeast Queensland Healthy Waterways Strategy



Source: SEQ Healthy Waterways Strategy (2007–12)

The goals, objectives, scientific foundation and actions for the Columbia River Restoration Programme are organized in a 'Fish and Wildlife Programme', which is an integrated approach to regional fish and wildlife mitigation and recovery (NPCC, 2009). The fundamental programme elements are:

- the vision that describes what the programme is trying to accomplish for fish and wildlife in the context of other desired benefits from the river
- the biological objectives, which describe the ecological conditions and population characteristics needed to achieve the vision
- the implementation strategies, procedures, assumptions and guidelines, which guide or describe the actions leading to the desired ecological conditions
- the scientific foundation, which ties the programme framework together.

The vision for the programme is:

> *A Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife, mitigating across the basin for the adverse effects to fish and wildlife caused by the development and operation of the hydrosystem.*

Biological objectives are specified in two ways: (i) biological performance, which describes population responses to habitat conditions (in terms of capacity, abundance, productivity, and life-history diversity); and (ii) environmental characteristics, which describe the environmental conditions necessary to achieve desired population characteristics. For example, the programme has set quantitative goals and related timelines for anadromous fish. These include, among other goals and timeframes, increasing total adult salmon and steelhead runs to an average of 5 million annually by 2025 in a manner that emphasizes the populations that originate above a lower dam (Bonneville), supports tribal and non-tribal harvest, and achieves smolt-to-adult return rates in the 2–6% range for Endangered Species Act-listed Snake River and upper Columbia salmon and steelhead.

Source: NPCC, 2009

THE ITERATIVE NATURE OF STRATEGY DEVELOPMENT

Establishing a restoration strategy is an iterative process that involves two related steps:

1. Setting goals and measurable (preferably quantifiable) objectives. This involves a process of prioritizing river ecosystem assets, values, functions, and services and agreeing on what levels of improvement constitute success. The question of which of these should be given priority when setting the restoration goals and objectives is primarily a strategic issue.
2. Developing a strategy to achieve those goals and objectives. This involves assessing the range of interventions and identifying the best approach for achieving multiple

(potentially competing) goals and objectives based on fixed or least cost (see Figure 4.8). This is primarily a technical issue.

The process of iterating between these two steps may be:

- Outcome driven – where the starting point is to achieve a particular (high-level) river health or ecosystem services outcome. From there, priorities for (lower-level) goals and objectives are determined to achieve that outcome in most effective way
- Budget driven – where the starting point is a fixed budget, and the prioritization and planning process is based on allocating the available funds for the greatest affect.

Historically, the process of assessing different restoration interventions may have been considered a process of optimisation: that is, identifying the optimal outcome given particular objectives or constraints. Increasingly, strategic approaches towards water resources management are moving away from seeking an 'optimal' outcome, in recognition of the fact that such an outcome will seldom exist in practice. Rather, planning (and restoration) processes often now aim for resilience across the river basin, and the capacity to respond to a range of different scenarios. Such an approach has been driven by the gross uncertainty over future conditions. While developing resilience is arguably the primary consideration, planning does still require a mechanism for assessing the relevant benefits that would be derived from different restoration and management scenarios.

Figure 4.8. The iterative process of prioritising outcomes and assessing options

SETTING GOALS

Restoration goals should describe the desired (higher-level) outcomes for the river basin over the planning horizon. Restoration goals are commonly focused on restoration of individual species, restoration of ecosystems or landscapes, or restoration of ecosystem services (Beechie *et al.*, 2008).

Determining the goals for a river restoration program or project should involve consideration of:

- what do we want or what is required from the river?
- what is feasible from a restoration perspective?

What we want or need from a river ecosystem – that is, what ecosystem services we want the river to provide – will often be set out in other planning instruments; a river basin or a development plan may already provide guidance on the future of the region and (explicitly or implicitly) the role the river ecosystem is expected to play in supporting it. In the absence of such documents the planning exercise may need to make decisions about these matters. Stakeholder views and values are commonly central to determining river restoration goals, and there is arguably no stage in the restoration process where stakeholder engagement is more important that in setting the goals. Stakeholder engagement is discussed in further detail in section 7.5.

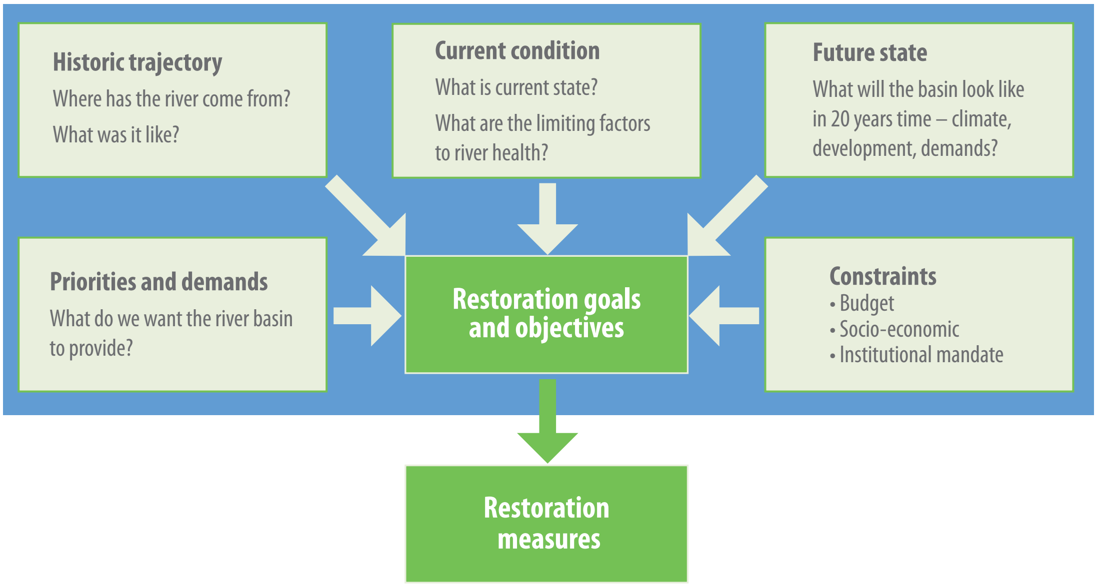
Assessing what is feasible to be achieved requires consideration of:

- The current condition of the river system and what is possible, given the current state, demands and impacts.
- The historical trajectory of the system. Where has it come from? What type of river was it originally? This will give some indication of the river basin's potential, as well as its limitations.
- The future of the basin. What will the basin look like in the future? What levels of development are expected, and how will this affect river function? What will the climate be like? What do people want the basin to be like?

- The cost of achieving particular goals and related objectives and available funding. River restoration measures are expensive, and the available budget is likely to place a limit on what is achievable in the short term.
- The extent to which it is within the mandate or powers of the implementing body to achieve certain outcomes. For example, in a basin that crosses multiple jurisdictions, the planning body may not have the capacity to regulate behaviour or implement projects on the ground.
- Any other factors which may constrain actions, for example, political considerations such as the level of impact on the economy or groups of stakeholders that is considered political acceptable, or land use constraints.

Setting restoration goals and objectives will often be an iterative process, and goals and objectives may need to be reassessed as the restoration strategy is developed and as the requirements for and implications of the actions required to achieve those particular outcomes is better understood. These considerations are shown in Figure 4.9.

Figure 4.9. Considerations in setting restoration goals and objectives



Box 13: Goals for river restoration: examples from the global experience

Restoring the Isar River – multiple goals for an urban river restoration project

Similar to many other European rivers, the Isar River, part of the Danube River basin, was engineered, straightened and canalised in the early 20th century to improve flood control and use hydropower. Weirs and channels were constructed in the Upper Isar region so that further water could be withdrawn for hydropower. This left the riverbed to run dry for much of the year, remaining primarily to transport floodwater.

The limited value of engineering works for flood protection, as evidenced by significant flooding over a period of decades, resulted in calls for a revised strategy on flood protection. This accelerated discussions about improving natural conditions and opportunities for recreation along the river, which ultimately lead to a significant restoration effort. As a consequence, the goals for restoration on the Isar were multi-faceted, and consisted of:

- improving flood control by widening the flood channel
- improving water quality and ecological situation for fauna and flora bringing back the natural structures to the river and floodplain, replacing weirs through ramps to improve the longitudinal connectivity
- improving outdoor recreation widening the riverbed and lower the bank for better access to the water.

Goals of the Singapore ABC Waters Programme

The goals and objectives of the Singapore Active, Beautiful, Clean (ABC) Waters Programme are: (PUB, 2008)

- to develop the water bodies into vibrant, clean, and aesthetically pleasing lifestyle attractions where recreational and communal bonding activities can take place for the public to participate and enjoy.
- to manage our catchments, reservoirs, and waterways as new community spaces while continuing to safeguard the quality of waters and safety to the community.
- all initiatives involving the catchments, reservoirs, and waterways will be integrated and holistically managed so as to achieve better synergy
- the community is closer to the water so that in the process, they will learn to treasure and take ownership of it.

Source: Tickner, 2013; Liao, 2013

DEFINING OBJECTIVES

Objectives define the specific state or outcome that is to be achieved, ideally during the planning horizon. Objectives may relate to the condition of the river ecosystem (e.g. the quality of the water, the population of key species); the nature of threats in the basin (e.g. the level of pollution, land use practices, or levels of water abstractions), or to management targets (e.g. the introduction of measures regulating harmful activities, or the establishment of a certain area of conservation zones).

Objectives should be specific and measurable. It may be appropriate to set objectives at different spatial and temporal scales, depending on the nature of the project. Indicative examples of a number of different measurable objectives are outlined in Table 4.1. Objectives may be set based on:

- previous natural conditions, or by reference to undisturbed sites
- previous point in time (for example through a link to living memory)
- achieving a particular state (e.g. existence of fish, water quality outcome)
- achieving or maintaining a particular function
- restoring for resilience and adaptability (which may be appropriate where it is not possible to envisage all possibilities).

Table 4.1. Examples of general and specific river restoration objectives. Ideally, objectives should specific and measurable, rather than general in nature

Element of the river ecosystem	General objective	Specific/measurable objective
Habitat	Maintain present river course	Over next 10 years, channel planform will not change by more than 5 metres (assuming no floods larger than a 20-year return interval)
	Improve substrate for organisms	Median particle size will double over 5 years
	More hydraulic diversity	Double the diversity of flow types found in the stream in 5 years
	Restore the vegetation of the riparian corridor	After 10 years, the planted vegetation should have similar diversity and density as that in a template reach
	Restrict stock access	Each year, fence no less than 2 km of stream between the road crossing and the town
Biodiversity	Increase the population of fish species 'X'	Over 5 years, a doubling in the population of species 'X' in the restoration reach compared with the control reach
	Macroinvertebrates	Doubling in invertebrate family richness in the reach over the next 5 years
Flow regime	More natural flood regime	After 2 years, similar storm events in control and target catchments produce flood events of similar duration
Water quality	Improved water quality	Within 5 years, water quality in the restoration reach meets X standard for Y% of the time

Source: Adapted from Rutherfurd et al., 2000.

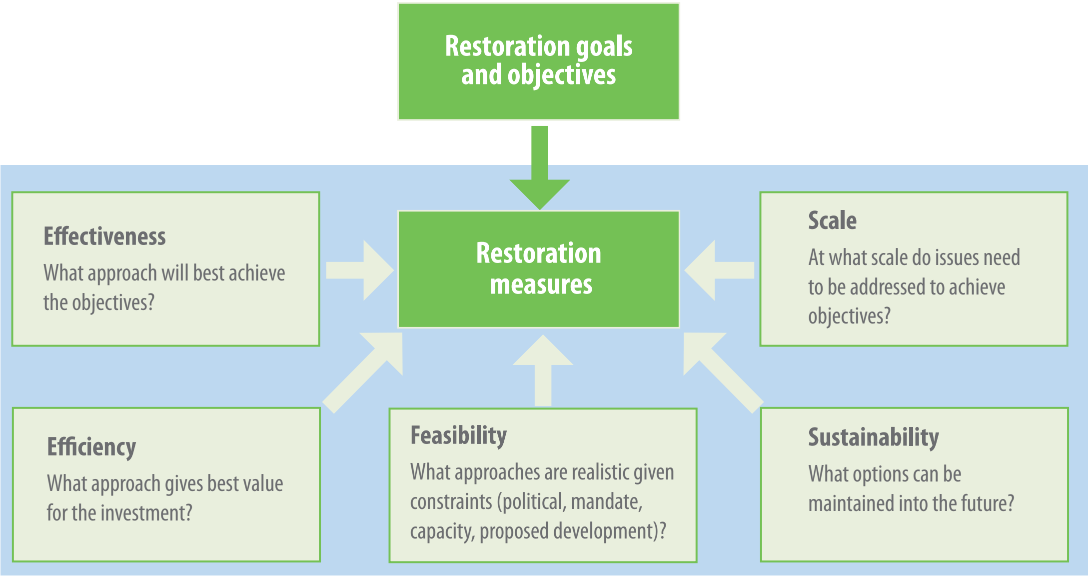
DETERMINING PRIORITIES FOR ACTION

Developing a river restoration strategy requires deciding which of the large suite of measures that is potentially available (see section 3.7) to apply to achieve the stated goals and objectives. A common problem with selecting restoration projects and sites is that the selection process may simply follow the path of least resistance (Hermoso *et al.*, 2012) – sites may be selected where land is available, action may be taken that is politically expedient or to address the highest-profile challenges, rather than basing the strategy on the most effective (and most cost-effective) approach. While political imperatives and practicalities are relevant considerations, a broader range of issues needs to be considered. Those include (Figure 4.10):

- Where to act: in what locations, and at what scale, do issues need to be addressed?
- The effectiveness of different measures: how will the river ecosystem respond to different interventions, and which are most likely to be successful in achieving the stated restoration objectives? What responses are required to address the rate-limiting factors to river health?
- The efficiency of different measures: which approaches will achieve the best outcomes per dollar of investment? How do the costs and benefits of different approaches stack up, including both: (i) upfront and ongoing costs; and (ii) direct and indirect benefits?
- Sustainability: which approaches are more likely to be enduring? Are the measures likely to be undermined by other actions in the basin? Which approaches will be most resilient to a range of future scenarios?
- Feasibility: as for setting the goals and objectives, identifying actions needs to consider the potential constraints in ensuring that the proposed approach is feasible, including recognising limitations that may exist as a result of budget, capacity, political will, or institutional mandate.

Chapter 9 discusses in detail the process of prioritizing restoration actions as part of developing and implementing a restoration strategy.

Figure 4.10. Considerations in deciding restoration measures and formulating a strategy



Box 14: Prioritising restoration actions

In South Korea, river reaches are designated for planning and management purposes, into three categories according to physical and environmental characteristics: conservation reaches, amenity reaches and restoration reaches. A conservation reach is usually designated where the natural characteristics of the river are well preserved and where conservation values are fragile. An amenity reach is designated where a river reach is used for recreational purposes. Restoration reaches are designated where the natural functions of the river, such as the ecological habitat and self-purification capacity of river water, are badly degraded and human intervention is needed. River restoration works are focused on these reaches.

Singapore's ABC Waters Programme is based on three master plans that between them cover the three major catchments that constitute the island state. Restoration sites are selected based on a series of criteria that reflect the multiple objectives of the program. The criteria include:

- the potential for water quality improvement
- the potential to incorporate education activities into the site
- the potential benefit to the community, for example from greater access to recreational space
- ease of implementation
- the potential for integrating with other projects
- potential for uniqueness, for example where there is some cultural significance attached to the site.

Further examples are provided in Chapter 9.

Source: Woo and Choi, 2013; Liao, 2013

4.4. Content of a restoration strategy

Documenting the outcomes of the planning process into a formal strategy or plan can be important for a number of reasons:

- it may be a legislative requirement and required to give the plan the force of law, which is particularly important where a restoration strategy or law will override other statutory or policy instruments
- it provides transparency and accountability about what is to be done, by whom, and why
- setting goals and objectives allows for the restoration strategy or plan to be evaluated
- it encourages a longer-term view of the problem, beyond immediate management issues, and can support responses that focus on the causes rather than symptoms of poor river health
- it can promote efficiency in implementation, by ensuring actions are undertaken in the right order
- it can assist with the process of 'explaining the story' to stakeholders and the broader public and generally making the case for the restoration actions (adapted from Lovett and Edgar, 2002).

As discussed in section 3.3, planning for river restoration can occur at various levels. Policy, goals and objectives, strategies, and actions can be set at the national or regional level, at a basin level, or at a local level. The documents that capture the outcomes of the planning process – such as a national river restoration strategy, or a river basin restoration plan – will vary in structure and content depending on the type of the plan and the extent to which other existing documents (e.g. laws, policies) define requirements. Typically, a restoration strategy or plan should capture the following content:

- **Context:** an overview of the current situation, including ecological and developmental matters. This can help tell the story of the region or the river basin, and make the case for restorative action. It should summarize the results of the situation assessment, including issues, threats, and trends.
- **Vision:** outline what the strategy or plan is trying to achieve, over the short, medium and long term. The vision provides the rational for the strategy and actions, and the basis for assessing the overall success of the restoration works.
- **Options:** different alternative strategies that have been considered and the relative merits of each option. This provides a record of what was considered and the reason for selecting certain approaches over others.
- **Strategy:** what measures will be implemented to achieve the vision and goals. This can include specifying specific, measurable objectives for different regions, reaches, or actions. This should also include establishing institutional roles and responsibilities.
- **Implementation and adaptive management:** setting out the specific tasks and timetable for giving effect to the strategy; identifying available resources, establishing budget and allocating funding; setting monitoring and reporting requirements; including what will be monitored, and how that information will be analysed, reported and incorporated into the strategy as part of the adaptive management process.

Figure 4.11. Typical content of a river restoration strategy

Box 15: Examples of the content of restoration strategies and plans

Following are the tables of contents (or summaries) of two river restoration strategies and plans to provide a snapshot of typical content.

Everglades River Restoration Strategy, 1999 (United States)

- current and future condition
- problems and opportunities
- plan formulation and evaluation
- recommended comprehensive plan (identifying locations and actions)
- implementation plan
- public involvement and coordination

Bronx River Ecological Restoration and Management Plan, 2006 (United States)

- context
- state of the river (existing conditions and problems)
- ecological objectives (water quality, hydrology, channel form and instream habitat, biodiversity)
- opportunities for change and recommended actions
- plan implementation and maintenance

CHAPTER 5
MONITORING AND ADAPTIVE MANAGEMENT

OVERVIEW AND KEY MESSAGES

This chapter sets out key issues relating to the questions of a) what to monitor and evaluate in terms of river restoration projects and programmes; b) when to monitor and evaluate; c) how to monitor and evaluate; and d) how to undertake adaptive management of river restoration in light of monitoring results. The key messages from the chapter are:

- Monitoring against defined and measurable objectives is critical for assessing the effectiveness of river restoration measures and for guiding adaptive management.
- Monitoring programmes should validate (or disprove) the scientific assumptions that underpin the restoration strategy and should provide evidence as to whether restoration projects have been successful.
- Monitoring should be built into the design of river restoration projects right at the start, and monitoring should begin at appropriate time period before the start of restoration actions.
- An appropriate scale of monitoring that will detect the impacts of restoration over a relevant timeframe is required and should continue long after the restoration actions have been 'completed'.

5.1. The role of monitoring, evaluation and adaptive management

Monitoring, evaluation and adaptive management play crucial roles in supporting effective river restoration. Globally, significant sums of money, often from public funds, are allocated annually to restoration projects and programmes so that rigorous monitoring to evaluate effectiveness is needed to assess whether restoration measures have been successful and to ensure accountability. Given the ongoing debate within the scientific community about the effectiveness of specific restoration techniques (e.g. Bernhardt *et al.*, 2007; Naiman *et al.*, 2012) monitoring can also provide invaluable knowledge to guide improvements in restoration practice at the basin, national and international scales, including identifying what approaches have and have not been successful, and why. At the project scale, adaptive management of projects depend on rigorous monitoring and evaluation to guide implementation so specific restoration measures are prioritized to deliver the best environmental and socio-economic outcomes in the most cost-effective way. Because of the complexity and changing context in different river systems, most restoration measures are, in essence, experiments. Therefore, monitoring and evaluation are crucial to help researchers determine which techniques are effective, worthwhile investments. Without well-designed monitoring and evaluation, adaptive management is impossible. Information from monitoring can also be a key input to communication with decision-makers, stakeholders and the public about the reasons for, and results from, restoration. This communication can strengthen the foundations for future river restoration efforts.

While monitoring and adaptive management are common in science, business and numerous other fields, monitoring and evaluation of river restoration has historically been inadequately funded, designed or implemented. Consequently, there are few documented examples of good adaptive management in restoration projects or programmes. The costs associated with poorly designed restoration and monitoring programmes are substantial both in terms of potentially negative impacts to the ecosystem and society from ineffective restoration, and in terms of the waste of financial resources allocated to ineffective monitoring (Downes, 2002).

Guidance is emerging on how to design and implement monitoring, evaluation and adaptive management processes for restoration projects (e.g. Roni 2005; Roni *et al.*, 2008; RRC, 2011 Ayres *et al.*, 2014). While the level of commitment, the complexity of the process, and the depth of understanding required for rigorous monitoring, evaluation and adaptive management goes well beyond anything imagined a few decades ago, positive steps can be taken and success is possible.

Box 16: Definitions of monitoring, evaluation and adaptive management

The terms monitoring, evaluation and adaptive management are often used in conjunction and sometimes interchangeably. However, they describe different and important elements of project and programme management. Different types of monitoring are needed to inform the processes of evaluation and adaptive management.

Monitoring describes the process of gathering qualitative or quantitative data using pre-determined indicators of progress towards project or programme objectives. A monitoring and evaluation plan should incorporate the collection of different data, which can provide robust answers to specific questions and so fulfil different purposes:

1. What was the state of the river system before river restoration commenced (baseline monitoring)?
2. Did the river restoration project do what the project plan said it would do (activity or implementation monitoring)?
3. Did the project cost roughly what the budget estimated it would (financial, cost effectiveness or value for money monitoring)?
4. Were the river restoration actions successful in terms of ecosystem functions and services and consequent ecological or socio-economic outcomes, in relation to the stated objectives of the project (impact or outcome monitoring)?
5. What else is happening in the river system that might have made a difference (surveillance or system monitoring)?

Evaluation describes the process by which project implementers, funders or other stakeholders analyse monitoring data, reflect on project or programme progress and consider options, either for adaptive management or for further restoration (or other water resource management) measures. The use of widely accepted statistical techniques is essential, as is integrated modelling. This is also the stage where the original hypotheses about the restoration actions are evaluated.

Adaptive management is often used in a generic sense to reflect the need for flexibility in project and programme management in the light of evidence gathered through some kind of monitoring and evaluation programme. There is also considerable academic literature that deals with more formal adaptive management theory and processes. It is formally described in this literature as a structured, iterative process of robust decision-making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring (Holling, 1978). Adaptive management is a tool that can be used not only to change a system, but also to learn about the system. Because adaptive management is based on a learning process, it improves long-run management outcomes and builds adaptive capacity. Monitoring provides the information that informs the process, and is central to adaptive management.

5.2. Common challenges and problems for monitoring, evaluation and adaptive management of river restoration

Reviews of past practice (Smith *et al.*, 2014, Ayers *et al.*, 2014, Bernhardt *et al.*, 2007, Morandi *et al.*, 2014) have concluded that many practitioners and project funders have historically not paid enough attention to monitoring and evaluation of ecological and ecosystem outcomes of river restoration. Although documented assessments of the ecological success, or otherwise, of river restoration have increased in the last ten years, there has been less progress in terms of monitoring and evaluation of socio-economic results of restoration measures, projects or programmes.

Barriers to effective monitoring and evaluation have included:

1. Poor definition of project or programme objectives at the outset, which makes it difficult to measure progress. For instance, Bernhardt *et al.* (2007) found that less than half of the 317 river restoration projects surveyed in the US set measurable (quantifiable) objectives.
2. The difficulty in dealing with complex systems and future uncertainties, which makes it hard to distinguish results of specific restoration measures from wider changes in river systems. Feld *et al.* 2011 found that very few restoration project evaluations used a design that helped to understand the effects of restoration measures from broader trends in hydromorphology or biology.
3. Lack of technical and scientific rigour in defining appropriate indicators and metrics and gathering sufficiently comprehensive and robust data. There is evidence that, for many projects, monitoring and evaluation has suffered because choices of evaluation metrics have been influenced

more by the nature and values of the institution in charge of the restoration effort than by a need for objective analysis (Morandi *et al.*, 2014). Further, monitoring and evaluating socio-economic outcomes from river restoration has often been weak. For instance, Ayres *et al.* (2014) found that in the EU, restoration projects were generally considered to deliver a bundle of use and non-use ecosystem services, and that inadequate consideration was given to distinguishing economic benefits for particular ecosystem services. Even in terms of ecological impacts of restoration, monitoring has generally focused on changes in physical habitat or vegetation, rather than broader catchment processes or river health. It has also been limited to individual projects or case studies that do not necessarily reflect the broader basin or region. Most monitoring has focused on various instream restoration techniques (e.g. riffles, boulders), with inadequate monitoring of other types of restoration that tries to restore catchment processes and river health. For example, while fish response to instream techniques has been occasionally evaluated, monitoring of macroinvertebrates and other aquatic biota is relatively rare (NRC, 1992; Roni, 2005). Moreover, monitoring of different physical, biological and socio-economic variables can provide conflicting results, which cloud the issue of whether or not restoration has been successful.

4. The need to monitor different outcomes over different timelines, including pre-restoration baseline monitoring and potentially long post-project periods, while most project evaluations take place no more than a few years after restoration (Feld *et al.*, 2011). For example, a survey of 44 river restoration projects in France found that, although more than 50% of projects included some baseline monitoring, most of these monitoring efforts were restricted to just one year before restoration works commenced. This is insufficient to develop a true understanding of ecosystem functions. Similarly, post-restoration monitoring seldom extended beyond 10 years (Morandi *et al.*, 2014), which can often be insufficient too.
5. A lack of funding, especially for post-project for monitoring and evaluation. Smith *et al.* (2014) concluded that:

   …a fundamental issue relating to the scarcity of monitored projects is that historically, there have been few incentives for monitoring and assessment built into project design or required by funders. Cost is a key issue, with larger projects more likely to have detailed monitoring and appraisal, whereas there is no budget for follow-up activity among smaller projects.

6. Generally, only a small fraction of funds spent on restoration activities are allocated for monitoring or research on restoration projects. For example, the US Army Corps of Engineers generally allocates 1% of restoration project construction funds to monitoring and evaluation (Roni, 2005). This is unlikely to be sufficient in most instances. Drawing on guidance from other types of development projects, it may be that the percentage of project cost that should be allocated to monitoring and associated data management and analyses is in the area of 5–10% (e.g. Frankel & Gage, 2007). Although public and private sector funding agencies and organizations increasingly ask project entities to conduct monitoring, they also struggle themselves with determining how the projects should be monitored; how many projects to monitor, at what frequency, duration, and intensity; the parameters to measure; and how to develop consistency among restoration projects and monitoring programs.

Evidence from the case studies summarized in Chapter 2 supports these conclusions. Most of the projects and programmes described in section 2.3 included some form of monitoring and evaluation effort. Some indicators have been relatively straightforward to measures, such as changes in water quality resulting from the Mersey Basin Campaign in England or in the Taewha River in Korea. There have also been significant investments in science to help monitor and evaluate restoration measures in some basins. In the Columbia River basin in North America, for example, three separate programmes have been established to monitor changes in habitat and fish populations, with the guidance of a dedicated team of science advisors. However, in other places monitoring and evaluation is lacking. In Singapore, only a few of the projects established to improve water quality as part of the ABC Waters Programme have incorporated monitoring elements; there is little peer-reviewed, quantitative evidence of the impact of the Lower Danube Green Corridor on flood risk or water quality, both of which will also be affected by a wide range of basin-scale and climatic changes, apart from floodplain wetland restoration. Monitoring efforts of the Southeast Queensland river restoration projects in Australia were patchy and often under-funded. In the UK, the River Restoration Centre's National River Restoration Inventory (NRRI) of over 2,500 projects shows that only 17%[8] of completed projects have some form of appraisal or evaluation.

A key challenge in using an adaptive management approach is finding the correct balance between gaining knowledge to improve management in the future and achieving the best short-term outcome based on current knowledge. The realities of time, funding and uncertainty mean that, for many river restoration projects, knowledge will always be limited to some extent. On the other hand, the fact that monitoring has often been insufficient has clearly made it far harder not only to evaluate progress towards achieving the stated objectives of a restoration project, but to ensure that appropriate adaptive management decisions are taken to maximise that progress.

8. These figures are from 2012.

Moore and Michael (2009) suggested that, even when monitoring data are gathered, a lack of expert analysis of the data can also impair adaptive management and that this lack of analysis is compounded when monitoring data is inconclusive.

Even though adaptive management has an long theoretical history, there has been only limited application of the approach to effectively to guide everyday natural resource management decisions. While river restoration project leaders nearly always state that adaptive management is used to modify the tasks and work elements, projects rarely have an experimental design to identify whether biological objectives have been met by employing specific strategies or a decision tree that would be used to modify management based on updated scientific information.

In a broad sense, the challenge of implementing adaptive management stems from (Allen *et al.* 2011):

1. a lack of clarity in definition and approach
2. few success stories on which to build
3. management, policies and funding that favours reactive rather than proactive approaches to natural resource management
4. failure to recognize the potential for shifting objectives
5. failure to acknowledge the social source of uncertainty, and hence increased risk of surprise.

More specifically, the pragmatic reasons for why adaptive management has not been implemented effectively, while varied and complex, can be summarized as overconfidence in the projected restoration outcomes; an unwillingness to terminate unproductive activities because project sponsors and staff are understandably reluctant to abandon efforts in which they have invested much time and energy; and the lack of real experimentation, effective monitoring, scientific consensus and adaptive governance (Cosens and Williams, 2012; ISAB, 2013). Projects often continue tasks and work elements, even when monitoring data indicates that biological objectives are unattainable.

Box 17: Adaptive management of biological systems – a review

Westgate *et al.* (2012) conducted a structured review of the adaptive management literature as it relates to biodiversity and ecosystem management, with the aim of quantifying effective adaptive management projects. They also investigated the degree of consistency in how the term 'adaptive management' was applied; the extent to which adaptive management projects were sustained over time; and whether articles describing adaptive management projects were more highly cited than comparable non-adaptive management articles. They found that, despite the large number of articles identified through the ISI web of knowledge (n = 1336), only 61 articles (<5%) explicitly claimed to enact adaptive management. The 61 articles cumulatively described 54 separate projects. Only 13 projects were supported by published monitoring data. The extent to which the 13 projects applied key aspects of the adaptive management philosophy – such as referring to an underlying conceptual model, enacting ongoing monitoring, and comparing alternative management actions – varied enormously. Further, most adaptive management projects were of short duration and empirical studies were no more highly cited than qualitative articles. Their review highlights that use of the term 'adaptive management' is common in the peer-reviewed literature. However, only a small (though increasing) number of projects have been able to effectively apply adaptive management to complex problems. They suggest that applying adaptive management may be improved by: (1) better collaboration between scientists and representatives from resource-extracting industries; (2) better communication of the risks of not doing adaptive management; and (3) ensuring adaptive management projects 'pass the test of management relevance'.

5.3. Designing a monitoring and evaluation plan

Because each river restoration project or programme will be specific to its physical, ecological and socio-economic context, no single monitoring and evaluation approach can fit all scenarios. However, the monitoring and evaluation plan should always refer to the overall objectives of the river restoration project or programme, to specific restoration strategies (including underlying hypotheses or theories of change) and to details of specific restoration measures that will be conducted. The key feature of any plan is the list of what is being monitored, how that monitoring is to take place, who is responsible for undertaking the monitoring and the frequency and time-scale over which monitoring should happen. Typically, a monitoring plan will provide a table of proposed locations, dates and methods of data collection. The River Restoration Centre in the UK has developed a tool to assist with preparing monitoring plans (see Table 5.1 and see www.therrc.co.uk/monitoring-planner).

Developing an effective monitoring program requires consideration of many questions and factors, including those relating to scientific, logistical and financial issues as well as to the particular objectives of the restoration initiative. Moreover, in designing a monitoring plan it is essential that managers of restoration projects understand the final use of the data before monitoring begins. The primary purpose of monitoring might be to enable the implementers of the project or programme to gauge the extent restoration measures are likely to deliver objectives through a combination of baseline and impact monitoring. However, some monitoring may also be intended to aid communication with funders, stakeholders and the wider public about their priorities. It may also be the case that monitoring is being undertaken for scientific purposes, i.e. to add more broadly to the sum of knowledge on river restoration approaches. Depending on the context, it may be desirable to publish monitoring data along with conclusions from evaluation of that data.

Table 5.1. Example of monitoring plan, using the River Restoration Centre monitoring planning

Why	What	How	Data	When	Who	Cost	Confidence	Evaluation
What is the objective of the works to be monitored?	What is your monitoring objective/what are you trying to observe?	What methods are you going to use?	Add information on the baseline data you have collected (type, frequency, method used)	What periods over the year and how often (to indicate variability)?	Who is going to do this?	(Can be in-kind)	High/ medium/ low robustness of monitoring	How/when/ who Monitoring results collated and evaluated
To increase the area of pool, riffle and clean gravel habitats by 80% over 2 km (Works to take place in March 2016)	To monitor increased habitat diversity and change in macro-invertebrate and fish assemblages	Fixed-point photography	None	Pre: June, October 2015 During: March 2016 After: April, June, October 2017; April, October 2018 All at five locations	In-house	In kind	Medium	Photos georeferenced and stored on server Evaluated after every set of photos (in-house) To be included in final evaluation report
		Habitat mapping	None	Pre: September 2015 Post: September 2016	X environmental consultant	£400	High	Report from consultant after every survey To be included in final report
		3-min macro-invertebrate kick-sampling; α-diversity, PSI index	Two 3 min macro-invertebrate kick-samples from two locations in autumn 2013, provided by XX	Pre: April and October 2015 at five locations + one control Post: April and October 2017, April and October 2019 at five locations + one control	In-house by XX	£12,000	Medium	Data recorded on standard sheets Evaluated after survey (in-house) Separate pre- and post-monitoring reports to be included in final evaluation report
		Electro-fishing; taxa, age, weight, length	None	Pre: May 2015 at two locations Post: May 2017 at two locations	In-house by XX	£1500 plus equipment	Low	Data recorded on standard sheets Evaluated after survey (in-house) Separate pre- and post-monitoring reports to be included in final evaluation report

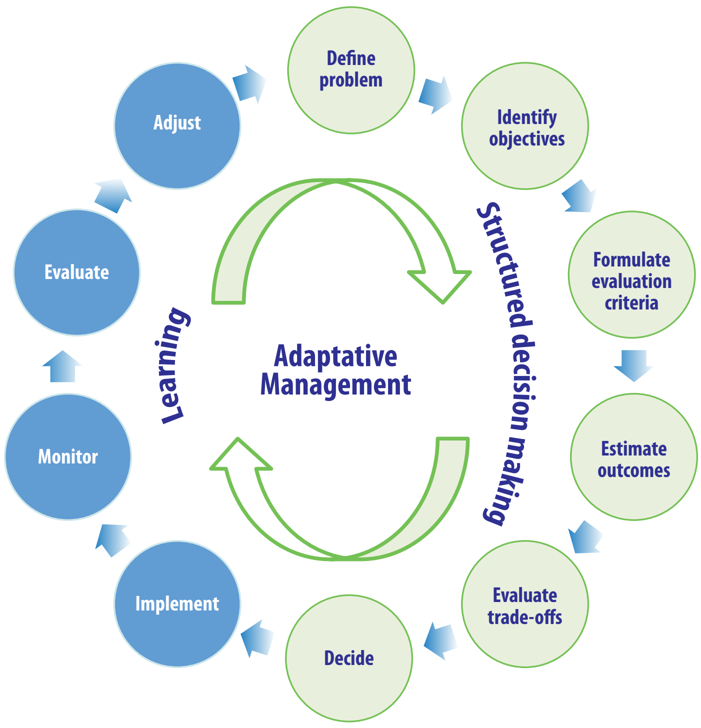
Source: RRC, n.d.

Box 18: Structured decision making and adaptive management

Restoration requires decision-making in the face of uncertainty. This gives rise to three needs: understanding the status and trends of focal socio-economic and environmental parameters, understanding the decision context of restoration, and understanding how to make decisions when we do not know everything we would like to know. In academic literature, these are the realms of monitoring, structured decision-making and adaptive management, respectively. They are three overlapping sets of tools from the field of decision analysis that help managers understand, frame, analyse, communicate and implement their decisions.

Structured decision-making refers to the application of formal decision analysis tools to natural resource management decisions (Runge, 2011), of which adaptive management is one commonly applied tool. Structured decision-making (the grey circles in Figure 5.1), a term often confused with adaptive management, is an organized and transparent approach to the decision process for identifying and evaluating alternatives and justifying complex decisions; however, structured decision-making does not require iterative and consequentially higher-order learning (white circles) that is inherent in adaptive management (Allen *et al.*, 2011).

Figure 5.1. Adaptive management, often characterized as 'learning by doing'



Source: Redrawn from Allen *et al.*, 2011.

The set of decision-analytical tools is large and varied, so the applications that fall under structured decision-making include a wide range of methods, including multi-attribute utility theory (Bain, 1987); info-gap decision theory (Regan *et al.*, 2005); expected value of information (Runge *et al.*, 2011); expert elicitation (Kuhnert *et al.*, 2010); stakeholder engagement (Irwin and Freeman, 2002); and methods for integrating scientific and traditional knowledge (Failing *et al.*, 2007). There is, however, a common framework that underlies all of these applications, namely, a fixed view of how decisions are constructed, grounded in value-focused thinking (Keeney, 1996).

The core steps in a decision analysis are: 1) understanding the context in which the decision is made; 2) eliciting the fundamental objectives; 3) developing a set of alternative actions; 4) evaluating the consequences of the actions relative to the objectives; and 5) identifying a preferred action that is expected to best achieve the objectives (Hammond *et al.*, 1999). This deconstruction helps the decision-maker identify the primary impediments and select tools to overcome those impediments. One of the most important hallmarks of structured decision-making is the emphasis on value-focused thinking, with early identification of the decision- maker's objectives; these objectives drive the rest of the analysis (Keeney, 1996).

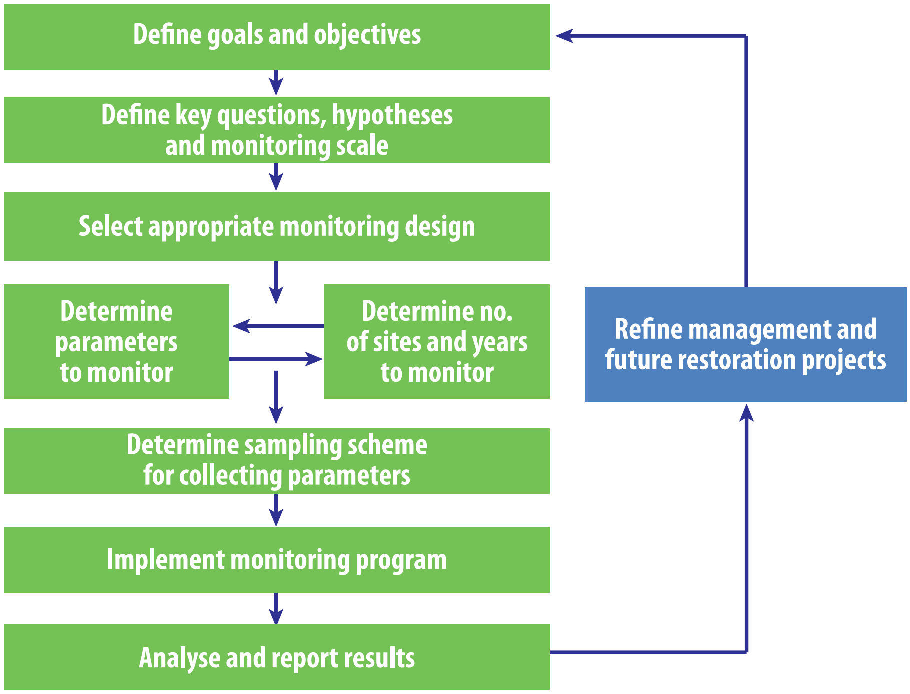
Numerous successful examples of structured decision-making have emerged in the academic literature, e.g. for recreational fisheries (Peterson *et al.*, 2008; Irwin *et al.*, 2011); water resources (Liua *et al.*, 2007); hydroelectric developments and water use (Failing *et al.*, 2004); coastal marine ecosystems (Espinosa-Romero *et al.*, 2011); lamprey control in the US–Canada Great Lakes (Haeseker *et al.*, 2007); and for other natural resource applications (e.g. Tenhumberg *et al.*, 2004; Wenger *et al.*, 2011). In addition, several recent management plans within the Columbia River Basin (US–Canada) have benefited from a similar, although indirect structured decision-making approach (e.g. the All-H Analyser model application to hatchery performance reviews). Also within the Columbia River basin, Peterman (2004) included a decision analysis example from the Snake River illustrating that decision analysis is a useful framework for focusing members of a diverse multi-stakeholder team, and accounting for sometimes differing views about hypotheses and uncertainties, even for contentious issues related to migrating salmon and dams.

The key steps to be followed and issues to be aware of when designing a programme to monitor and evaluate the effectiveness of various types of restoration activities include (adapted from Roni, 2005 and Roni *et al.*, 2005):

- determining goals and objectives of the restoration project or programme
- establishing the primary and secondary purposes of the monitoring programme – is it only intended for adaptive management purposes, is it also for scientific research or to provide information for communication to funders, stakeholders or the wider public?
- defining key questions and restoration hypotheses or theories of change, as well as monitoring design and project scale
- selecting monitoring parameters, i.e. indicators and metrics
- determining the spatial and temporal replication and sampling schemes for indicators
- analysing data and reporting results.

Although these steps are often presented sequentially (Figure 5.2) in reality, many will need to be addressed concurrently. For example, selecting the monitoring parameters depends on the hypotheses and the project scale, and selecting the sampling scheme may affect which and how parameters are measured.

Figure 5.2. Basic steps for establishing a monitoring and evaluation program for river restoration



Source: *Roni et al., 2005*

Roni *et al.* (2005) also provided essential advice on a number of basic issues related to design of monitoring and evaluation for river (and other aquatic) restoration programmes, with a focus on monitoring physical and ecosystem changes:

- River restoration projects, like many natural resource management actions, are experiments. They should be implemented according to the standard rules of experimental design; otherwise, little is learned from them.
- Designing restoration projects as experiments enables hypotheses or theories of change to be tested about the physical, chemical, and biological responses to different restoration actions – and socio-economic benefits or trade-offs arising – and helps understanding cause and effect relationships. This type of monitoring includes both effectiveness monitoring and validation monitoring: determining if the project had the desired physical effect and validating whether basic assumptions about biological responses are correct. This monitoring could possibly be extended to socio-economic responses to changes in river systems.
- Clearly lay out the overall goals of the restoration project or programme and the objectives of the monitoring and evaluation before initiating a study to evaluate restoration actions. Goals typically are broad and strategic, while objectives should be more specific and, most importantly, quantifiable.
- Well-defined objectives can be easily translated into questions; then redefined more specifically into testable hypotheses.
- For monitoring of changes in ecosystem function, there are only a handful of experimental designs, based on whether data are collected before and after treatment (before–after or post-treatment designs) and whether they are spatially replicated or involved single or multiple sites (intensive or extensive). None is ideal for all situations.
- Monitoring parameters should be relevant to the questions asked, strongly associated with the restoration action, ecologically and socially significant, and efficient to measure.
- The ability of monitoring to determine change related to restoration action (or actions) depends upon the parameter variability and to what extent the monitoring is replicated across space and time. Initiating monitoring without an idea of the ability to detect a change is a poor use of time and resources.
- Data acquisition, quality control and assurance, and data management are key parts of monitoring programs, large or small.
- Learning from restoration activities requires adhering to the basic principles of the scientific method, and reporting findings to both the scientific community and the general public.

While this guidance is useful, the extent to which it can be followed is often determined by the availability of funding and by organizational values and biases. It is essential that monitoring and evaluation is recognized in project budgets accordingly and that efforts are made to ensure that monitoring and evaluation follows scientific process as much as possible. If resources are limited, it may not be necessary to develop scientifically comprehensive monitoring and evaluation plans for every restoration measure within a large programme providing agreed basic data are gathered across the whole programme and there is agreement to select a smaller number of representative projects for closer attention.

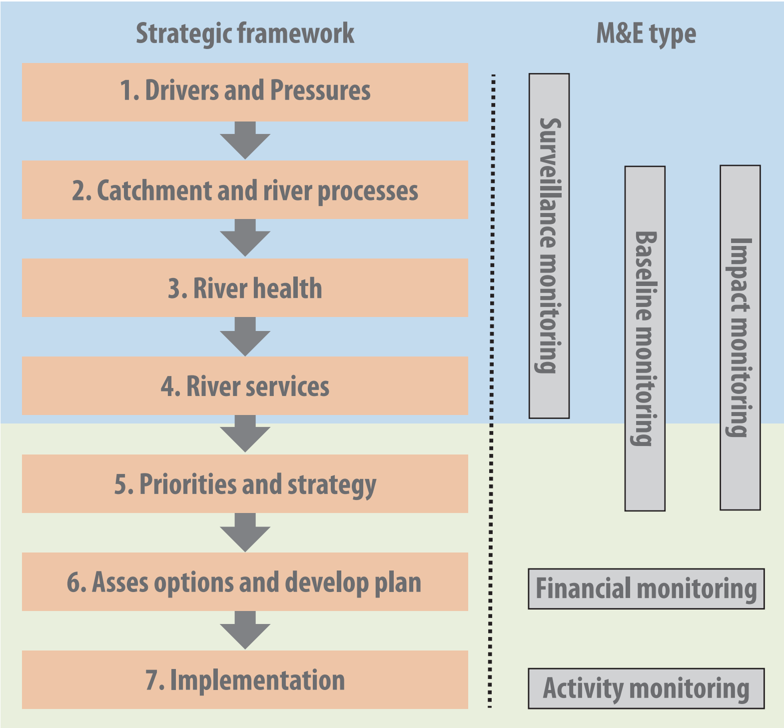
Because of the dynamism of river ecosystem functions, the complex distribution of ecosystem services and the often political nature of socio-economic processes, no scientifically-derived monitoring and evaluation plan will be able to provide definitive answers to all questions regarding the actual or perceived effectiveness of every restoration measure. Realistic monitoring and evaluation planning should recognize this uncertainty and ensure that expectations of stakeholders are managed accordingly. In circumstances where uncertainty is likely to remain a factor, the aim of monitoring and evaluation should be a) to try to reduce uncertainty to a level that facilitates 'good enough' assessments of cause and effect relationships between different elements of the river system; and b) to enable continual review of whether such assessments are borne out by evidence from river restoration outcomes and appropriate adaptive management of restoration projects.

Finally, as climate change takes effect on rainfall and runoff in many parts of the world, historically recorded conditions will not be reliable indicators of the future. The range of future fluctuations in physical, biological or socio-economic elements of a river system may be substantial. Adaptability is needed to adjust options and to manage in an uncertain environment (Rogers *et al.*, 2013). Challenges include identification of potential thresholds beyond which the risk of the river system shifting into a new regime increases. Monitoring is central to that process. When establishing monitoring protocols, uncertainty and levels of evidence should be addressed from the beginning. For example, monitoring plans should describe areas of uncertainty and what will be done – in terms of monitoring – to address the uncertainties. Traditional hypothesis testing is one tool used to address uncertainty and levels of evidence. An alternative approach is to estimate parameters and show their variability with confidence intervals. For example, environmental parameters of interest might include river flows, water quality, sediment loads, and fish production expected after specific restoration actions. To inform management and policy decisions, the estimated magnitude of the parameter, along with its estimated uncertainty, can be compared to the level that is considered ecologically meaningful and socio-economically acceptable.

WHAT TO MONITOR AND EVALUATE

To determine specific parameters that should be monitored, specific questions need to be considered in relation to appropriate levels of the strategic framework for river restoration (see section 3.1 and Figure 3.2). For instance, outcome or impact monitoring can inform evaluation of whether restoration measures have led to changes in priority areas (water security, economic, social/cultural or ecological aspects), river function or river health. Activity or implementation monitoring, along with financial monitoring, is normally undertaken to assess whether a restoration measure was the best option in terms of costs and benefits. Surveillance monitoring supports assessment of whether wider changes in drivers or pressures or in catchment processes had countered or enhanced the outcomes from restoration efforts. All monitoring efforts taken together, and compared with data from baseline monitoring, enable adaptive management so that river restoration provides optimal outcomes. The relationship between the strategic framework and monitoring and evaluation type and purpose is set out in Figure 5.3.

Figure 5.3. The relationship between the types and purposes of monitoring and evaluation and the strategic framework for river restoration



Specific indicators that are monitored will vary according to required outcomes of restoration and the basin context. Historically, where monitoring and evaluation has been documented as part of restoration projects or programmes, the focus has tended to be on restoration of physical and ecological components of river systems. Gathering data on relevant physical and biological variables should form a core component of any monitoring plan, although the range of variables to be measured may vary considerably. In the EU, for instance, the Water Framework Directive requires that progress of water bodies towards Good Ecological Status is assessed against biological quality elements such as fish, macrophytes and invertebrates; 'physico-chemical' elements such as water temperature and nutrient levels; and 'hydromorphological' elements such as water flows, sediment composition and habitat structure. There are a number of more detailed discussions of specific biological and physical metrics in the academic literature, e.g. Woolsey *et al.*, 2007; Skinner *et al.*, 2008.

In circumstances where restoration projects are implemented for a stated socio-economic goal, it is important to also measure ecosystem services and socio-economic outcomes. Effective restoration requires integrated monitoring of physical, biological, and socio-economic processes, including data that reflects cultural diversity and well-being. Including data about people, cultures, and economies alongside environmental elements of the catchment and the biota helps underpin success (Naiman, 1992; Rogers, 2006; Susskind *et al.*, 2010; ISAB 2011; Kareiva and Marvier, 2012). Gathering this type of data may require specific social science expertise. As with monitoring and evaluation of physical and biological factors, it is critical that the framework for socio-economic monitoring and evaluation is considered at an early stage during the overall restoration project or programme design.

Socio-economic monitoring and evaluation can include gathering quantified data on, for example, the number of people using a restored site for amenity purposes compared with the number who used the site pre-restoration. It can also include analysis of the broader economic costs and benefits of river restoration, which is discussed further in Chapter 7. Assessment of people's perceptions of change can also be useful. For example, in South Korea, almost ten years after restoration of the Taewha River was initiated, a survey investigated the level of satisfaction with the river. The same questions were administered to two groups: members of the public and experts such as university professors and researchers. Respondents evaluated the current satisfaction level compared with the situation five years ago, and the satisfaction level without any comparison to the previous state of the river. The evaluation scale was between 0 (very unsatisfactory) and 5 (very satisfactory). For members of the public, the results indicated that water quality, smell, and level of dryness had not been improved significantly, but accessibility, usability of the stream corridor, and surrounding conditions had improved slightly, compared with the situation five years ago (Table 5.2). For experts, all items except for the level of dryness, were improved slightly. The overall satisfaction level for professionals appeared to be higher than that for other citizens.

Finally, as well as monitoring outputs, outcomes and impacts, it is important to gather data on project inputs including the financial and non-financial costs of specific measures in order that the cost-effectiveness of river restoration methods can be assessed. Data on non-financial inputs such as volunteers' time or donated materials can also be a helpful indication of public support for restoration.

Table 5.2. Satisfaction levels for the Taewha River, Korea in April 2004

	Members of the public				Experts			
	Comparison with 5 years ago		Without comparison		Comparison with 5 years ago		Without comparison	
	Average	sd	Average	sd	Average	Sd	Average	sd
Water quality	2.85	*1.10*	2.21	*0.92*	3.48	*0.89*	2.43	*0.89*
Smell	2.85	*1.11*	2.19	*0.91*	3.34	*0.77*	2.43	*0.84*
Level of dryness	2.95	*0.99*	2.46	*0.83*	2.94	*0.89*	2.57	*0.79*
Accessibility	3.27	*0.92*	2.78	*0.98*	3.49	*0.82*	3.00	*0.89*
Usability of stream corridor	3.50	*0.89*	2.82	*0.98*	3.30	*0.87*	2.82	*1.07*
Surrounding condition	3.50	*0.92*	3.00	*0.98*	3.33	*1.03*	2.80	*1.00*

5.4. When to monitor and evaluate

Monitoring should be built into the design of river restoration projects right at the start, and monitoring should begin at an appropriate time before restoration activities start.

Baseline monitoring is essential if implementers, funders and stakeholders are to be satisfied that their investment of time and energy has made a difference to the river system. Even before this, ongoing surveillance monitoring can help to point to problems that might require some kind of river restoration intervention. Data from ongoing surveillance monitoring of river systems can also help to develop hypotheses or theories of change that, in turn, determine the specific kind of river restoration measures that might be needed.

An issue that complicates river restoration is the fact that some outcomes and impacts may not be seen until a long period of time after the restoration project has finished. This is especially the case for projects that involve physical disturbance to rivers, such as re-meandering of channels, because the disturbance itself can be damaging in the short-term and the ecosystem may take some time to recover. Similarly, restoration projects that include objectives relating to flood risk management may be impossible to empirically monitor and evaluate until there is a post-restoration flood event, although impacts on flood risk can be modelled in the interim. Conversely, some restoration impacts might occur quickly, e.g. upstream fish migration can resume within weeks after dam removal and water quality can improve dramatically after the implementation of some restoration measures. It follows that monitoring and evaluation plans need to cover whole span of pre, during, end and post project stages for different purposes (Table 5.3).

Table 5.3. Definitions of monitoring types and examples of what might be monitored for a river restoration project targeting fish diversity and population.

Monitoring type	Monitoring question and purpose	Example	When to monitor
Baseline	*What was the state of the river system before river restoration commenced?* Characterizes the existing physical, ecological and socio-economic conditions for planning or future comparisons	Fish presence, absence, or distribution	Before start of restoration measures
Activity	*Did the river restoration project do what the project plan said it would do?* Determines if project was implemented as planned	Did contractors plant area of marginal plants or construct instream or marginal habitats as described in plan?	At end of restoration measures (also during implementation if mid-term evaluation and adaptive management is required)
Financial	*Did the project cost roughly what the budget estimated it would?* Helps to assess cost-effectiveness and value for money and facilitates accountability	Final spend against budget for each restoration measure and in total	At end of restoration measures (also during implementation if mid-term evaluation and adaptive management is required)
Impact	*Did river restoration make a difference, in terms of ecosystem functions and services and consequent ecological or socio-economic outcomes, in relation to stated objectives of the project?* Determines if actions had desired effects on priority areas, river function, river health and catchment processes; and whether the hypothesized cause and effect relationship between restoration action and response were correct	Did pool area increase? Did change in pool area lead to desired change in fish or other species abundance?	At end of restoration measures (also during implementation if mid-term evaluation and adaptive management is required) Post-project monitoring after a period of months or years to assess whether outcomes/impacts have been sustained
Surveillance	*What else is happening in the river system that might have made a difference?* Determines changes in conditions over time, including changes not attributable to river restoration	Fish spawning surveys and temporal trends in abundance	Ongoing

Source: Adapted from Roni, 2005 and MacDonald et al., 1991

5.5. How to monitor and evaluate

PROJECT, PROGRAMME AND POLICY MONITORING – HIGHER-LEVEL INDICATORS

Monitoring is required across different levels of river restoration effort, including individual measures or projects; combinations of measures that make up a restoration programme for a given river; and at the level of national or regional policy for river restoration. At the most specific scale (the individual restoration measure) it is necessary not only to document that the measure has been undertaken according the agreed specifications but also that it has achieved the stated objectives. This level of reporting often contributes to a data archive for essential and detailed information. At a broader programme scale, numerous restoration actions are usually implemented simultaneously or sequentially to attain a common goal such as improved water quality, fish production or flood risk. In this case, it is not only necessary to monitor the individual outcomes – if feasible – but to determine that the broader goals are being achieved.

In many cases, it is not possible to carefully monitor the outcomes of all individual projects because of uncertainty, complexity or logistical and funding constraints. In such instances it is necessary to either sub-sample an appropriate proportion of the individual projects or to identify integrated parameters (e.g. nitrogen concentrations, fish growth, peak flood flows) that are indicative of the overall status of the river system in comparison with stated objectives. These integrative measures have been termed high-level indicators (HLIs) and can be used to evaluate the effectiveness of larger-scale restoration programmes and even broader policy. For instance, in 2009 the Columbia River Basin Fish and Wildlife Program of the Northwest Power and Conservation Council (US) committed to adopt and periodically update HLIs for the purpose of reporting program success and accomplishments to the US Congress and the region's governors, legislators, and citizens (NPCC, 2014).

HLIs are derived from one or more individual environmental or socio-economic metrics, generally at broad geographic scales. An HLI derived from multiple metrics or even other HLIs might be expressed as an index or presented in scorecard form, as with the River Health Assessment approach (see Chapter 8 for more information on River Health Assessment). Once core HLIs are agreed, additional effort is needed to identify the most common and meaningful metrics for deriving the HLIs. These data will be routinely monitored, updated and presented to stakeholders. Ideally, HLIs should depict how well provincial, basin and sub-basin objectives are being met. For simplicity and impact, HLIs for reporting to policymakers should be relatively few in number, yet accurately and concisely convey, in quantitative or quasi-quantitative form (e.g. class or rank), status and trends of critical aspects of the river system. In the Columbia River Basin example, HLIs depicted the status and trends of fish and wildlife at the sub-catchment and catchment-wide levels, and were designed to be entirely consistent with provincial and sub-catchment biological objectives in the programme. The Columbia River Basin HLIs were designed to be indicative of the overall performance of the programme, and, therefore included biological, implementation and management components.

The presentation and utility of HLIs is increased substantially when coupled with appropriate benchmarks and synthesis statements to allow the audience to understand their significance. Understandably, the HLI are most useful if the 'take-home' message is obvious, and care should be exercised to see that is always the case. For example, increasing fish abundance may look good, but does it answer the full range of questions implied by the restoration goals? Are the overall trends strong, consistent and encouraging, or are they mixed and uncertain? Are goals nearly met or quite distant? It took over a decade for the large and comprehensive Columbia River Fish and Wildlife Program to decide on an initial set of HLIs (www.nwcouncil.org/fw/). Restoration programmes should take care in choosing HLIs that are seamlessly aligned to the specific objectives.

STANDARD VS FLEXIBLE MONITORING PROTOCOLS

Standardization of monitoring is needed, but should be applied judiciously. Advances in physical, biological and chemical measurements, socio-economic surveys and analytical technology may render some approaches to monitoring obsolete. Monitoring protocols must be open to new, more efficient techniques in freely available, automated, low-cost monitoring (Biggs and Rogers, 2003; Venter *et al.* 2008). Consistency is needed to enable broad regional syntheses of status and trends, but a single standardized monitoring approach may not be achievable or desirable. Given that a diverse set of agencies and investigators might be measuring a range of ecosystems, the aim should be to require collection of a minimum set of data for specific impacts or benefits (e.g. water quality, kilometres of habitat restored, flood storage capacity, certain types of economic benefits) using reasonably standard protocols (especially where this is required for HLIs and/or for legal compliance purposes) while allowing investigators to pursue other information that they deem appropriate.

INFORMATION SHARING

Communicating to help stakeholder understanding and engagement makes effective management and restoration more likely. The ultimate goal of sharing information is to develop a common vision for the future of the catchment and to engage the public – at all levels – to assume responsibility, provide information and participate in the discussion of possible solutions. As far as possible, data from monitoring and evaluation should be made available to stakeholders and other river restoration practitioners to help with understanding of progress, stimulate feedback on impacts and future priorities, aid adaptive management – especially desired socio-economic goals of restoration measures – and build a body of expertise at basin, national and international scales.

Information sharing can occur at all levels and can help build a common vision for restoration. But it must be targeted, continuous and convey consistent and factual messages. The three main components of information sharing are: access to data, education and training, and effective communication:

- Access to data, as well as access to information, is a recurrent problem for many water resource management initiatives around the world. Although there is increasing potential to improve data availability and sharing (e.g. through for example cloud computing and social media), substantial effort is required to share relevant data and to standardize basin-scale analyses. Adaptive management requires adequate capacities for data collection and analytical evaluation. These arrangements should be in place when river restoration interventions are initiated.
- Education and training for monitoring activities are most effective when they match the diversity of people, cultures, and skills in the catchment. Opportunities for educating and training public and professional participants in monitoring programs could include citizen science programs, training workshops on specific topics, meetings of groups and associations (e.g. engineering institutes, conservation and environmental clubs, and commercial or recreational fishing organizations). Education and training can potentially enhance the adaptability of local people by helping to build a common vision for restoration and by establishing responsibility for execution of restoration activities. This can greatly enhance the success of adaptive management processes.
- The nature of the audience dictates how information is most effectively communicated and what format will be most easily understood. Some audiences will struggle with complex scientific and technical information, preferring simple, direct graphics that inform central issues of public or scientific concern, like trends in key variables over space and time. Visual graphics are only one form of information sharing; film, music, theatre, and storytelling also can be highly effective. The means by which information is communicated are changing rapidly with the advent of social media sites (e.g. Facebook, Twitter, Weibo) and the ability to quickly and easily search for and map information (e.g. Google). Restoration programmes have an opportunity to engage the public and local agencies by embracing a diverse suite of communication media and exploiting communication tools to their full potential.

Box 19: Citizen science and river restoration

Citizen science – engaging the public in monitoring activities – has several important benefits. Firstly, citizen labour can provide more data from more locations at more times. Citizen engagement can also expand the ability to monitor on private property, enabling co-operation from private landowners. Citizen data can provide a large-scale, on-the-ground view to complement data obtained through remote sensing and other technical means. Citizens also gain experience by participating in monitoring activities, such as mapping habitat characteristics and conditions or learning the rationale behind the protocols. They better understand the reasons for data gathering, how data are gathered, procedures for getting quality data, and they learn about ecological processes from the observations. Most importantly, citizens become engaged and informed in the discussion, knowledgeable about the issues, and interested in the outcome. In effect, they often gain enough knowledge to participate in decision-making and to ask valuable questions (Buck *et al.*, 2001; Curtis *et al.*, 2002) and are empowered to assume an appropriate level of responsibility to improve program effectiveness. Citizen science serves as an example of what can be accomplished educationally by working with partners, and without a large budgetary cost (ISAB, 2011).

One example of a citizen science initiative for rivers is FreshWater Watch, established by the NGO Earthwatch as part of the HSBC Water Programme (see www.thewaterhub.org/). FreshWater Watch is a research project in 25 cities around the world that aims to involve 100,000 people to learn about and safeguard the quality and supply of freshwater in the future. The aim is to gather data on water quality and other variables from more than 35,000 locations, most of which have never previously been studied. Participants from HSBC and other organizations take an active role in scientific data gathering, supervised by experts, joining a global community working together to promote freshwater sustainability.

CHAPTER 6
COSTS, BENEFITS AND FUNDING OF RIVER RESTORATION

OVERVIEW AND KEY MESSAGES

This chapter discusses key issues relating to assessment of the costs and benefits of river restoration and mechanisms for financing projects. It also sets out some ongoing challenges and constraints that can cloud these issues. The key messages from this chapter are:

- There can be significant financial costs and benefits from undertaking river restoration. Any analysis of river restoration options should consider who wins and who loses from each potential intervention.
- Options for financing river restoration include requiring the polluter, the beneficiary, or society (through taxation) as a whole to pay, or a combination of these.
- Sustaining river restoration efforts requires a financing mechanism that will ensure funds are available to meet any on going costs, not just the cost of initial implementation.

6.1. Costs of river restoration

As is the case with other aspects of water resource management, it is important to consider both the costs and benefits of restoration in order to determine where such investments should come from, or who should pay. These costs and benefits will need to be assessed in the context of available water sector and other budgets and in light of the potential direct contribution of restoration to the goals set out in river basin or water resource management plans. Other impacts of restoration schemes, in terms of indirect or longer-term benefits for society, may also be an important consideration. Understanding who has caused degradation of river ecosystems and who benefits from their restoration – especially in terms of direct beneficiaries – is likely to be helpful to the design of financing mechanisms.

At the project scale, the organization responsible for implementation of the project (which could be a local authority, NGO, private sector entity or research institution) should ensure that estimates of costs and benefits are part of pre-project assessment and project design, taking account of any common indicators of cost and benefit that might be in place at the basin or national scales. At the basin or national scale, basin authorities and/or national agencies should ensure that there is sufficient guidance to project implementers on the kinds of data on costs and benefits that are already available, as well as the kinds of baseline and impact monitoring of costs and benefits that will be required. Further details of institutional responsibilities are described in section 7.3.

THE NATURE OF RIVER RESTORATION COSTS

River restoration invariably requires financial investment in capital works of some description, ranging from planting of trees to installation of wastewater treatment plants. Ongoing operational expenditure may also be needed to ensure that restored rivers, or sections of rivers, continue to provide strategically important ecosystem services. Other costs may be incurred through agreements to buy back water entitlements from farmers, as has happened in parts of Australia; or through payments to upstream landholders in return for implementation of certain land management practices. There may also be opportunity costs associated with restoration, which can take effect through, for instance, the need to compensate land owners or water users whose business is affected by restoration.

Documentation of expenditure on, and outcomes from, specific river restoration interventions has been poor in the majority of river restoration projects (Bernhardt *et al.*, 2007; Ayres *et al.*, 2014) with costs being frequently reported only as estimated, aggregated (for entire restoration projects rather than specific interventions) or non-standardised figures. In part this reflects the challenges of predicting the impacts of specific restoration measures in systems as complex as rivers. It also results from the fact that river restoration practitioners have only recently begun to document costs, and benefits, in sufficient detail. Authoritative global estimates of costs and value for money of different restoration measures are therefore difficult to find. Nevertheless, restoration interventions can range from the inexpensive (e.g. volunteer-led re-vegetation of riparian zones) to expensive mega-projects (e.g. the multi-billion dollar restoration project in the Florida Everglades or the Korean Four-rivers project). In the U.S., since the passage of the Clean Water Act in 1972 more than US $84 billion has been spent to improve water quality, including for wastewater treatment and nonpoint source runoff (US EPA, n.d.). Less expensive schemes can also add up. One assessment suggests that, in the USA alone, more than US $1 billion has been spent annually on ecological river restoration in recent years (Bernhardt *et al.*, 2007), excluding the costs of installing and operating wastewater treatment plants as a means of improving river water quality; and in Japan, some US $1.2 billion is spent annually on a combination of river conservation and restoration (Nakamura, 2006).

The median costs of different restoration interventions in Australia and the USA (following the typology of measures described in section 3.7) are summarized in Figure 6.1. Data were taken from two surveys of restoration projects, drawing on analyses of more than 2,200 river restoration projects in Victoria, Australia (Brooks and Lake, 2007) and more than 37,000 projects in the USA (Bernhardt *et al.*, 2005). Note that not all projects reviewed in these analyses included detailed data on costs; and not all types of restoration interventions were represented in both analyses (e.g. there was an absence of data for land acquisition in the Australian analysis). Some general patterns emerge. For instance, interventions that often involve substantial physical works (such as stormwater management or floodplain reconnection) emerge as relatively expensive options, along with land acquisition. It is notable that costs of some measures were markedly lower in Australia than in the USA. Interventions aimed to improve stormwater management cost less than half as much in Australia (just over US $70,000) than in the USA (approximately US $180,000). On the other hand, median costs of measures to improve fish passage were consistent between the two surveys, at approximately US $30,000–$40,000. Where differences in costs exist, this may be as a result of local economic factors (differences in costs of materials, labour), or because of differences in the scale of the 'typical' intervention.

This analysis suggests that, while some measures will always be expensive, the specific physical and socio-economic context can greatly influence costs of interventions. Depending on the benefits sought from restoration, careful analysis of the costs of different intervention options will be needed. Improved documentation of the costs of different options in project proposals and reports will also be important in order to strengthen national, regional and global assessments of the value for money achieved from river restoration.

ESTIMATING RIVER RESTORATION COSTS

There is no standard typology of river restoration costs. However, Ayres *et al.* (2014) assessed river restoration costs of according to whether they were recurring or non-recurring as follows:

- Non-recurring costs:
  - planning and design costs
  - transaction costs
  - land acquisition costs
  - other construction/investment costs
- Recurring costs:
  - annual maintenance costs
  - annual monitoring costs.

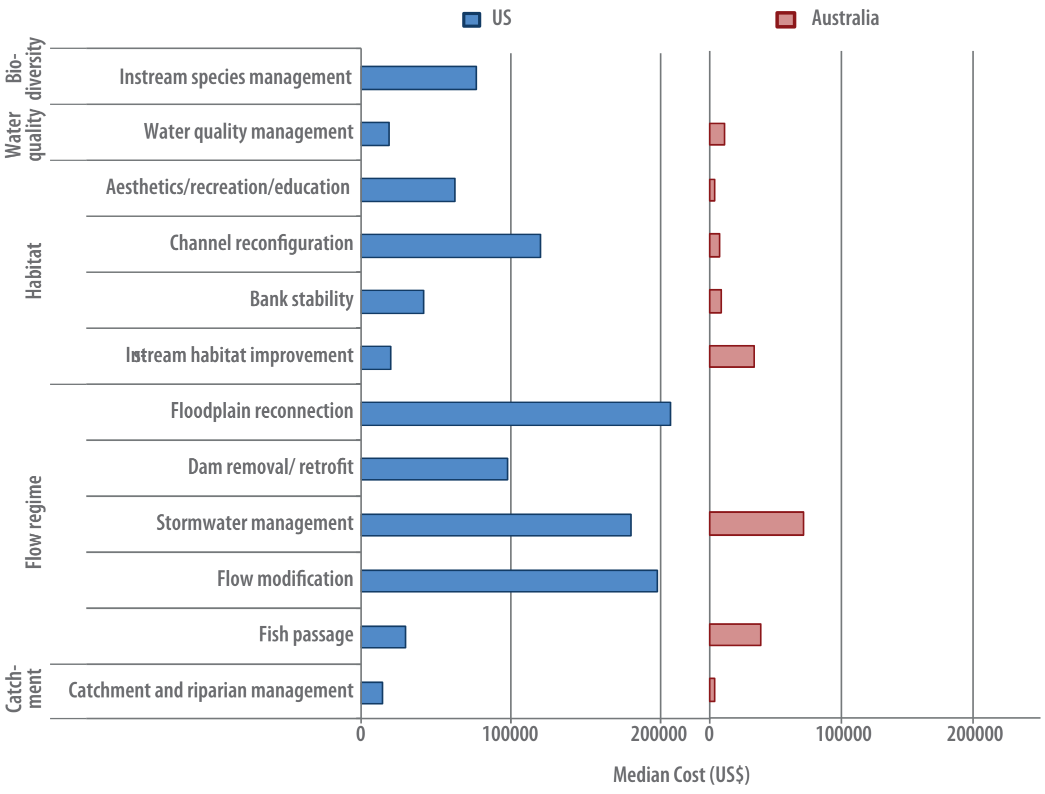
This typology is helpful because it specifically requires costings of both initial restoration measures and ongoing maintenance and monitoring costs that have often been under-funded or unfunded in the past (Bernhardt *et al.*, 2007; Smith *et al.*, 2014). It may be important to also think beyond the financial costs of individual project interventions and to consider the indirect economic and social costs of river restoration. These costs might include the opportunity cost of any river restoration intervention[9], non-recurring and recurring costs for regulators

9. For example, funding spent on any given restoration intervention cannot be spent on other water resource management activities that may have produced social, environmental or economic returns on investment.

who must maintain oversight of the restoration project, or the costs of any subsidies or incentives (such as tax incentives) associated with overarching policy for river restoration.

Estimating the likely costs of river restoration projects or programmes can be challenging. Costs will vary according to context even within the same basin. For instance, Table 6.1 illustrates the range of expenditure on better management practices (BMPs) on farmland that were implemented as part of the Chesapeake Bay restoration scheme in the US. For some measures, such as installing grass buffer strips, costs varied considerably.

Figure 6.1. Median costs in of river restoration interventions in the United States and Australia (US $)



Source: Adapted from Brooks and Lake, 2007 and Bernhardt et al, 2005).

Table 6.1. Average costs and removal efficiencies in the Chesapeake Bay restoration project for selected agricultural Better Management Practices

BMP	Total Annual Cost per BMP Acre ($/acre/year)	Removal Efficiencies (%)		
		Total Nitrogen	Total Phosphorus	Total Suspended Solids
Forest buffers	$163–291	19–65%	30–45%	40–60%
Grass buffers	$99–226	13–46%	30–45%	40–60%
Wetland Restoration	$236–364	7–25%	12–50%	4–15%
Livestock Exclusion	$81–117	9–11%	24%	30%
Cover Crops	$31	34–45%	15%	20%
No-till	$14	10–15%	20–40%	70%
Reduced fertilizer Application	$37	15%	0%	0%

Source: US EPA, 2012

Costs of river restoration should be compared with costs of other management approaches that could contribute to the desired water management goal. For instance, the cost of restoring floodplain wetlands as a means of reducing flood risk for downstream communities should be compared with the cost (as well as the benefits and risks) of building engineered flood defences. In comparing costs, it is useful to note that well-designed river restoration schemes may contribute to multiple water management objectives. The same floodplain wetland restoration project might contribute to enhancing river water quality, improving amenity value, supporting fish recruitment and increasing biodiversity. Conversely, it is also important to consider costs of any functions that will be lost when a river or associated wetland is restored (e.g. residual functions of old dams will no longer be available if the dam is removed). Comparison of costs between restoration and other interventions may therefore be more complex than simply comparing two single-issue solutions.

6.2. Benefits of river restoration

THE NATURE OF RIVER RESTORATION BENEFITS

As discussed in Chapter 1, the social and economic benefits derived from healthy rivers can be expressed in terms of provisioning, regulatory, cultural or supporting ecosystem services (MEA, 2005). The degradation of freshwater ecosystem functions in many parts of the world has led to a rapid decline in many of these services. The benefits of well-designed river restoration projects will mainly be felt from the return of at least some services as a result of improvements in river health.

Although they have rarely been expressed explicitly in terms of ecosystem services, researchers have begun to establish a typology of the ecological benefits that restoration projects try to provide. For instance, Palmer *et al.* (2014) summarized the most common goals and methods for 644 projects in the US, concluding that biodiversity (the primary goal for 33% of projects), channel stability (22%) and riparian habitat (18%) were the most frequently cited objectives of river restoration projects. Although many projects also claim to provide benefits stemming from enhanced ecosystem services, relatively little data has been published on specific, measured impacts, although Fischenich (2006) attempted to set out the relationship between ecological functions and 'beneficial uses'.

Table 6.2 shows a typology of ecological and socio-economic benefits, which can be linked to the river restoration interventions (see section 5.3 for the typology of restoration interventions).

Any single river restoration measure may provide multiple benefits; similarly, a specific socio-economic benefit could be provided by more than one type of river restoration intervention. Thus, floodplain restoration could provide benefits for fishery productivity, flood risk reduction, amenity improvement and biodiversity enhancement; and fishery productivity could be increased not only through floodplain restoration but also by improving flow regimes and tackling water quality problems. Boxes 20 and 21 provide greater detail of restoration initiatives in the Danube River (Europe) and the Elwha River (US) that were designed to improve different ecosystem services and provide multiple benefits.

Box 20: Lower Danube Green Corridor economic analysis

The Danube River flows for 2,780 km through central and eastern Europe to the Black Sea. The 801,463 km^2 river basin is home to approximately 80 million people. The lower Danube is typically described as the section running from the Iron Gates Gorge, on the border to Romania and Serbia, to the Danube Delta and the Black Sea.

Key management challenges for Lower Danube include improving water quality and mitigating flood risk. The Danube contributes the largest input of nutrients into the hypoxic Black Sea 'dead zone' near the delta. Agriculture contributes approximately 50% of the anthropogenic nutrient load received by the river with industry (25%) and urban wastewater (25%) contributing the remainder (Behrendt, 2008). Although the upper and central Danube have been more heavily modified, 28% of the floodplain in the lower Danube was converted into agricultural land, aquaculture or forestry in the 20th century, mostly through the construction of flood defence dykes parallel to the river (UNDP/GEF, 1999). Nevertheless, floods have continued to cause significant problems in the region. It has been estimated that €1.6 billion in damages were caused by flooding in Romania between 1992 and 2005 (Mihailovici, 2006) and there is concern that climate change may exacerbate this problem (Ebert, *et al.*, 2009). Much of the land reclaimed through the construction of dykes is of low economic value especially since the change from centralized economic planning in the 1990s.

In the 1990s and 2000s, the restoration potential for these floodplain wetlands along the lower Danube was assessed. One study estimated the economic value of restored floodplain wetlands at €1,354 per hectare year based on the nutrient reduction services, fisheries, reed harvesting, farming and tourism (Kettunen and ten Brink, 2006). Another study calculated the economic benefits of nutrient reduction alone at €870 per hectare per year. By way of comparison, the economic value of areas used for intensive agriculture has been estimated at €360 per hectare per year (DDNI, 2008).

Table 6.2. Socio-economic benefits of river restoration interventions and their examples

Element	Approach to restoration	Ecosystem services			
		Provisioning	Regulating	Cultural	Supporting
Catchment	**Catchment and riparian management**	Timber and/or firewood, food for human consumption and fodder for livestock, e.g. on-farm riparian zone, New Zealand (White *et al.*, 2014)	Controls water temperature, lessens sediment and nutrient run-off, e.g. Albany, Western Australia (McKergow *et al.*, 2003)	Aesthetic value of riparian zones, and historic and cultural significance of waterways, e.g. on-farm riparian zone, New Zealand (White *et al.*, 2014)	Increased habitat for biodiversity on land and in streams, e.g. Albany, Western Australia (McKergow *et al.*, 2003)
	Land acquisition	Improving native flora and fauna, including threatened and endangered species, e.g. Florida Everglades, US (Stern *et al.*, 2010)	Reducing nutrient loads, increased flexibility to manage water during floods and droughts, e.g. Florida Everglades, US (Stern *et al.*, 2010)	Benefits to tourism, job creation, and areas for public recreation, e.g. Florida Everglades, US (Schmitz *et al.*, 2012)	Recreation and preserving lands for fish habitat, e.g. Florida Everglades, US (Schmitz *et al.*, 2012)
Flow regime	**Fish passage**	Affect fish population and also other ecosystem services that rely on the presence or abundance of migratory fish, e.g. Pawtuxet watershed, Rhode Island, US (Johnston *et al.*, 2011)	Improvement in water quality, e.g. Axe and Exe River, UK (AERIP, 2012)	Job creation, increased eco-tourism and outdoor recreation, e.g. Axe and Exe River, UK (AERIP, 2012)	Important spawning habitat; small fishes and benthic invertebrates pass and colonize the passage, e.g. Pawtuxet watershed, Rhode Island, US (Johnston *et al.*, 2011)
	Flow modification	Increases availability of water form conjunctive water management, e.g. Roanoke River, North Carolina, US (Richter and Thomas, 2007)	Alter the timing and delivery of water quantity, e.g. Kissimmee River, Florida, US (Ardón and Bernhardt, 2009)	Supplement irrigational needs, e.g. Roanoke River, North Carolina, US (Richter and Thomas, 2007)	Benefit fish spawning and access to low-lying floodplain areas, e.g. Savannah River, US (Richter and Thomas, 2007)
	Stormwater management	Access to clean water, e.g. London, UK (Lundy and Wade, 2011)	Intercept runoff and discharge it to rivers at a controlled rate, restore groundwater supplies, e.g. Portland, Oregon, US (Lennon *et al.*, 2014)	Improve health and community liveability, provides neighbourhood green spaces, e.g. Portland, Oregon, US (Lennon *et al.*, 2014)	Improves habitat by reducing stormwater volume and filtering pollutants, e.g. Portland, Oregon, US (Lennon *et al.*, 2014)
	Dam removal/ retrofit	Increase number of fish species, e.g. Pine River, Michigan (Burroughs *et al.*, 2009)	Improves fish passage; changes in river geomorphology; increased flow fluctuations, e.g. Pine River, Michigan, US (Burroughs *et al.*, 2009)	Creates a local amenity due to increase in fish, e.g. Milltown Dam, Clark Fork river, Montana, US (Havlick and Doyle, 2009)	Sediment changes improves spawning habitat, e.g. Pine River, Michigan, US (Burroughs *et al.*, 2009)
	Floodplain reconnection	Increase in fishery yields, e.g. Northern Australia (Pusey and Arthington, 2003)	Flood risk reduction; prevent aggradation by avoiding sediment deposition, e.g. Burdekin River, Australia (Pusey and Arthington, 2003)	Public-safety benefits by reducing flood risks for nearby towns, cities or agricultural areas, e.g. Sacramento River, US (Watts *et al.*, 2011)	Allows fish to exploit spawning habitats; provides habitat for juvenile fish, e.g. Burdekin River, Australia (Pusey and Arthington, 2003)
Habitat	**Instream habitat improvement**	Increase in availability of key fish species, e.g. Drau River, Austria (Muhar *et al.*, 2007)	Oxygenation and sediment flushing of the water, e.g. Hind River, New Zealand (Lessard, 2014)	Variety of channel structures improves aesthetics, e.g. Hind River, New Zealand (Lessard, 2014)	Physical habitat heterogeneity enhances biological diversity, e.g. Drau River, Austria (Muhar *et al.*, 2007)
	Bank stability	Improves fisheries, e.g. Rea River, UK (Severn Rivers Trust, n.d.)	Reduced diffuse and point source pollution, e.g. Rea River, UK (Severn Rivers Trust, n.d.)	Improves environment for recreation, e.g. Rea River, UK (Severn Rivers Trust, n.d.)	Improves and stabilizes physical habitat of for resting and breeding, e.g. Rea River, UK (Severn Rivers Trust, n.d.)
	Channel reconfiguration	Improve trout fishery, e.g. Gunnison River, Colorado, US (Elliott and Capesius, 2009)	Increased water residence time in the channel and reconnect the river to its floodplain, e.g. Silver Bow Creek, Montana, US (Mason *et al.*, 2012)	Provides protection to unmovable infrastructure, e.g. North Carolina, US (Miller and Kochel, 2010)	Increased macro invertebrate richness and density and enhance spawning, feeding, and refugia habitats for resident fishes, e.g. Skjern River, Denmark (Pedersen *et al.*, 2007)
	Aesthetics/ recreation/ education	Preserve native species, e.g. Sheboygan River, Wisconsin, US (Miller *et al.*, 2009)	Flow regulation and flood prevention, e.g. Sheboygan River, Wisconsin, US (Miller *et al.*, 2009)	Increasing heritage value and enhanced tourism due to improved environment, e.g. Sheboygan River, Wisconsin, US (Miller *et al.*, 2009)	Preserve native species and supports diverse biota, e.g. Sheboygan River, Wisconsin, US (Miller *et al.*, 2009)
Water quality	**Water quality management**	Supports harvest of native fish, e.g. Platte River, Nebraska, US (Loomis *et al.*, 2000)	Improvement in instream water quality, e.g. Platte River, Nebraska, US (Loomis *et al.*, 2000)	Enhance the economic and social amenity value; improve the quality of life, e.g. Platte River, Nebraska, US (Loomis *et al.*, 2000)	Reduces habitat inhabitance by invasive species and increases in populations of rare or endangered fish, e.g. Platte River, Nebraska, US (Loomis *et al.*, 2000)
Biodiversity	**Instream species management**	Increase in availability of native fish species, e.g. Fossil Creek, Arizona, US (Marks *et al.*, 2010)	Improves water quality and reduces competition for resources for native fish species, e.g. Fossil Creek, Arizona, US. (Marks *et al.*, 2010)	Improves river health for recreational activities, e.g. Fossil Creek, Arizona, US (Marks *et al.*, 2010)	Alter aquatic native species distribution and abundance, e.g. Kissimmee River, Florida, US (Ardón and Bernhardt, 2009)

Box 21: Dam removal on Elwha River, Washington, United States

A large dam removal project began in September 2011 on the Elwha River, located on the Olympic Peninsula in Washington State, US. Constructed in early 1900s, the 108 feet (33 m) high Elwha dam and the 210 feet (64 m) Glines Canyon dams are now dismantled.

This project has re-opened more than 70 miles of pristine salmon habitat in the Olympic National Park. The dams blocked salmon migration up the Elwha, devastating its fish and shellfish and the livelihood of the Lower Elwha Klallam tribe (Nijhuis, 2014). The river is already transporting sediments to the river mouth bringing geomorphic alterations and changing bed sediment grain size affecting aquatic habitat structure, salmonid fish spawning, rearing potential, and riparian vegetation (East *et al.*, 2015).

The estimated cost of removing both dams was $40–$60 million. The total cost of the Elwha River restoration is approximately $351.4 million. In comparison, the non-market benefit to residents of the State of Washington was expected to be $138 million annually for 10 years and between $3 and $6 billion to all US households[10] (Loomis, 1996).

WHO BENEFITS FROM RIVER RESTORATION?

Most restorations interventions will, in some way, benefit the whole of society in the surrounding area. This could be because of augmentation of water resources on which multiple stakeholders depend (e.g. through improved water quality or river flows), an increase in carbon sequestration in restored floodplain wetlands or the enhanced amenity value, which arises from urban river restoration. However, some groups may benefit more directly and significantly than others from specific interventions. There may be some groups or organizations who lose out from river restoration too, e.g. land owners or tenants who sacrifice riparian land, industries which are required to invest in pollution control technology, or water users who give up all or part of their allocations or water rights in order to support enhanced river flows. Any analysis of river restoration options should therefore consider who wins and who loses from each potential intervention. Engagement of key stakeholders and the wider public will be necessary in many restoration projects in order to help reconcile competing demands for benefits from river restoration, gather information that they might hold which could support restoration design and benefit optimisation, test their perceptions of measures and enhance a sense of ownership for the final restoration plan.

10. Based on contingent valuation method for estimating the willingness to pay for removing the two dams on the Elwha River.

6.3. Quantifying costs and benefits

As with all water resource management efforts, it is important to gather and analyse data, including quantified metrics of costs and benefits, to assess the effectiveness of river restoration measures in terms of providing intended benefits. Historically, restoration practitioners have either gathered or published insufficient monitoring data although there are indications that standards are improving at least with respect to measurements of ecological changes resulting from river restoration (Palmer *et al.*, 2014; Smith *et al.*, 2013). However, to really understand the effectiveness and efficiency of restoration measures, data should be gathered on carefully targeted metrics relating to costs, ecological benefits and socio-economic (ecosystem service) benefits. Chapter 5 provides a more detailed discussion of approaches and challenges to monitoring and evaluation of river restoration measures and projects.

Many benefits from river restoration will take effect through changes in the intrinsic values of ecosystems. This is especially true with respect to enhancements of cultural and supporting ecosystem services and biodiversity. Nevertheless, policy-makers and budget holders very often decide priorities for action on economic grounds, so river restoration practitioners increasingly need to understand the different approaches and tools for valuing the economic costs and benefits of restoration options. One of the best-studied examples is the New York City Watershed Agreement. In the 1990s, the quality of the city's drinking water supplies was threatened by a combination of urban development and non-point source pollution from agriculture in the catchments from which raw water supplies for the city were sourced. The City assessed the costs of building a new water filtration system versus those of protecting these catchments through paying better urban planning and land management. The capital investment needed to protect and restore natural ecosystem processes in the upstream catchments was estimated at $1 billion to $1.5 billion compared with a cost of $6 billion to $8 billion to build and operate a new filtration system to meet water quality standards (Ashendorff *et al.*, 1997). On a smaller scale, a restoration initiative for Mayesbrook Park in London and its associated stream, the 1.6km long Mayes Brook, cost €3.8m (approximately US $3.4m) over 4 years and it has been estimated that over 40 years, at a 3.5% annual discount rate, it will provide €31.2m (US $28.1m) in benefits associated with improved flood and climate risks, enhanced recreation and tourism, nutrient cycling, wildlife restoration and regional regeneration (Everard et al, 2011).

Tools are emerging which enable the estimation of the economic values of specific ecosystem service, such as the InVEST tool (Kareiva, *et al.*, 2011). More generally, economists have developed a number of methods for quantifying costs and benefits of ecosystem restoration (Table 6.3). All of these techniques have advantages and disadvantages and obtaining definitive data is often challenging but approaches are becoming increasingly sophisticated as experience is gained across the river restoration and economics communities (e.g. Brouwer *et al.*, 2015).

In assessing the potential costs and benefits of different restoration options, decision-makers in project implementation agencies and/or basin or national authorities will need to understand the levels of uncertainty around any quantification of costs and benefits. Dialogue about the relative merits of restoration options will be enhanced through reliance on qualitative information about benefits as well as economic valuation. Selection of the most appropriate method will depend on factors such as the magnitude of the costs, who is paying for restoration, the nature of the restoration project and the physical, ecological and socio-economic context within which river restoration is planned. For instance, if restoration is required as a direct result of ecosystem damage caused by a single company, that company may simply be charged the full cost incurred to restore the ecosystem to its previous state. On the other hand, if taxpayers are paying for the project, and if funding is insufficient to pay for the best-case restoration options, some sort of willingness to pay method may be appropriate to understand priorities (Holl and Howarth, 2000). A practical first step could be to approach others who have undertaken economic assessments of river restoration initiatives in order to benefit from their hands-on experience (see for instance the outputs of the EU REFORM project, http://www.reformrivers.eu/).

Table 6.3. Techniques for evaluating costs and benefits of ecosystem restoration

Method	Brief description	Advantages/disadvantages
Replacement cost	Calculates the direct cost of replacing or restoration of a damaged ecosystem.	Simple, but perhaps too simple. Requires prior agreement on restoration measures; relies on often unavailable or unreliable cost estimates of similar measures; may fail to account for indirect restoration costs, e.g. planning costs, monitoring costs.
Replacement cost multiplier	Calculates cost of restoring an ecosystem plus additional funding for lost values due to damage and uncertainty.	As above, but inclusion of contingency funding allows for uncertainties. May be difficult to justify contingency budget to funders though.
Valuing ecosystem services	Evaluates economic benefits of restoring a given ecosystem service using a tradable substitute, e.g. watershed restoration vs a water treatment plant to improve water quality.	Explicitly recognizes value of ecosystem services, but can be difficult to quantify and may be over-reliant on narrow valuation of use values, ignoring non-use values such as aesthetics.
Contingent valuation	Evaluates people's willingness to pay for a restored ecosystem.	Includes non-use values. People may find it difficult to make quantitative estimates of their willingness to pay. There may be discrepancies between what peoples say they would be willing to pay and what they will actually pay when required. Can be expensive to apply.
Travel cost method	Estimates the value that people place on an ecosystem by their willingness to pay and spend time travelling to the ecosystem.	Useful where the restored ecosystem has amenity or recreational value, but less valuable if it does not.
Hedonic pricing	Estimates the value of a restored ecosystem by evaluating the effect of a restored area on nearby property values	There is substantial evidence that home buyers will pay a premium for proximity to a healthy ecosystem and desirable environmental amenities. This method is less useful where housing is not near restored ecosystems.

Source: Adapted from Holl & Howarth, 2000

6.4. Who pays, and how?

SOURCES OF RIVER RESTORATION FINANCING

Broadly speaking, there are three ways major financing for river restoration works can be arranged (Figure 6.2). In practice, a combination of these financing mechanisms may be needed, especially when private sector organizations (that may be both polluter and beneficiary) contribute funds. The policy and legal frameworks for organizing financing from these frameworks will normally need to be established by the national (or sometimes sub-national) level governments. In some cases, however, direct contributions by non-government actors, such as NGOs or companies can be made to help fund restoration projects without the need for specific public policies.

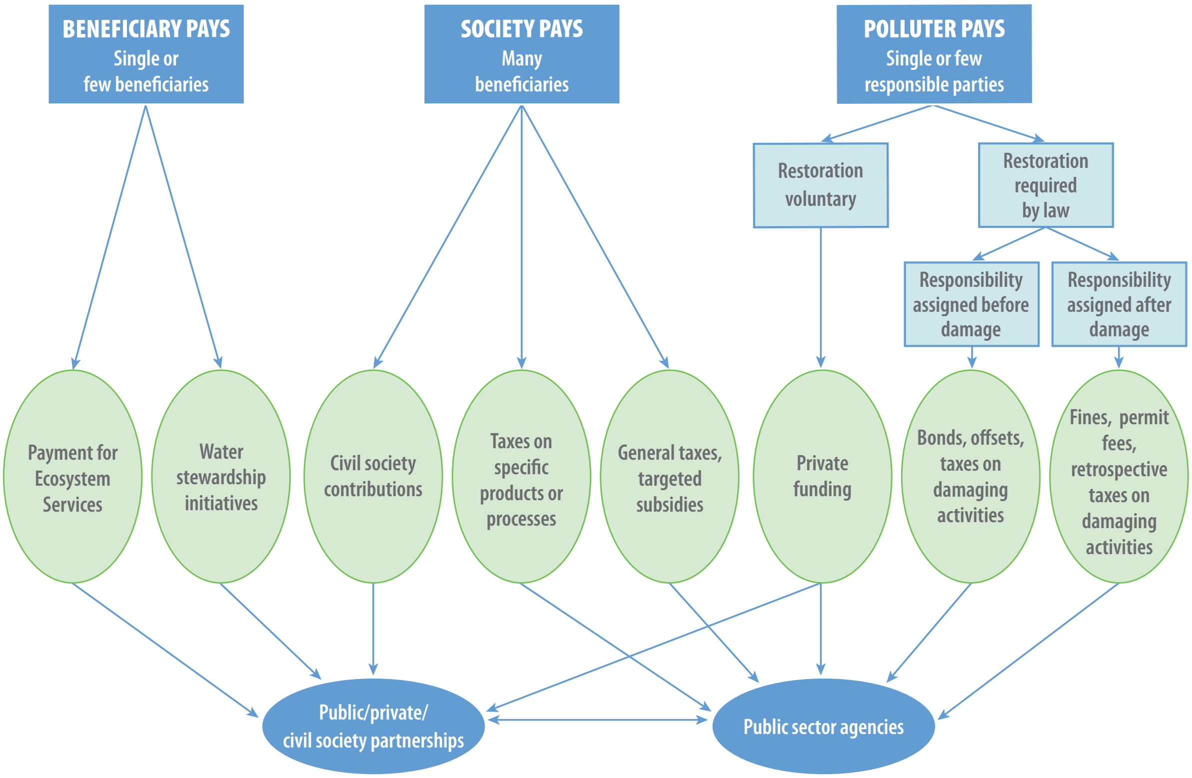
1. **Polluter pays:** Many countries have existing, albeit imperfect, mechanisms for imposing fines on or charging for permits to industries or individuals who cause damage to ecosystems. Funds raised through such schemes are used in various ways – in some countries, funds will be returned to the local or central government exchequer, in other countries they may be ring-fenced for environmental projects that, to some extent, offset damage to ecosystems. There may be legislative requirements for companies to take out restoration insurance for some developments, which will ensure that unforeseen costs of restoring ecosystems can be met. Restoration bonds are a variation of this approach, where businesses are required to pay a bond before a potentially damaging activity is undertaken to ensure sufficient funds are available to public authorities or others for restoration measures after the development has taken place (Holl and Howarth, 2000). The involvement of the hydropower industry, through the Bonneville Power

Authority in the Colombia River, is an example how 'polluters' can contribute to restoration.

2. **Beneficiary pays:** Recent decades have witnessed the development of Payment for Ecosystem Service schemes. Often stimulated by civil society actors, these schemes transfer payments from 'buyers' of enhanced ecosystem services (mostly downstream businesses or municipalities) to 'sellers' (usually upstream land managers or farmers). In return, the sellers either undertake instream restoration activities or modify the way they manage river catchments to reduce pollution or safeguard river flows. Water stewardship initiatives are a variation on this theme and might involve companies that are concerned about water-related risks to their businesses investing in collective action with other stakeholders to address such risks. For instance, a company may be worried it might suffer reputational risk, and therefore financial damage from fines or damage to its social licence to operate, because of real or perceived river pollution impacts connected to factory effluents. In response, the company might jointly invest with local authorities and others to enhance municipal wastewater treatment facilities, support improved data collection on environmental and social impacts of pollution or work with NGOs to push for better implementation of existing pollution control regulations at the basin or sub-basin scale. Sometimes, there can be win-win situations where organizations can benefit more directly from river restoration. In the Danube River Basin, for instance, the river navigation sector has helped to fund river restoration schemes designed for ecological benefit and to improve river transport (Philip Weller, personal communication). Providing such actors continue to see a benefit from restoration projects, and if institutional arrangements are sustainable, one benefit of this kind of approach is that funding can be self-sustaining.
3. **Society pays:** A common feature of many river restoration initiatives is the prominent financing role played by government, or quasi-government organizations. It makes sense for the public sector to make finance available for projects where there is a) broad social or economic benefit to society from river restoration; b) it is technically not feasible to attribute damage to river ecosystems, or benefits from restoration of river ecosystems, to specific parties. Civil society, through non-governmental organizations (largely supported by philanthropic donations), also funds river restoration projects.

More specifically, funding for river restoration can come from a number of organizations. Restoration projects are often financed by a blend of contributions from local, national and international public sector organizations, the private sector and civil society actors reflecting the fact that benefits may accrue to multiple stakeholders (Table 6.4). For instance:

Figure 6.2. Options for funding river restoration. Adapted from Holl and Howarth (2000)



- The Mersey Basin Campaign in the UK benefited from core funds from central government and in-kind funding from local authorities and other partners. The central government funds were linked to the 25-year vision to restore the river as a mechanism for urban regeneration. Project funds came from a variety of sources including the private sector, especially for major wastewater treatment infrastructure (the private sector being the water utility that was transformed from a public to private sector entity in the mid-1990s); and contributions from regional economic organizations, especially the European Union.
- Many of the core costs of co-ordinating the Lower Danube Green Corridor initiative were substantially underwritten by an NGO (WWF), which in turn raised its funds from a variety of sources, including public subscription and charitable foundations. Major funds for specific floodplain wetland restoration projects were often made available through regional and global multi-lateral organizations including the European Union, the World Bank and Global Environment Facility.
- River restoration in Singapore has been substantially funded by a combination of national agencies including the Public Utilities Boards (PUB), the National Park Board, and the Urban Regeneration Authority. However, there has been a recognition that these agencies alone cannot effectively and efficiently care for every piece of the land to safeguard the water quality. PUB launched the ABC Waters Certification scheme in 2010 to encourage other public and private sectors to incorporate the ABC Waters approaches in their development projects.
- In the Murray–Darling Basin, Australia, the federal government directly allocated A $12.9 billion in funds to buy back water entitlements, improve water use efficiency, and for other measures aimed at improving flows and thus the health of the river basin (DEWHA, 2008).
- In the Columbia River, the restoration planning effort and the Fish and Wildlife Program are guided by the Council and funded by Bonneville Power Authority, a federal non-profit agency which receives funds from hydropower generation in the Columbia basin that are then spent on environmental projects. A similar arrangement helped to fund restoration works along the Isar River in Germany.
- Increasingly, private sector organizations in some sectors are becoming concerned about strategic business risks stemming from water scarcity, pollution or shifts in water regulation. The Coca-Cola Company is one organization that has invested heavily in several river restoration initiatives around the world including the UK, Vietnam, Guatemala, China and the Danube basin as part of a broad 'water stewardship' approach, which seeks to manage and mitigate its water-related risk (The Coca-Cola Company, 2012).

MARKET MECHANISMS FOR RIVER RESTORATION: PAYMENTS FOR ECOSYSTEM SERVICES

In keeping with the beneficiary pays concept, and linked to the ideas of private sector water stewardship, there is increasing interest in the establishment of market mechanisms for aspects of water resource management, including river restoration. In part this reflects the fact that the benefits societies derive from nature are often under-valued by conventional markets (e.g. for water) and, consequently, over-exploited to the detriment of at least some groups of people (Smith *et al.*, 2013). The use of market mechanisms is an attempt to make the value of some otherwise un-priced ecosystem services explicit so they are better managed.

Market mechanisms can include a range of measures such as eco-certification, tradeable pollution permits and offsetting. The most common way market mechanisms have been used for river restoration is through Payment for Ecosystem Services (PES) schemes. The New York City Watershed Agreement is among the most well-known of these initiatives, but there are many other examples. In Latin America, for instance, a number of water funds have been established by The Nature Conservancy, working in conjunction with municipalities and businesses, to pay for restoration of riparian forests by upstream communities. PES is a complex subject and the state of knowledge is evolving rapidly. Fortunately, guidance is available to those considering such market mechanisms as a tool for natural resource management. There are now a number of practical guides available from the likes of the UN Environment Programme (Forest Trends, The Katoomba Group and UNEP, 2008), the OECD (OECD, 2010) and the UK government (Smith *et al.*, 2013).

All PES schemes rely on a simple premise: that someone is able to provide a specific and additional ecosystem service; and that someone else is interested in buying that service. In other words, there is potential for a demonstrable win-win business case for buyer and seller. If these conditions are present, then market-based mechanisms might be an effective and efficient way of funding river restoration. There is, of course, more to it than this and the specific details of PES schemes can vary substantially. For instance, there can be one or several sellers; similarly, there can be single or multiple buyers. Schemes can be formal markets, in which case some sort of government oversight is normally essential, or informal arrangements between self-organized buyers and sellers. In some cases, poverty reduction will be an important, and explicit, aim alongside improved management of natural resources. PES schemes can operate a range of scales from local arrangements between neighbouring farmers to larger scale agreements between upstream landowners and downstream cities and businesses.

It has been suggested that there are four key steps to developing PES schemes (Forest Trends, The Katoomba Group and UNEP, 2008):

- Identification of ecosystem service prospects and potential buyers: This involves defining the specific ecosystem service to be bought and sold; determining its market value; identifying buyers who benefit from the service and who are willing to pay for it (which implies that they must perceive potential additional value to 'business as usual' arrangements); and considering whether to sell the service to individuals or a group.
- Assessing institutional and technical capacity: This includes assessing legal and policy contexts and any issues relating to land tenure; clarifying rules under which PES schemes might operate; and understanding the extent to which different organizations could support PES operations.
- Structuring PES agreements: This includes designing business plans; reviewing and optimizing payment types and transaction costs; ensuring that the deal is evaluated for equity and fairness; and drafting a contract.
- Implementing PES agreements: This necessitates finalising the PES management plan; verifying service delivery; and monitoring and evaluation.

Smith *et al.*, (2013) classified four main types of actors within PES schemes: buyers, sellers, intermediaries and knowledge providers. In different contexts, different organizations can play each of these roles. Buyers of ecosystem services (such as clean water supply or reduced flood risk) can typically include individual business or groups of companies, municipal authorities or national governments. Sellers are often individual landowners and farmers (who could be individuals or branches of government, the private sector or NGOs). Intermediaries often play the roles of initiator/facilitator of a PES scheme and broker of any deal between buyers and sellers. They could be NGOs, government agencies or private sector brokers who specialize in such transactions. In the case where there is a formal market for ecosystem services, government agencies may be needed to regulate the market, which is another type of mediation. Knowledge providers can include researchers who advise on the state of the socio-economic and biophysical conditions within the river system. They might also include local or basin scale stakeholders who hold information about aspects of the system. The basin organization or water resource management agency with ultimate responsibility or oversight for river restoration may be an important player falling within this category. Lastly, there may be private sector or NGO organizations who act as verifiers or certifiers of PES schemes, ensuring that sellers are continuing to implement the actions for which buyers are paying.

According to Smith *et al.* (2013), seven principles should underpin effective PES schemes (see Box 22) alongside good baseline and impact monitoring and involving stakeholders in PES design and adaptive management. In practice, few existing schemes fulfil all these principles and, given the socio-economic and biophysical complexities and uncertainties in any given context, there may not be such a thing as a 'perfect' PES scheme. Nevertheless, these principles are a useful guide.

Box 22: Principles for effective PES schemes

- Voluntary: stakeholders enter into PES agreements on a voluntary basis.
- Beneficiary pays: payments are made by the beneficiaries of ecosystem services (individuals, communities and businesses or governments acting on behalf of various parties).
- Direct payment: payments are made directly to ecosystem service providers (in practice, often via an intermediary or broker).
- Additionality: payments are made for actions over-and-above those that land or resource managers would generally be expected to undertake. Note that precisely what constitutes additionality will vary from case-to-case but the actions paid for must at the very least go beyond regulatory compliance.
- Conditionality: payments are dependent on the delivery of ecosystem service benefits. In practice, payments are more often based on the implementation of management practices that the contracting parties agree are likely to give rise to these benefits.
- Ensuring permanence: management interventions paid for by beneficiaries should not be readily reversible, thus providing continued service provision.
- Avoiding leakage: PES schemes should be set up to avoid leakage, whereby securing an ecosystem service in one location leads to the loss or degradation of ecosystem services elsewhere.

Source: Smith *et al.*, 2013

While PES can provide new opportunities for river restoration, there are key questions basin authorities or others considering using these schemes should consider.

- A key issue is the need sustain efficient market conditions for as long as the ecosystem service needs to be maintained. For some ecosystem services, such as reduced flood risk or clean water supply, this may be in perpetuity. Can the PES intermediaries or regulators ensure that there is enough equilibrium between numbers of buyers and sellers?
- Capacity is also important. Who will play the roles of intermediary, regulator, knowledge provider and certifier for the foreseeable future and do these organizations have the skill, human and financial resources and willingness to play these roles? This is important for formal market schemes that need to be overseen by a government agency. Further, if the PES scheme is part of a broader approach to river restoration and water resource management, the links between the PES broker or overseer agency and the lead agency co-ordinating restoration and management of the river must be clear and constructive. Some PES schemes are initiated by NGOs acting in an entrepreneurial capacity. But what happens when NGO funding runs out or strategies

shift? Are PES markets self-sustaining or will they collapse once the NGO leaves?

- Equity is a vital consideration. How will the design, monitoring and adaptive management of PES schemes involve all relevant stakeholders, including the poorest and most disadvantaged groups, in setting market rules? A perceived lack of involvement of affected parties can quickly give rise to critical scrutiny (for instance, see Pearce, 2015) and might even undermine the credibility of the scheme.
- Monitoring and evaluation inform adaptive management of any PES scheme to ensure that it delivers against stated objectives in the context of broader river restoration goals. Will this adaptive management be based on inputs such as changed farm management practices, or outputs such as changes in river water quality or flood hydrographs? Inputs are simpler to verify, but may not actually deliver the desired changes in river condition. Outputs may penalise buyers if the desired change in river condition does not eventuate, even though they have implemented contracted changes in practice.
- It is important to ensure that there is sufficient evidence of impact on socio-economic and biophysical elements of the river system to warrant continuing investment in PES schemes. Research has suggested that this is not always the case and that some PES schemes have been insufficiently based on good biophysical science (Naeem *et al.*, 2015) and that evidence of socio-economic impacts is scarce (Samii *et al.*, 2014).
- It is also important to consider potential trade-offs between different ecosystem services, and between ecosystem services and biodiversity, e.g. re-forestation of hillslopes might reduce sediment run-off and improve downstream water quality for a buyer, but others may notice a reduction in river flows due to increased evapo-transpiration from trees that have been planted. Will the PES scheme mean that beneficiaries of non-traded ecosystem services be at a disadvantage?

Box 23: Eco-compensation in the Xin'an River Basin, China

The Xin'an River flows from west to east, through Anhui and Zhejiang provinces. While water quality in the river has historically been among the best in China, in recent years it has declined. Notably, since 2000, total nitrogen and total phosphorus levels in the river at the boundary of the two provinces have been increasing.

In 2011, to protect and improve water quality in the river via a market-based approach, the Chinese Ministry of Finance and the Ministry of Environmental Protection instigated a pilot eco-compensation programme to promote the protection of water in the basin. That programme has involved enhanced water quality monitoring at the boundary of the two provinces, and the establishment of a compensation fund. The annual amount paid into the fund is RMB 500 million. Sixty per cent of this is contributed by the central government, and the two provinces contribute 20% each.

All of the funds contributed by the central government go to Anhui Province (the 'upstream' province). The remaining funds are distributed depending on water quality levels in the river at the point where it crosses from Anhui Province into Zhejiang Province. Payments are made based on a 'compensation index'. If the value of the index is less than or equal to one (indicating that water quality has not met the target) or if there is a major pollution event, then the remaining funds are paid to Zhejiang Province. Otherwise, the payment is made to Anhui Province. Based on these rules, from 2012–2014, payments have been made by the Zhejiang Province (in the downstream) to Anhui Province, indicating water quality has met the required target.

Payments made under the compensation fund can only be spent in the Xin'an River basin on projects designed to protect and improve the condition of the aquatic environment. Examples of authorized projects include structural adjustment measures for industries, improved industrial design and layout, integrated basin management, water pollution control, and ecological protection. Specific examples have included water source conservation in upstream, agricultural non-point pollution control, control and prevention of industrial pollution, rural and urban wastewater treatment, improved refuse management, pollution control on vessels using the river, and removal of floating debris.

As the table shows total funds that have been raised, allocated, and spent up until the end of 2014. This includes the funds allocated as part of the eco-compensation pilot programme (the 'Special Fund'), as well as funds raised directly by local government and from 'social funds', which have included funding via bonds issued by a local construction company, as well as the use of private–public partnerships to fund restoration works. Of 192 projects that have been identified, 134 have been implemented at a total cost of approximately RMB 8.6 billion. This includes RMB 1.60 billion from the Special Fund, and RMB 6.18 billion raised by local governments (including RMB 5.65 billion from the China Development Bank) and RMB 810 million raised from social funds.

Type of projects	No. of projects	Special Fund (million RMB)	Direct expenditure on restoration (million RMB)
Rural non-point source pollution	102	267	420
Waste/sewage interception projects	34	116	424
Point source pollution management	14	126	1047
Ecological restoration	31	1,035	6,645
Capacity building	11	56	58
Total	**192**	**1,601**	**8,595**

Source: GIWP

Table 6.4. Sources of finance for river restoration

Sector	Finance source	Interventions typically financed	Examples	Who pays (polluter, beneficiary or society)?	Pros & cons
Public sector	National/federal government	Infrastructure, institutions, water quality improvements, ecosystem restoration	UK government finance for Mersey Basin Campaign; Mexican federal funds for El Realito project; Australian federal government funding for Murray–Darling Basin buyback scheme	Society	Significant source of funding especially for strategically important projects; often funds both capital and operational costs. Seldom finances projects 100%; public funding in many countries under increasing pressure.
	State/regional government	Water quality improvements, ecosystem restoration	Bavarian länder finance for Isar River restoration, Germany; Queensland State Government finance for SEQ Healthy Waterways project	Society	Significant source of funding; often funds both capital and operational costs. Seldom finances projects 100%; public funding in some countries under increasing pressure.
	Local/municipal government	Infrastructure, water quality improvements, ecosystem restoration	Munich City Authority funding for Isar river restoration, Germany; Taewha River Restoration project, Korea	Society	Useful to fund involvement of local stakeholders. Often reliant on leverage of significant financing from other public sector sources; public funding in some countries under increasing pressure.
	Supra-national/ multilateral organizations (e.g. GEF, EU)	Institutions, water quality improvements, ecosystem restoration	EU & GEF funding for Danube River initiatives, including Lower Danube floodplain wetland restoration projects	Society	Can be a significant source of funding for strategically important projects; can include an emphasis on strategic ecosystem functions and services and on biodiversity. Relies on national governments to prioritize river restoration projects; obtaining financing can be time-consuming and bureaucratic
	Development agencies/ banks	Infrastructure, institutions, water quality improvements	ADB financing of Pasig River restoration in Manila, Philippines; World Bank funding for Ganges River rejuvenation	Society	Can be a significant source of funding for strategically important projects; funds both capital and operational costs. Often in the form of loans rather than grants.
Private sector	Utility companies, especially water and energy utilities	Infrastructure, water quality improvements	North-west Water/United Utilities finance for Mersey Basin Campaign; Bonneville (hydropower) funding for Colombia River restoration; Hydropower company funding for Isar restoration. EDF Energy in France, Rhone	Polluter or beneficiary or society depending on circumstance	Can be an important source of funding for specific projects and especially for water quality improvements (through water utilities). Relies on regulators requiring/permitting utilities to finance restoration activities.
	Water stewardship approaches	Water quality improvements, ecosystem restoration	The Coca-Cola Company funding for WWF and other river restoration projects, e.g. in the UK; SABMiller support to The Nature Conservancy's Water Funds in Latin America. RSA Insurance co. funded £200,000+ for Mayesbrook river restoration project in London (CSR funding).	Polluter or beneficiary depending on circumstance	Potentially important new source of financing, linked to strategic water-related business risks. Too soon to assess impacts. Links to government priorities unclear.
	Polluters of those responsible for degradation of river health, e.g. through restoration insurance, restoration bonds, or fines	Water quality improvements, ecosystem restoration	Rhine River (Restoration following Sandoz chemical disaster) Utility companies in UK. Pollution. Thames water £500K for R. Wandle – started the Wandle Trust, £400K River Lea (both Thames tributaries)	Polluter	Can be difficult to repair some aspects of river health after damage; might be better to ensure compliance with safeguards before damage is done. Can be lengthy legal process before funds are released for restoration.
	Philanthropic funding	Institutions, water quality improvements, ecosystem restoration	HSBC, through its Water Programme funding work with WWF and other organizations.	Society	Can complement other sources of funds. Usually channelled via NGOs (see below). Mostly small-scale and of limited duration.
Other	NGOs (originally from companies, foundations/ trusts, major donors, public or other sources)	Institutions, water quality improvements, ecosystem restoration	WWF funding, originally from the MAVA Foundation, for Lower Danube Green Corridor	Society	Can be important source of catalytic seed finance (and often accompanies NGO 'policy entrepreneur' role). Almost always reliant on leverage of significant financing from other sources.
	Payment for Ecosystem Services (PES) schemes	Water quality improvements, ecosystem restoration	New York City Watershed agreement; Working for Water programme, South Africa South West Water – Upstream thinking project ~ £4m to pay farmers to manage the land better to reduce water treatment costs	Beneficiary	Potentially important new source of finance. Too soon to assess impacts; reliant on functioning 'market' for ecosystem services and on institutional architecture for regulate this market.

Box 24: Financing restoration in the Breede River catchment

The Breede River catchment is found in the southern-most part of South Africa, located in the Western Cape province (see map below). The Breede River is part of the Breede/Overberg Water Management Area (BOCMA), which is the basin organization responsible for water management at the catchment level. The Breede River, which drains most of the catchment, is 322 km long, with the Riviersonderand River being its main tributary. The entire area draining the Breede River catchment is 12,600 km^2.

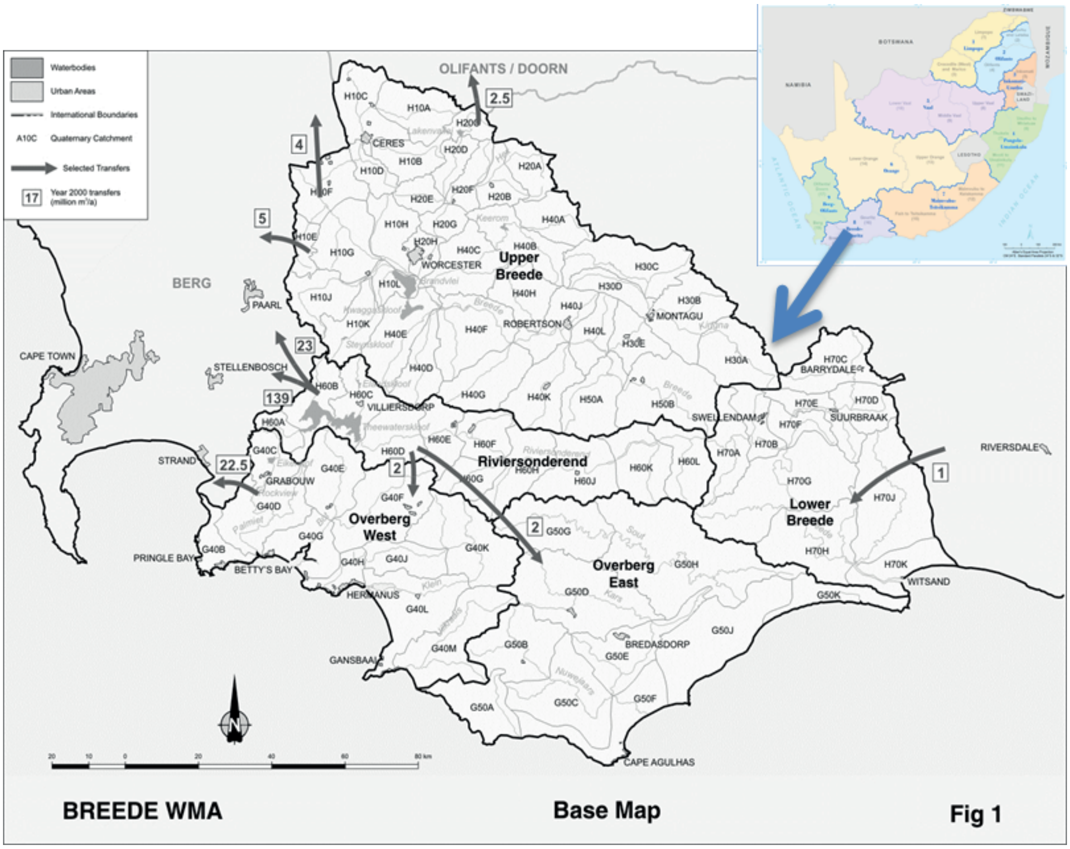
BOCMA is legally mandated under the National Water Act to manage at the catchment level and is required to develop a catchment management strategy. BOCMA recently completed its catchment management strategy, which includes a vision captured by their slogan 'Quality water for all forever'. The catchment management strategy vision seeks to:

- protect the environment that keeps catchments clean and healthy for people's quality of life and business opportunities
- develop agriculture to creates wealth and jobs for communities, and meet the aspirations of disadvantaged rural people
- create opportunities for people and business to adapt to the changing world through innovation and technology
- Ensure that as the region grows, people continue to enjoy improved quality of life and services.

BOCMA is not directly involved in restoration activities, but plays a coordinating role with different stakeholders such as water user associations, local governments and commercial farmers to promote sustainable catchment management. The actual restoration activities are undertaken by programmes such as Working for Water and Working for Wetlands under the Department of Water Affairs, supported by local conservation agencies and NGOs. Working for water (WfW) is a South African Government initiative launched in 1995 to address the challenge of invasive alien plant species that were posing a major threat to surface water resources. The programme was also designed to create jobs for unemployed people through clearing activities. Since its establishment, WfW has implemented 300 projects countrywide and has been dubbed one of the largest conservation projects in Africa. The programme aims to enhance South Africa's water security, improve ecological integrity and undertake land restoration, while providing employment opportunities for South Africa's most vulnerable communities.

Under a 1999 pricing strategy, a portion of the costs associated with clearing alien invasive plants could be applied to urban-industrial and agricultural irrigation water users in a Water Management Area, linked to the water resources management charge. WfW charges were typically between R0.01/m^3 and R0.05/m^3 for urban users and only 10% of this for agriculture, due to a 90% subsidy arrangement. The approximately R75 million annual billing was supported by a much larger fiscal subsidy of in excess of R300 million, reflecting the public works and biodiversity value of the programme.

With the updated 2007 pricing strategy, this was shifted to a willing user arrangement, where stakeholders and users in a catchment area with infestation could agree to fund the alien clearing with charges calculated on the relative use by each user, possibly supported by subsidies where available. Additional water made available above that required to address environmental and over-allocation needs could be allocated to those contributing financially to the clearing. This reflects the closest experience that South Africa has to a payment for environmental services scheme.



Source: Pegasys, 2012 South Africa Department of Environment www.environment.gov.za/projectsprogrammes/wfw

CHALLENGES FOR FINANCING RIVER RESTORATION

A number of factors cloud the issue of how to finance river restoration. The complexity and uncertainty associated with the functioning of river ecosystems makes it very hard to predict precise outcomes of river restoration. This in turn means that it is difficult to estimate costs relative to benefits (see Ayres *et al.*, 2014) especially when the uncertainties of economic valuation methods are taken into account. For river basin and water resource managers familiar with the comparative accuracy and certainty of engineered approaches, this can be uncomfortable. At a time when, in many countries, public funding is becoming more limited, the need to demonstrate value for money means overcoming this challenge – through better monitoring and evaluation of outcomes and impacts at both project and national scales, and through improved economic methods. Funders of river restorations need to allow for costs of monitoring and evaluation in project budgets.

If river restoration is to be an integral tool for river basin or water resource management, funding for restoration projects should be provided, at least in part, from public water management budgets. There is a challenge about recognizing restoration as part of the water management toolkit for budget allocations. This issue is compounded by maintenance considerations. As is the case with engineering interventions, many river restorations projects incur not only initial expenditure for feasibility studies and capital works, but ongoing operational costs. Restoration planning should consider each of these elements, but the operational costs of maintaining a restored river system can be difficult to quantify and there is little case study material where such planning and budgeting has happened.

Evidence from some projects (e.g. Singapore) points to the fact that urban river restoration projects may be more costly compared to rural projects simply because of high land values and crowded networks of infrastructure. These factors limit the space available for restoration and complicate restoration works (Bernhardt *et al.*, 2007). They may also increase compensation bills where landowners or tenants need to be rehoused. The ABC Waters Programme in Singapore addressed this by integrating multiple functions into restoration projects, which increased value for money and by integrating with other development projects.

As with other aspects of water management, institutional constraints can make financing restoration more difficult too. For instance, payment for ecosystem service schemes face particular challenges relating to roles and responsibilities for quality assurance of ecosystem services and maintenance of natural infrastructure and to regulating what is, in effect, a market.

Tensions may occur between stakeholders requiring different outcomes from restoration projects. The discipline of river restoration has largely arisen from the conservation community. Practitioners, along with many stakeholders, may have expectations of ecological outcomes, including enhanced biodiversity. But in many contexts, other stakeholders, funders and regulators may prioritize improvements to socio-economic benefits linked to specific ecosystem services. While there may be overlap between these objectives in some instances, measures to restore socio-economic benefits may not focus on the full suite of ecosystem functions in the same way that ecological restoration should (Palmer *et al.*, 2014). Some ecosystem service restoration schemes may actually cause further damage to ecological elements of river systems, e.g. through constructing water storage and transfer infrastructure in one sub-basin to safeguard flow regimes to downstream water users in another. Linked to this, some restoration measures, such as removing obstructions to fish passage, may provide benefits immediately while others, such as re-establishing riparian forest to reduce sediment flows and pollution, may take years or even decades to result in measurable outcomes. Therefore, restoration initiatives should take explicit account of the temporal scale for delivering benefits to different stakeholders (Smith *et al.*, 2014).

CHAPTER 7
ENABLING ENVIRONMENT

OVERVIEW AND KEY MESSAGES

This chapter provides an overview of the key supporting systems and factors that are required to enable successful river restoration, including policy and legislation, institutional arrangements, and stakeholder engagement. The key messages from this chapter are:

- Legal and policy frameworks can be vital for driving river restoration initiatives. They can provide the imperative, mandate, and goal for restoration.
- Sustaining river restoration outcomes require regulatory measures to be in place to protect benefits realised from river restoration and prevent them being undermined by activities within the basin, including future development.
- Stakeholder engagement in the restoration process is critical. An integrated approach, addressing land and water issues, and involving inter-agency and community collaboration, is likely to achieve the best results.

7.1. Overview

Successfully developing and implementing a river restoration strategy is a challenging task that can take years or even decades. It is important that the preconditions for successful river restoration, as well as some of the common barriers to success (see Box 25), are well understood from the outset.

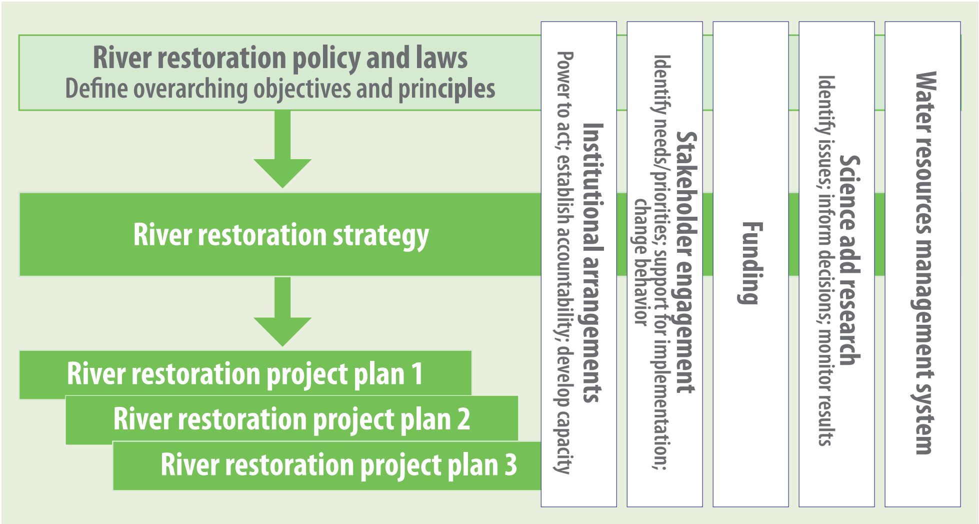
Beyond the specific technical and practical aspects of developing and implementing a river restoration strategy, a range of administrative, management, and other supporting elements need to be considered. These include (Figure 7.1):

- policies and laws, to define the overarching objectives and principles for the restoration work, as well as to provide a head of power for certain actions
- institutional arrangements, to establish the mandate and accountability for restoration actions, and to coordinate between different institutions
- stakeholder engagement, to ensure different views are considered as part of the planning process and to strengthen political support, at all levels, for action
- funding, to ensure that the financial resources are available to support implementation as well as manage ongoing costs
- science, monitoring and research, to provide a basis for rational decision-making, as well as to assess compliance and impact (through monitoring) and to support adaptive management
- water resources management systems, to provide the tools for giving effect to elements of the restoration strategy, particularly through regulatory controls and other planning systems

As well as providing a framework to support planning and implementation, these systems and processes can also be critical for ensuring the long-term sustainability of restoration efforts. For example, by ensuring long-term revenue streams to maintain or refresh capital works, by establishing appropriate institutional arrangements to ensure alignment with long-term development plans, and through regulatory arrangements that protect the gains made through restoration and avoid undermining of those efforts through ecologically harmful practices within the basin.

Issues related to science and research, in terms of both the situation assessment and monitoring, and funding river restoration have been discussed in previous chapters. Other aspects of the enabling environment are discussed in the following sections.

Figure 7.1. Supporting systems and processes for river restoration



Box 25: Common challenges for river restoration projects

Difficulties in implementing river restoration projects can include those related to:

- ecological factors: for example due to a poor understanding of the connection between ecological succession and ecological restoration, or because of underestimates of the recovery time
- technical factors: such as a lack of the required skills or data availability
- socio-economic factors: including those related to stakeholder involvement and the cost of the project
- legal factors: such as a lack of supporting policies and laws (GWP, 2015).

These challenges are consistent with the administrative and management problems identified in preparing the Spanish National River Restoration Strategy. These included:

- lack of knowledge and experience in restoration procedures of technical staff
- limited cooperation and frequent conflicts between administrative institutions
- development being undertaken without consideration for its impacts on river health
- insufficient staff to support monitoring efforts
- little social awareness of river degradation and the need for restoration (González del Tánago *et al.*, 2012).

7.2. Policy and legislation

Policy and legislation play a central role in promoting, supporting, and guiding restoration efforts. Policies or legislation might establish the requirement to undertake river restoration. For example, the EU Water Framework Directive (2000) established a legal obligation for member states to achieve 'good status' in all waters by 2015. This in turn has driven significant legislative, policy and (ultimately) practical action at the national and local levels across the EU. At the same time, high-level policies can establish the principles for undertaking river restoration, which can help in setting restoration goals, as well as in deciding what to do and where.

Policies and legislation can also create incentives for river restoration. For example, laws can establish tax measures or create other financial incentives that encourage river restoration or improved land use practice.

Laws may be necessary to establish the power required to support or implement river restoration. For example, restoration may require the compulsory acquisition of land. Regulatory frameworks, such as those that govern land-use, the discharge of pollutants, or the abstraction of water are typically all underpinned by legislation. Law reform can also be required to reconcile legislative priorities, where existing laws (for example those related to development) may conflict with restoration objectives or actions.

Laws can be species-focused, like the US Endangered Species Act (1973) or the Australian Environment Protection and Biodiversity Conservation Act (1999), both of which establish regimes for protecting listed species. Alternatively, laws can be ecosystem-focused, like the U.S. Clean Water Act (1972) establishes both a framework and obligation for states to improve water quality (see section 2.3), or the EU Water Framework Directive.

Relevant laws and policies can exist at an international, national, basin, regional, or local level. For example, the restoration of the Danube River has been driven and guided by policies and laws at the European-level, including the EU Water Framework Directive, by basin-specific agreements, and by national laws. A number of these policies and laws and their significance for restoration of the Danube are shown in Table 7.1.

Table 7.1. Major policy, legislation and planning instruments relevant to river restoration in the Danube

Year	Country	Legislation/Policy
1991	EU-wide	**Urban Wastewater Treatment Directive.** Its objective is to protect the environment from the adverse effects of urban waste water discharges and discharges from certain industrial sectors and concerns the collection, treatment and discharge of: ■ domestic waste water ■ mixture of waste water ■ wastewater from certain industrial sectors. For restoration, this has been a major driver of investments to improve water quality across Europe.
1992	EU-wide	**Natura 2000 Directives.** EU-wide network of nature protection areas established under the 1992 Habitats Directive and the 1979 Birds Directive. The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats. Across Europe, 40 % of Natura 2000 sites are freshwater sites.
1994	Danube River Basin	**Convention for the Protection of the Danube River** (DRPC). From this, the **International Commission for the Protection of the Danube River** (ICPDR) was established in 1998. Since its creation, the ICPDR has promoted policy agreements and the setting of joint priorities and strategies for improving the state of the Danube and its tributaries. The ICPDR coordinates implementation of EU Water Framework Directive and EU Floods Directive on basin-wide level.
2000	Bulgaria, Romania, Ukraine and Moldova	**Lower Danube Green Corridor** agreement between Bulgaria, Romania, Moldova and Ukraine on the restoration, protection and maintenance of up to 1 million ha of floodplain wetlands along the Lower Danube from the Iron Gates dam to the Danube Delta.
2000	EU	**Water Framework Directive** establishes a framework for the protection of all surface waters and groundwater with the aim of reaching Good Ecological Status (on the basis of biological, chemical and hydromorphological assessments) in all waters by 2015 (EC, 2000): integrated river basin management plans required, including programmes of measures for achieving Good Ecological Status six Danube countries are not EU member states so WFD Article 3(5): 'appropriate coordination with relevant non-EU Member States shall be endeavoured for achieving WFD objectives'.
2010	All of Danube basin	Adoption of the first **Danube River Basin Management Plan**. The plan guides the way to achieving at least good status for all waters of the Danube River Basin, by combining each country's management plan at the international level, using the ICPDR as the platform. The current plan covers the period from 2009 until 2015.
2007	EU	**Floods Directive** aim of which is to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity. Flood risk management plans to be adopted in 2015.
2012	All of Danube basin	The **EU Danube Strategy**, first proposed in 2010, adopted in 2011 and imposed in 2012, is a strategy to boost the development of the Danube Region, in EU and non-EU countries. An EU Strategy for the Danube Region can therefore contribute to EU objectives, reinforcing major EU policy initiatives, especially the Europe 2020 Strategy.

Box 26: Policy and institutional arrangements to support river restoration in China

The report to the Eighteenth National Congress of the Communist Party of China (2012) proposed a range of measures to promote ecological progress. These measures included the establishment of comprehensive and integrated institutions and systems, as well as implementing the 'strictest water resource protection system' (see Box 4). These measures aim to improve environmental management and ecological restoration systems, and to set rules to protect the ecological environment. This will include measures such as:

- improving the system of natural resource property rights and natural resource utilization control, including through a unified registration of natural ecological spaces such as rivers, to establish a natural resource property rights system with rights and responsibilities clearly defined and characterized by effective oversight
- promoting development in accordance with the definition of 'functional areas' (i.e. zoning arrangements), including establishing a mechanism to monitor and give early warning when utilisation rates are approaching the carrying capacity of resources and the environment, and to implement restrictive measures in those regions where the environment, land, water and marine resources have been excessively exploited
- implementing sound compensation systems for the use of natural resources and penalties for causing damage to the ecological environment
- establishing and improving an environmental protection system that strictly supervises the emission of all pollutants, improving reporting system, strengthening public sector supervision, improving the licensing system for pollutant emissions, and implementing quantity control system for pollution emission by enterprises and public institutions.

River restoration in China has also been guided by more specific edicts, such as the 2011, 'Tai Lake Management Ordinance', which is aimed at enhancing water resources protection and water pollution control in Tai Lake to ensure water supply for domestic, industry, and ecological demand, and to improve ecological environment of Tai Lake basin.

More recently, the Water Pollution Control Action Plan, issued by the State Council in 2015, requires that by 2020, over 70% of the basins of China's seven major rivers should be in 'Good Condition' (based on achieving Grade III under the National Water Quality Standards), and over 93% of centralized water supply sources in urban areas should be at or above Grade III water quality.

The Water Pollution Control Action Plan proposed strategies related to: (1) controls over pollutant discharge; (2) promotion of economic structural reform, (3) promotion of water saving and conservation, (4) enhanced technical support, (5) the use of market mechanisms, (6) enhanced environment law enforcement, (7) enhanced water environment management, (8) guaranteeing the safety of the water environment, (9) clarifying responsibilities of all parties, and (10) promoting public involvement and society supervision.

Responsibilities for implementing these and other actions are split across a range of government departments and agencies. The Ministry of Water Resources and its subordinate departments have primary responsibility for river restoration, and guide the development of river restoration at the macro level through watershed management planning and water-related policies. The Ministry of Environmental Protection deals primarily with water pollutant prevention and control as well as water quality management. More specifically, responsibilities of the Ministry of Water Resources include:

- ensuring the reasonable exploitation and use of water resources and leading water resources strategic planning
- overall planning and protection related to water use for domestic, industrial, and agriculture, as well ensuring water for the natural environment
- protecting drinking water sources.

Source: GIWP

7.3. Institutional arrangements and responsibilities for river restoration

Due to the wide range of activities that affect river health and the fact that river basins commonly span multiple administrative jurisdictions, river restoration projects tend to involve many organizations. In addition, the grassroots nature of many restoration activities often requires or lends itself to the involvement of NGOs and community groups, as well as local governments. The high cost of many restoration activities can mean financial support is often required from central governments, even if the work is being undertaken locally, resulting in the involvement of multiple levels of government. Where rivers cross national boundaries, transboundary organizations may need to be involved.

In many instances, particularly for large-scale programmes, managing the institutional arrangements for river restoration can present bigger challenges than technical issues (see for example Adams & Perrow, 1999; Hughes *et al.*, 2004; Downes *et al.*, 2002). Equally, establishing the right institutional arrangements can be as important to the success of a restoration project as the technical approaches adopted.

In larger basins, establishing appropriate institutional arrangements is even more challenging, as well as more important. Strategic approaches to restoration of larger river basins typically require a combination of high-level direction on the overarching goals and strategy, and devolution of responsibilities to local groups, such as local government, government agencies, or community groups.

In determining appropriate institutional arrangements, it is necessary to consider (i) which organizations should be involved, (ii) what the primary roles each organization will take in the restoration work, and (iii) how interactions between different organizations will be managed.

While there is no one model for institutional arrangements that can or should be adopted when designing a river restoration project, the principles of good, multi-level water governance apply equally in this context. Good governance includes ensuring that there is comprehensive coverage of the full range of issues and requirements, and that common governance 'gaps' are avoided, including (OECD, 2011):

- Policy gaps: the arrangements should address any institutional or territorial fragmentation of water (and development) policy
- Administrative gaps: reconciling different administrative and hydrological boundaries
- Funding gaps: ensuring there is not a mismatch between responsibilities for restoration activities and the allocation of funds
- Capacity gaps: ensuring that there is sufficient hard (infrastructure) and soft (expertise) capacity at the relevant levels to undertake the restoration activities
- Accountability gaps: ensuring that responsibilities for action are clearly assigned
- Objective gaps: ensuring alignment between goals, objectives and priorities for different sectors, at different scales, and for different regions
- Information gaps: establishing the knowledge base, including understanding the relevant physical, biological, and socio-economic systems, to support planning, implementation, and monitoring.

In determining those organizations that should be directly involved in the process, it is important to consider:

- different levels of government, including federal, regional, and local governments
- different agencies that are likely to have an interest in the outcomes, or with mandates which have the potential to affect (positively or negatively) river health, including those involved in land management, regional and development planning, agriculture, and the environmental protection
- funding bodies, including government treasuries
- research institutions
- community groups and NGOs
- private sector organizations, trade bodies and unions.

Which organizations will or should be involved in a restoration project will depend on various factors, including the spatial extent of the restoration project. The source of funds is of course critical, and the entity providing the funds to support the restoration work will typically have a major say in which organizations will be involved in the project and their respective roles. The issue of stakeholder engagement is discussed further in section 7.5.

In basin-scale restoration programmes, it is common for responsibilities to split among multiple organizations. In establishing the institutional arrangements, it can be necessary to determine roles including who is responsible for determining the goals and objectives as well as the strategy for the restoration programme, including decisions about adaptive management; implementation; monitoring, data collection and knowledge management; and funding. Issues related to each of these roles are shown in Table 7.2.

At the same time, maintaining a strategic approach to restoration requires that there is an appropriate mechanism for organizing and overseeing the various entities that can be involved. Some of the approaches taken internationally are discussed in the section below.

Table 7.2. Institutional roles in river restoration and considerations

Role	Considerations
Setting overall goal and strategy	Responsibility for setting the overall goal and strategy for rive restoration will typically be linked closely to the funding arrangements: whoever is paying for the restoration works will usually decide what their money is ultimately trying to achieve.
Setting local goals and strategies	■ Devolving responsibilities for determining local goals and strategies (such as local government or community groups) can allow local interests to develop measures that make sense in the local context (for example, Koonce *et al.*, 1996). ■ Sufficient strategic and technical guidance needs to be provided to ensure that the approach adopted locally is consistent with the overarching goals of the programme. ■ It is critical that there is accountability at the local level for not only implementing actions but also for progress towards the stated outcomes.
Prioritising restoration projects	■ Assessment process requires a degree of technical expertise. ■ Importance of objectivity and transparency in process, as relates to where funding will be directed.
Implementation	■ Those organizations given responsibility for implementing restoration measures need to have sufficient human resources and financial resources, technical capacity, and powers. ■ Where implementation requires action or support of local groups, industry, or individuals, it is important that those stakeholders have been adequately engaged in the process of developing the strategy (see section 7.5).
Data collection, monitoring and assessment	■ Globally, there have been challenges as a result of fragmented approaches to collecting data. There are significant advantages from the establishment of systematic processes for collecting data to support monitoring, assessment, and future research. ■ It can be important to maintain independence and impartiality in the monitoring and reporting process. This allows for unbiased assessments of the success or otherwise of restoration measures in achieving the desired ecological outcomes.
Funding	Co-funding of restoration works is common. Contributions and associated conditions should be clearly articulated.
Assessing and revising the programme	To ensure an adaptive approach to implementation, programme design should identify responsibilities for deciding: ■ whether project or programme goals have been achieved ■ whether adaptive management measures are being effective, or whether programme design needs to change ■ when a programme should be terminated.

Box 27: Funding local organizations to coordinate strategic restoration

One of the biggest threats to the health of Australia's Great Barrier Reef is the quality of the water entering the reef from neighbouring catchments along the Queensland coast. In particular, impacts from diffuse agricultural pollution pose a major threat (see Australian case study in section 2.4). The Queensland Government has primary responsibility for the health of the reef catchment waterways. Actions for improving water quality are coordinated under the Reef Water Quality Protection Plan, which involves collaboration between the Queensland and Australian Governments and their agencies, along with non-government entities.

One means for delivering on-ground activities is through funding from the Queensland Government to regional natural resource management (NRM) bodies, which are not-for-profit non-governmental organizations. There are 14 NRM bodies in Queensland, each with a defined geographic region, and which between them cover the whole of the state. The NRM bodies aim to improve delivery of natural resource management outcomes in partnership with industry, community and government. Six of the bodies are responsible for regions that include reef catchments. NRM bodies are funded by the state government under the Reef Plan to deliver:

- extension and education activities to agricultural industries
- undertake land restoration programs
- administer Australian Government Reef Programme grants (primary water quality improvement grants to agricultural producers and peak industry bodies)
- collect data on farm management practices.

The funding model offers benefits because it allows for organizations that are more closely connected to local conditions and businesses to lead implementation work on the ground. However, a recent review by the Queensland Audit Office highlighted significant shortcomings. In particular, it found there was no cohesive state program to support the Reef Plan objectives. In many cases, initiatives undertaken under the auspices of the program predate the plan and it is not clear they are the most effective or efficient way of implementing the plan. The water-related benefits of many of these initiatives were identified as being tenuous and secondary to other objectives. The audit also found governance arrangements needed to be significantly improved. There is no single body accountable for coordinating, managing, and evaluating the programme and spending under the programme is poorly tracked. Different government departments arbitrarily assign proportions of costs incurred on statewide programmes to reef locations, allowing the government to claim that total funding on reef restoration is consistent with public commitments, while in reality actual expenditure is fair less certain.

Source: QAO, 2015

INTERNATIONAL EXPERIENCE

The international experience shows a spread of approaches about: (i) primary responsibility for river restoration; (ii) coordination across government agencies; and (iii) engagement with and involvement of the community and other stakeholders. The approach adopted varies with the local context, including the local political system, the extent of the basin (transboundary or not), the scale of the issue, and the nature of the problem.

Singapore's ABC Waters Programme is a government-led restoration programme, with the Public Utilities Board (PUB), the national water authority, taking the lead role. The programme is run in collaboration with the National Parks Board. PUB has also developed a certification process to encourage other public agencies and private developers to incorporate the ABC Waters features into their projects. The certification process recognizes developments that meet the ABC Waters standards and allow developers to use the ABC Waters logo to promote their developments as 'ABC Waters certified', and by implication environmentally responsible.

In contrast, in South Korea responsibility for river restoration works is split across multiple government agencies and local government, although the primary division is between the Ministry of Land, Infrastructure and Transport and the Ministry of Environment. The nature of the restoration programs run by each ministry is show in Table 7.3. While not shown in the table, community and environmental groups are also involved in restoration projects, usually as part of the planning and monitoring process.

Table 7.3. River restoration programs in Korea by different agencies

Agencies	Restoration Programs	Characteristics of Programs
Ministry of Land, Infrastructure, and Transport	Nature-friendly River Improvement Program	Demonstration projects started in 1998. Three reaches of river designated, with restoration reaches given first priority. Focus on medium and large rivers.
Ministry of Environment	Eco-river Restoration Program	First projects started in 1987. Focused on water quality improvement in urban rivers until 2000. Ecosystem restoration measures have been added since 2000. Primarily medium and small urban rivers.
Ministry of Safety and Administration	Small Stream Improvement Program	First projects started in 1990s. Focused on flood safety of small streams with so-called 'close-to-river' techniques applied.
Local Governments	River-Environment Improvement works	Focused on amenity restoration in their urban rivers. Implemented independently to Central Government under own plan of river restoration.

Source: KICT, 2012

Institutional arrangements may change over time to meet the needs of the restoration project. For example, when it commenced in 1985, the Mersey River Campaign was led by an independent chair leading a unit from the Department of Environment (the relevant UK government ministry), and linking with a range of partners. These arrangements changed significantly in 1996, when the campaign gained a degree of independence from government, becoming an 'arms length management organization'. This was considered necessary to allow the campaign to better engage with the private and voluntary sectors. Nonetheless, the campaign continued to receive its core funding from government. The campaign structure was further adjusted following a review in 2001 to allow wider participation. The structure of the partnership during the last eight years of the campaign is shown in Figure 7.2. The campaign included the Council (the non-executive governing body); the Mersey Basin Business Foundation (the legal personality of the Campaign); the Healthy Waterways Trust (the Campaign's charitable arm); and advisory groups providing advice on policy development and the work of the campaign (see Figure 7.2).

A partnership approach has also underpinned the restoration work undertaken in the catchments of Southeast Queensland, Australia. The Healthy Waterways Partnership included six Queensland Government agencies, all 19 local governments in the region, four universities, 30 major industries and 38 catchment, 'Landcare', environment and community groups. A secretariat provided the day-to-day coordination for the partners and led regional programs including monitoring and reporting. One important element of the SEQ restoration work has been a comprehensive ecosystem health monitoring programme, which reports on river health annually. This assessment is undertaken by an independent scientific advisory panel, with its annual assessments released publically. The independent nature of the monitoring and assessment adds greater scrutiny to the role of government agencies in improving river health.

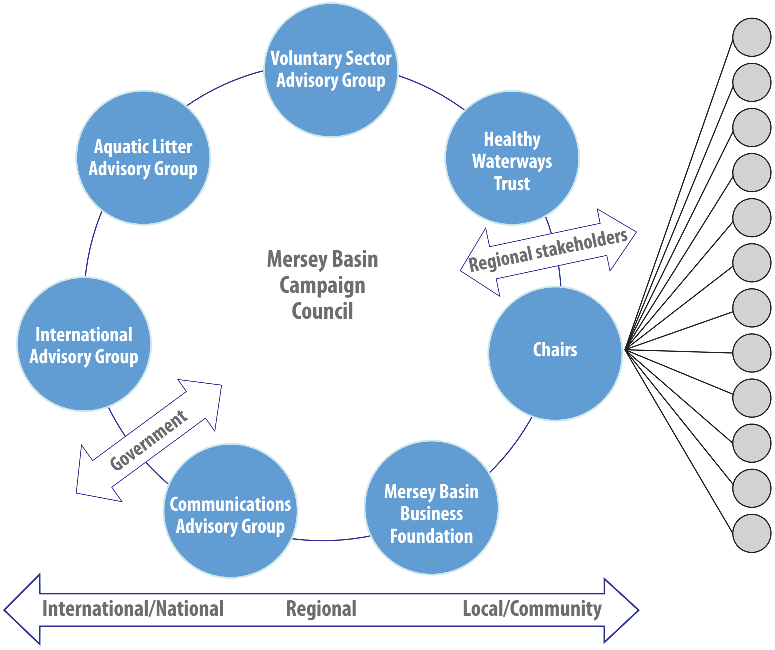
In the United States, the Clean Water Act authorizes water quality programs, requires state water quality standards, requires permits for discharges of pollutants into navigable waters, and authorizes funding for wastewater treatment works, construction grants, and state revolving loan programs (National Research Council, 2008). The US Environmental Protection Agency (EPA), the US Army Corps of Engineers, and the individual state governments are jointly responsible for implementing the Act:

- States are responsible for submitting periodic water quality assessment of impaired waters to the EPA and to restore impaired waters by developing Total Maximum Daily Loads.
- The EPA establishes federal guidance water quality criteria and oversees the establishment of state water quality standards to ensure that they are consistent with the requirements of the Act, including ensuring that

state criteria are sufficient to attain the designated uses assigned by the state. The EPA also oversees state National Pollutant Discharge Elimination System permitting, issuing permits to dischargers in states that have not assumed this permitting authority and helping to resolve interstate water pollution issues.

- The US Army Corps of Engineers implements the wetlands permit programme in almost all states, subject to EPA oversight, which is the mechanism for regulating construction activities in wetlands (National Research Council, 2008).

Figure 7.2. Organizational structure of the Mersey Basin Campaign



Source: Batey, 2013

7.4. Water resources and natural resource management

River restoration can be considered as forming part of the broader water resources management system: that is, the policies, processes, and mechanisms used for regulating access to and the use of water resources (see section 2.1). At the same time, river restoration strategies will often be dependent on that same system to give effect to various restoration measures: for example through controls over the abstraction of water or the discharge of pollutants. Similarly, related natural resource management and conservation measures – such as those regulating land use, mining, fisheries, and other resources – can be equally important.

Systems of water resources management are designed to recognize limited natural resources as assets, to identify sustainable limits on their use, and to determine who will be able to use the resources and under what conditions. These systems therefore have the potential to both protect and restore the natural asset base. River restoration projects can involve measures for revitalising natural assets, thereby improving river ecosystem function and river health. These management systems can also be critical for ensuring that further development with in a basin does not undermine the gains achieved by restoration measures implemented elsewhere.

River restoration depends on systems that effectively manage water and other natural resources, including systems for:

- establishing limits on the total resource available for exploitation, for example determining the total water available for allocation, the quantity of sand that can be sustainably mined from a river, or sustainable harvest rates for fish or other biota
- establishing access rights for resource users, including deciding who will be able to use the particular resource and setting conditions on the way and extent to which users are able to exercise those rights
- providing incentives for improved practices, for example in the form of penalties for non-compliance or tax or other incentives for landholders who adopt best practice land management

- identifying institutional responsibilities for implementation and oversight
- monitoring and enforcing compliance
- adapting all the systems above in light of data gathered through monitoring and evaluation.

Establishing user rights can be a valuable mechanism for promoting the sustainable use of resources. In the absence of rights – whether over land, water resources, fisheries, or other natural assets – users are less likely to take responsibility for their protection and restoration (see for example Hardin, 1968). The corollary is that where rights systems are established, it can provide strong incentives for rights holders to protect their rights, including either directly or indirectly supporting restoration measures that will enhance their rights. Rights systems also provide a basis for introducing market mechanisms, such as the trading of rights between users (e.g. water trading), or for payment for ecosystem services (section 6.4).

Conservation planning and management can also play an important role in supporting river restoration. Conservation measures are of course important in reducing the need for river restoration in the first place. They are also important:

- for identifying priority conservation sites, which can assist with prioritising restoration measures
- for providing refugia for aquatic and riparian species, and supporting the rebuilding of populations
- for providing reference sites, which can be relevant in understanding how the condition and function of the river ecosystem prior to human development and related disturbance.

Box 28: Water entitlements and the Commonwealth Environmental Water Holder

Improving the health of the Murray–Darling Basin has included a major focus on increasing environmentally important flows. Guided by the 2012 basin plan, the Australian Government has been leading a series of initiatives aimed at reducing consumptive water use in the basin and increasing the water left in the river system. These inititatives have involved an investment of A $12.9 billion over ten years in water buybacks, infrastructure to improve water use efficiency and policy reforms. Of the total investment, A $3.1 billion has been directed to purchase long-term water entitlements in the Murray–Darling basin tha will be returned to the river for environmental purposes (DEWHA, 2008). Water entitlements are being purchased under a voluntary programme, with irrigators in overallocated regions invited to submit offers to sell some or all of their entitlement to the government. Water entitlements purchased by the government are then managed by the 'Commonwealth Environmental Water Holder'. As of March 2015, the Commonwealth environmental water holdings totalled 2.27 billion m^3. This approach to restoring flows in the basin has been wholly dependent on earlier reforms that established a rights-based approach to water management in the basin, based on clearly defined, secure and tradable entitlements to water.

Source: Commonwealth of Australia, n.d.

7.5. Stakeholder engagement

While recognized as a core element of integrated water resources management, stakeholder engagement has a particularly important role to play in river restoration. Restoration projects are often as much a social undertaking as an ecological one (Wohl *et al.*, 2005) and are often driven from the grassroots, rather than by strategic considerations (Rieman *et al.*, 2015). Many restoration projects involve community groups and rely on the work of volunteers. These factors increase the importance of ensuring adequate awareness and support at a local level.

In addition, the nature of restoration projects means that there can be a wide range of institutions and mandates involved, which creates challenges to meet the many and varied expectations. Stakeholders can include different levels of government, different government agencies, industry, the agricultural sector and other landholders within the basin, conservation groups and other non-profit organizations, and the community at large. Stakeholder engagement can be important to ensure that relevant views and information are available to those leading the restoration process, to ensure alignment with other activities within the basin, and to foster support for and (ideally) ownership of the restoration strategy.

River restoration planning should involve the development of a stakeholder engagement strategy, with a view to identifying relevant stakeholders, their potential role in the planning and implementation process, and the time and mechanism for engaging them.

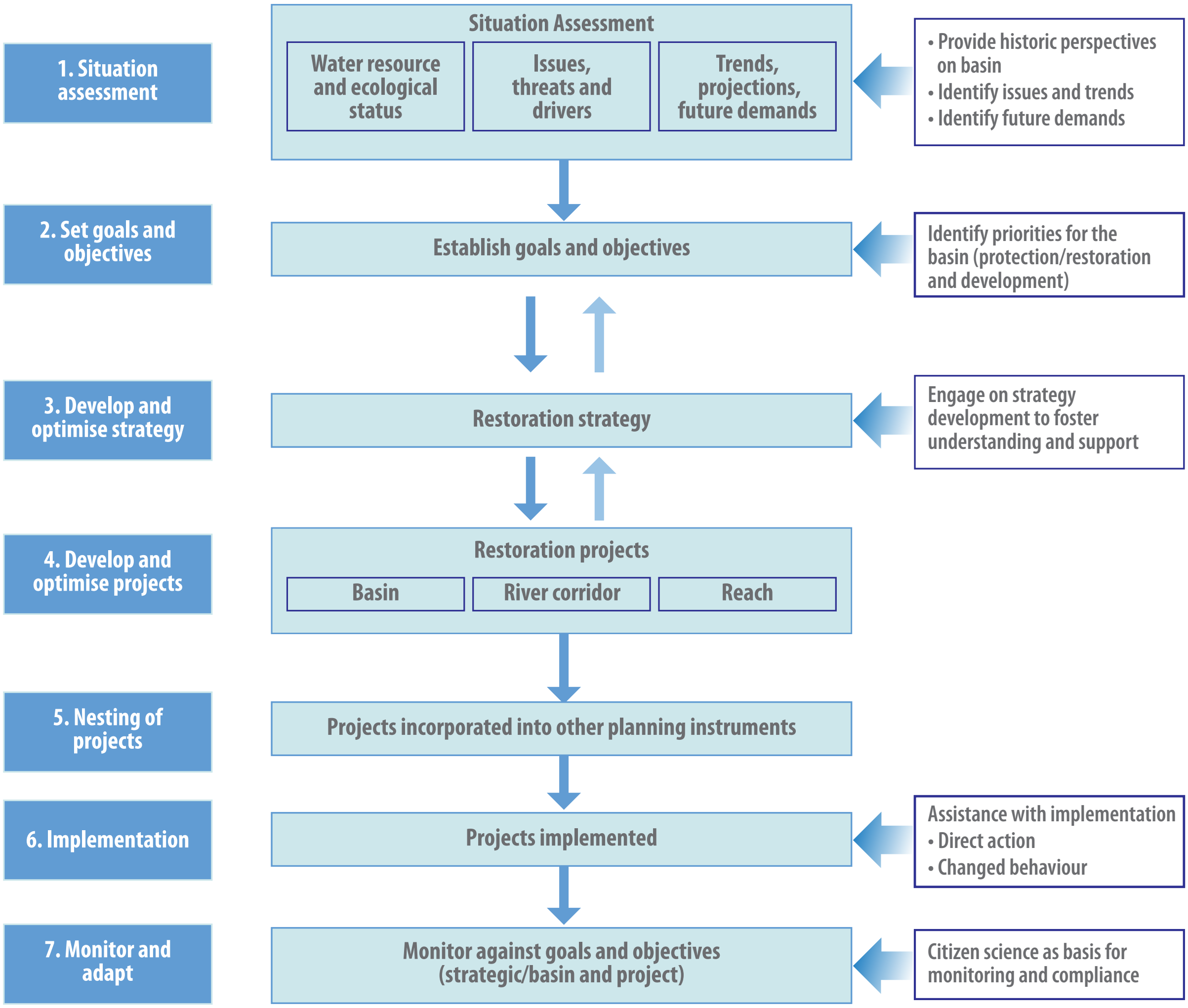
Various stakeholders can play a critical role at different stages in the restoration process (see Figure 7.3). These roles can include:

- Informing the situation assessment: a range of stakeholders are likely to have information that will be important for understanding the context in which restoration planning is undertaken. For example, they can help in identifying trends, pressures, and future demands in the basin, as well understanding other plans and objectives (e.g. economic or land development plans) relevant to the region to ensure alignment between plans, goals, and actions.
- Setting goals and objectives: the setting of goals and objectives, while informed by science, should ultimately be a socio-political process. This requires engaging with relevant stakeholders to ensure that community values and desires are reflected in the outcomes sought by the restoration process. Setting goals and objectives with stakeholders can benefit from models that predict the socio-economic and environmental outcomes of different strategies (Beechie *et al.*, 2008).
- Developing the strategy: many of the measures used for restoring river health involve direct inputs from different stakeholder groups. Engaging different stakeholders in

the development of the strategy is important to ensure proposed measures are likely to be practicable and effective, and to promote support at implementation phase.

- Implementing the strategy: where restoration measures include new regulatory controls, different stakeholders will be responsible for complying with those new requirements. Other measures can involve voluntary action, such as adopting water stewardship approaches within industry sectors or the application of improved agricultural practices. Many on-ground restoration activities are led by community groups.
- Monitoring and enforcement: for example, citizen science offers significant opportunities for individuals and community groups to be engaged in river health assessments and other monitoring activities. Such approaches can not only provide a wealth of information, but also foster greater awareness, understanding and ownership at the local level (see Box 19).

Figure 7.3. Role of stakeholders in the river restoration process



Box 29: Examples of community engagement and voluntary action in river restoration

One of the five main action lines under the Spanish River Restoration Strategy related to voluntary work. This line aimed to coordinate volunteer cooperation in river field surveys (diagnosis and evaluation), questionnaires and public opinion polls, cleaning projects, environmental education, invasive species control and other types of actions. (González del Tánago *et al.*, 2012).

Community engagement has been a prominent feature of many of the river restoration projects undertaken in Southeast Queensland, Australia. As an illustration, one project to restore Echidna Creek, a tropical stream flowing to the Sunshine Coast, was implemented by the local waterwatch group (Maroochy River Catchment Area Network Waterwatch) and included landholders who were active members of the Barung Landcare group. This was an example of a bottom-up approach, where community members who had an interest in water quality and catchment management from an ecological point of view, actively petitioned the local government and catchment group (Maroochy–Mooloolah Catchment Coordinating Association). The working partnership set the following objectives, (Claridge, 2005):

- implement a strategically planned, practical and cost-effective demonstration of riparian rehabilitation within the Echidna Creek catchment
- ensure canopy closure of 75% within two years (weather permitting)
- achieve a plant survival rate of 90% after two years
- monitor the success (or otherwise) of the project in terms of improved ecosystem health and water quality
- identify benefits and disadvantages for the immediate area, downstream reaches and receiving water bodies

In addition, individual stakeholders set their own objectives in line with their own beliefs for the outcome of the project, e.g. increasing biodiversity, controlling weeds. Initial landholder engagement was on a one to one basis to gauge interest in participating in the project. Group meetings were held regularly in the beginning to develop a good sense of coordination and ownership of the project. Varying amounts of restoration work were required for each property, which did not allow an equitable distribution of funds, so a balancing of financial and non-financial benefits was achieved to seek equity.

The EU Water Framework includes a specific article requiring public participation in the preparation and implementation of river basin management plans, including the design of measures to restore and maintain Good Ecological Status in rivers (see Blackstock *et al.*, 2015). The Directive provided a significant stimulus to river restoration activity across Europe and there are many examples of innovative approaches to involving communities and stakeholders in basin planning and river restoration. One example can be found in the River Tweed, which straddles the border between England and Scotland. The Tweed Forum, which comprises a broad membership of organizations and individuals representing a spectrum of interests throughout the Tweed basin, has driven and facilitated the restoration of many sites across 5,000 km^2 basin, including in the 70 km^2 sub-catchment of Eddleston Water. Set up by the Scottish Government, the Scottish Environmental Protection Agency and the Tweed Forum, the Eddleston Water project is designed specifically to try to create the science evidence-base for analysis of the costs and benefits of effective restoration. These costs and benefits are measured by detailed assessment of parameters relating to ecology, hydrology, stakeholder acceptability and other issues. The project has twin objectives of (a) improving habitats and the Water Framework Directive's ecological status of the river (which has improved in recent years from Bad to Moderate Ecological Status as a result of the project); and (b) measure the effect of such restoration, and associated land management interventions, on attenuating floods (i.e. natural flood management). Key to progress has been the Tweed Forum's role as trusted intermediary and local knowledge and ability to work with landowners and farmers in the catchment to ensure that river restoration meets their needs as well as that of habitat restoration and natural flood risk reduction (see also Spray and Comins, 2011). Other Tweed projects with strong elements of community engagement include the control of invasive, non-native plant species across 300 miles of river, which represents a huge voluntary effort year on year; and the restoration of the Bowmont Water (another tributary of the Tweed) in conjunction with the farming community after two consecutive devastating floods. Associated studies include farmer acceptability and costs of introducing natural flood management measures on farm businesses and the role of participative catchment NGOs in this process (Cook *et al.*, 2013; Spray, pers comm; and Tweed Forum, http://www.tweedforum.org/). The Tweed Forum was awarded the inaugural UK River Prize in 2015 in recognition of its partnership approach with local communities and others.

Also in Europe, a completely different scale of community engagement has been undertaken across the whole Danube River basin through the establishment of an annual Danube Day. Co-ordinated by the International Commission for the Protection of the Danube River (the inter-governmental body that oversees transboundary aspects of basin management) Danube Day is marked on 29 June every year across the 14 countries which share the basin. The aim is 'to celebrate one of Europe's greatest river systems and the people and wildlife that rely on it...' (ICPDR, n.d.). A wide range of events are held including festivals, public meetings, and educational events, all with the aim of promoting better protection, including restoration, of the river and its tributaries.

PART B

TOOLS AND TECHNIQUES

CHAPTER 8
RIVER HEALTH ASSESSMENT

OVERIEW AND KEY MESSAGES

The purpose of this chapter is to describe how restoration practitioners can use river health assessment tools as a way of implementing the guidance in earlier chapters, especially for building a conceptual framework for restoration (as described in 3), understanding river systems and prioritising river restoration interventions (4) and putting in place effective and efficient monitoring and evaluation frameworks and adaptive management approaches (5). The key messages from the chapter are:

- River health assessments can be used to identify rivers that are in poor health, or at risk; identify the likely causes of poor river health; and assess the effectiveness of management actions.
- It is critical to establish the purpose of the river health assessment at the outset as this will determine the spatial scale, the indicators to be used, and the most appropriate reference values.
- Many indicators can be used to assess river health. Typically, a suite of indicators will be required to fully consider the different elements that make up a river ecosystem. Indicators should be selected that respond predictably to changes in river health.
- Over time, trends in river health are likely to be more informative than assessments against a benchmark.
- River health report cards, based on the outcome of a river health assessment, can be a valuable tool for presenting information on river condition to a wide range of stakeholders.

8.1. River health and river health assessments

A river health assessment (RHA) is a structured and systematic approach to diagnosing key problems with river health and identifying the sources of those problems. RHAs also support monitoring, evaluation and adaptive management of river restoration and, through developing river health scorecards, can provide the foundation for effective communication of river health issues to stakeholders.

River health refers to the overall condition of a river ecosystem, and will reflect the combination of the ecosystem structure and function and the ecosystem services provided by the river (see section 1.1). River health is often considered in terms of biological integrity, which can be defined as:

> *…the ability to support and maintain a balanced, integrated adaptive assemblage of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region (Karr and Dudley, 1981).*

As a concept, river health incorporates both ecological and human values. The health of a river depends on its ability to maintain its structure and function, to recover after disturbance, to support local biota and human communities, and to maintain key processes, such as sediment transport, nutrient cycling, assimilation of waste products, and energy exchange (Speed *et al.*, 2012).[11]

RHAs rely on monitoring a series of indicators that reflect the state or condition of different elements of the river ecosystem. These indicators vary along a gradient of environmental disturbance and therefore demonstrate the degree of deviation from a 'healthy' state. Assessments ideally involve consideration of a range of elements of a river ecosystem, including elements that respond at different spatial and temporal scales. These commonly include hydrology, water quality, the structure, abundance and condition of aquatic flora and fauna, levels of catchment disturbance, and the physical form of the channel system. Increasingly, RHAs can also specifically consider the extent to which a river is providing certain ecosystem services. Assessments can also incorporate human health or socio-economic indicators, where those factors indirectly reflect the condition of the river ecosystem.

Importantly, no single variable is likely to indicate ecological condition unequivocally. As such, a suite of complementary variables is typically required to provide an accurate picture of river health. For example, while water quality monitoring programs are routinely undertaken in many places, and can provide useful, low-cost data on the river condition, water quality assessments only provide a snapshot of the river at a point in time, and therefore results can be strongly influenced by recent runoff or pollution events. Water quality data will also not indicate whether the flow regime is sufficient to support key ecosystem processes, or whether the channel structure is adequate for transporting floodwaters and thus mitigating the risk of flooding. As such, water quality monitoring alone is inadequate for providing a thorough understanding of the condition of a river over time.

It is common now for RHAs to present results using indices that combine a number of different indicators. Indices can present a significant amount of complex information in a simple form. At the extreme, they can condense the findings of an RHA into a single result, declaring the river to be in 'good' health, 'poor' health, or somewhere in between. This can provide a powerful message and one that is easily communicated to a range of stakeholders. At the same time, much detail is lost in the process of amalgamating results into a single indicator, including the different weightings that might have been given to different indicators, the uncertainty around aspects of the assessment, and the overall implications of findings for the provision of ecosystem services. Care should be taken when collating data to strike the right balance between supporting communication objectives and ensuring that the decision-makers understand the full picture.

8.2. Objectives of a river health assessment and its role in river restoration

Maintaining and improving river health – for example through river restoration – requires an accurate assessment of the current ecological state of a river ecosystem. The objectives of such an assessment can include (Speed *et al.*, 2012):

- Identifying rivers or river reaches that are in poor health, or at risk of poor health. This can include identifying trends in river health, for example where there is a steady decline in condition over time. This identification can help to understand where (and which) key ecosystem services are at risk, and the implications if river health continues to decline.
- Identifying the likely causes of poor river health. RHAs should do much more than simply identify which rivers are in poor condition. Ideally the assessment should be diagnostic, allowing for some determination of which factor or factors are contributing to poor river health: for example, an assessment might identify particular types and sources of pollution. These first two points allow for RHAs to prioritize river restoration measures. Assessments can help identify which catchments, rivers, or parts of rivers are most in need of intervention, as well as identifying what sort of management action is likely to be most effective and efficient.
- Assessing the effectiveness of management actions. As discussed in Chapter 5, monitoring programmes, including RHAs, can help validate or negate the rationales that underpin various management actions, and generally assess whether management goals for a river basin are being met and are supporting adaptive management. This is particularly important for river restoration, where significant public funds may be invested in improving river health, and where interventions are inevitably undertaken with imperfect information on the current condition or expected response of a river system to the action taken. For example, the Strategy for Protecting and Restoring the Chesapeake Bay Watershed includes a goal of improving the health of streams so that 70% of sampled streams sites throughout the Chesapeake watershed, rated as 'fair', 'good', or 'excellent' as measured by the Index of Biotic Integrity by 2025, which relies on a form of RHA.
- Reporting on river health to improve awareness. River health report cards and related tools, can be valuable in informing both government and the broader community of the current condition of a waterway. This can be important in raising awareness of the need for river restoration and galvanizing political support at all levels for restoration interventions.

11. This chapter draws heavily on a series of reports that were prepared as part of an Australian Government-funded project that supported the development of river health assessment protocols in China. Speed *et al.*, 2012 is the summary report from this project, but is underpinned by a large number of related reports that address in detail different aspects of RHA. The reports are available at http://watercentre.org/portfolio/rhef

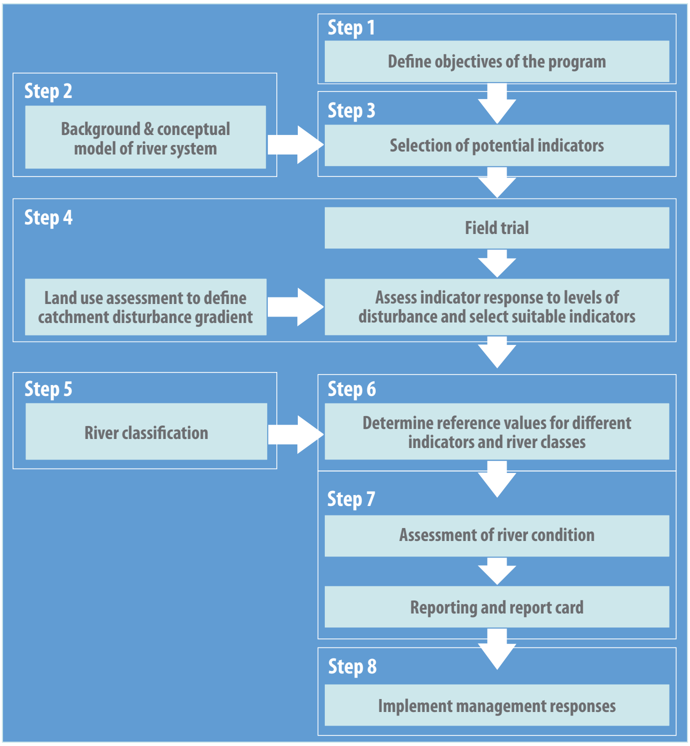
8.3. Framework and principles for assessing river health

Undertaking an RHA requires decisions to be made about which indicators will assessed, which data will be collected, and how that information will be analysed. A framework for developing a river health assessment programme is shown in Figure 8.1. Many of the steps shown will always be required when establishing and undertaking an RHA. As always, the most appropriate approach will depend on the local situation, and elements of the framework may need to be modified or even dropped depending on the context. The key steps and principles that apply to each are described below. Some steps are then discussed in greater detail in following sections.

RHAs can be undertaken as part of a routine monitoring programme, or can be customised to provide information to inform particular water and environmental management tasks, such as water resources or river restoration planning. The framework below describes the key steps in developing a routine (i.e. long-term, ongoing) RHA programme. This process could be undertaken independent of any river restoration process. The results though provide potentially valuable inputs to both the situation assessment and the monitoring process (see steps 1 and 7 in process for developing a river restoration strategy, as discussed in section 4.1 and shown in Figure 4.1). At the same time, RHAs can be developed or modified to improve the utility they provide to a river restoration process, such as by ensuring that the objectives of the RHA align with any requirements for river restoration planning and implementation, or to specifically assess the effectiveness of restoration measures.

Ultimately, RHAs should be designed to inform management responses (see step 8 in Figure 8.1), and a common response may include restoration measures. As such, all RHAs inherently have the potential (and indeed objective) of supporting river restoration (see for example, Bunn *et al.*, 2010).

Figure 8.1. Framework for undertaking developing a river health assessment programme



Source: Speed et al., 2012

Step 1 – Define objectives of the RHA programme. It is critical from the outset to establish the purpose of the RHA: this definition will influence the spatial scale at which the RHA will need to function; which aspects of the river ecosystem (and hence what indicators) should be assessed; and what are the most appropriate reference values to use.

Objectives may relate to understanding the condition of particular parts of the river ecosystem (e.g. the status an ecologically important species); assessing the impact of particular threats (e.g. monitoring the impacts of a mine or other development); or monitoring the effectiveness of management actions. As noted, RHAs can be developed or modified to support a river restoration process. In this instance, the objectives for the RHA need to be aligned with that process. It is relevant to distinguish between the objectives of the RHA and those of the river restoration process itself. A river restoration strategy might identify objectives in respect of improved river health or the removal of key threats (see section 4.3). The RHA, however, is more likely to have objectives related to identifying where and what aspects of river health should be targeted for improvement (i.e. in the case of informing the situation assessment) or assessing the effectiveness of restoration measures (in the case of the RHA forming part of the monitoring and evaluation process).

Box 30: Setting objectives for a river health assessment: the Yellow River, China

A pilot RHA program for the Yellow River was developed built around existing management objectives. The policy framework for managing the Yellow River is built around a vision statement, four overarching objectives, and nine actions (Li, 2004). The objectives relate to outcomes that are undesirable, and are known as 'the four nos': no river embankment breaching, no river running dry, no water pollution beyond standard, and no riverbed rising further. The pilot RHA was designed to report on the extent to which these management objectives were achieved. The programme incorporated a series of indicators that related to each of the objectives. For example, indicators related to channel capacity (which linked the objective of no river embankment breaches), and indicators of low flow (which linked to the objective of the river not running dry).

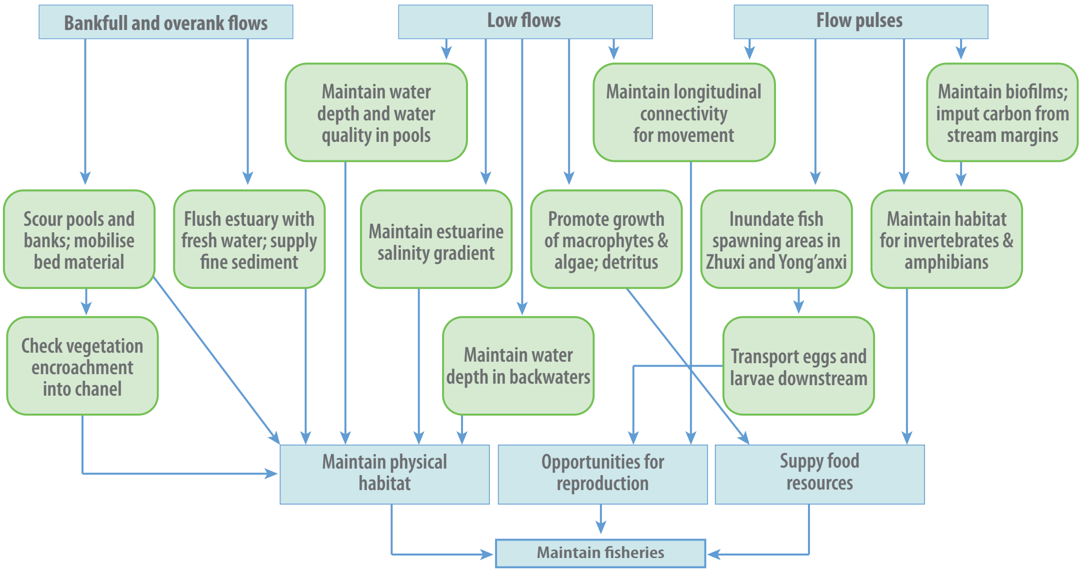
Source: Gippel *et al.*, 2012

Step 2 – Background and conceptual model of the river system. RHAs rely on a sound understanding of the scientific basis of how the relevant ecosystems function. Conceptual models are an important element of the development of a river health monitoring and assessment programme as they can be used to demonstrate how human disturbances are likely to affect river health (see Box 31). Conceptual models also help to identify and provide a clear understanding of what the important processes are that help maintain healthy ecosystems, and how these might change as ecosystem health declines. This understanding can help determine what aspects of river health should be monitored, and guide indicator selection and interpretation. The process of developing conceptual models can also help identify any areas of disagreement about which processes are important, and identify any major gaps in understanding that need to be addressed. Finally, conceptual models are valuable communication tools (Bond *et al.*, 2012).

Box 31: Using conceptual diagrams in river health assessments

Conceptual diagrams are useful tools for understanding how the different components and processes that make up a river ecosystem interact with one another. By developing scientifically based conceptual diagrams, it can be possible to predict how changes to one aspect of the system (e.g. to aspects of the flow regime) might impact on other elements (e.g. to the river channel or to biota). Understanding such relationships is important in undertaking a river health assessment, as it allows for predictions to be made of how changes in the environment are likely to impact on different river health indicators, and can thus aid the interpretation of the results of a river health monitoring programme.

Figure 8.2. Example conceptual diagrams showing links between river flows, geomorphology, vegetation, and maintenance of fisheries



Source: Gippel *et al.*, 2009

Step 3 – Select potential indicators. There are many potential indicators of river health (see Table 8.1). Indicators need to be selected based on their relevance to important environmental assets and values, and their likely response to different threatening processes. Indicator selection is discussed further in section 8.4.

Step 4 – Assess the indicators. The initial set of indicators identified should be tested for local relevance. This process should determine whether there is a predictable relationship between different indicators and disturbances known to affect river health, such as changes in water quality or land use (see Box 32). The testing process should also determine whether different indicators are feasible in the local context (e.g. whether appropriate reference values can be determined, whether data collection is realistic), as well as excluding redundant indicators, to minimise future costs.

Box 32: Selecting indicators of ecosystem health in Southeast Queensland

Southeast Queensland's Ecosystem Health Monitoring Program assesses the condition of the region's rivers and estuaries, as well as the condition of Moreton Bay. The Ecosystem Health Monitoring Program is designed to guide management strategies and to assess their effectiveness. The selection of freshwater indicators involved two phases. The first was a desktop process, which included identifying potential indicators. The second phase was a major field trial to test short-listed indicators of ecosystem health across the known disturbance gradient (derived primarily based on land use in the catchment). Indicators were tested to identify those that responded predictably to changes in levels of disturbance. Redundant indicators were excluded, to reduce future monitoring costs. Using this process, 75 indicators were tested, resulting in the recommendation that 16 of those indicators, from five indicator groups, be included in the monitoring programme.

Source: Bunn *et al.*, 2010

Step 5 – River classification. It is important to recognize the differences in river types when developing a monitoring program because:

- different types of rivers (and other freshwaters) will not look and behave the same even when they are healthy
- the types of indicators that might be appropriate in one type of river may not be appropriate for another
- the methods used to sample in one type may not be possible or relevant in another
- Even where the same indicator can be used in different river types, the thresholds or targets are likely to differ. (Bond *et al.*, 2012).

Because of these natural differences, it is often inappropriate to directly compare indicator threshold and target values from very different types of rivers. This challenge may be addressed by a river classification based on landscape and climatic features that are known to influence water quality and biota (such as rainfall, runoff, temperature, geology, topography and other landscape features), but are not directly influenced by human activity (Speed *et al.*, 2012).

Box 33: River classification in the Taizi River to support river health assessments

As part of a river health assessment for the Taizi River, part of the Liao River, China, a river classification was undertaken. Rivers within the basin were divided into different classes, based on natural biological and physical characteristics using spatial data. Variables used in the classification included a digital elevation model, topology, slope, soil type, vegetation type, annual average temperature, annual precipitation, annual evaporation, and the normalised difference vegetation index. Correlations were then made between aquatic ecosystems and natural geographic factors. Based on this analysis altitude and annual precipitation were chosen as the basis for the final classification. The process resulted in three classes of river – highlands, midlands, and lowlands. The different classes of rivers were used to set reference values for different indicators. For example, different reference values were used for highland versus lowland rivers where a different species richness or composition was expected.

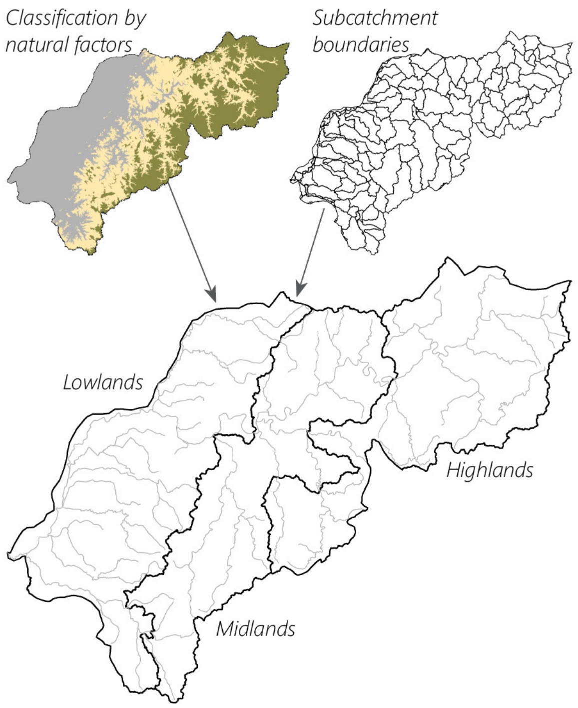


Figure 8.3. Classification of the Taizi River basin

Source: Bond *et al.*, 2012

Step 6 – Define reference values. Reference values need to be established for each river health indicator to provide the benchmark against which river condition can be assessed. Establishing reference values is a major challenge, as appropriate reference values will vary significantly between different rivers and regions. Even parameters such as water quality can vary significantly across and between river basins. Reference values are discussed further in section 8.5.

Step 7 – Assessment of river condition and reporting. River health values can then be determined based on the indicators and reference values selected. Assessments commonly produce a large amount of data, and presenting the results for a range of stakeholders can be a challenge. One response has been to develop indexes that aggregate results and provide 'scores' for different sites and/or indicator groups. For example, by using reference values to scale results, it is possible to score indicators along a scale (for example) from 0 to 1. Results can be classified into any number of categories. The results for an indicator at a site could be graded between good, fair and poor. Alternatively, some approaches grade sites from A to E (best to worst), or from 1 to 5. The approach adopted should be based on what will make most sense to the intended audience.

Once individual scores have been converted to a common scale (e.g. 0–1), it is possible to aggregate scores to provide an overall score for a site, indicator group, or even a basin. That is, different scores can be provided individual indicators (e.g. dissolved oxygen), different indicator groups (e.g. water quality), and for overall river health. These scores may be presented for individual sites within a basin, or for the basin as a whole.

There are various approaches that can be applied in aggregating scores. Scores may simply be averaged. Alternatively, scores may be weighted (e.g. water quality may be considered more important in assessing river condition). Even where a site scores highly against all other indicators, it may be relevant to score the site poorly if it fails against a single, critical indicator. For example, if the water is toxic for one metal, then it should be regarded as toxic, even if all other water quality indices are below the trigger value. In all cases, there is no right approach to formulating an index, but rather it is a matter of deciding how best to present the underlying information.

'Report cards' are now commonly used in many countries as a means of presenting complex information to stakeholders in a simple format, including river health assessments. In preparing a report card, careful consideration needs to be given to the objective of the report, including the intended audience and the particular message it is trying to convey. Different audiences can require different levels of detail as well as different strategies for communication and engagement.

Step 8 – Implement management responses. Ultimately, river health assessments should be about informing decision-making on river management. This may include river restoration efforts. Therefore, the last step in the process should be implementation of appropriate measures to respond to any issues or threats identified by the river health assessment. This step provides the link between river health assessment and adaptive management. In the case of river restoration, this is the point where restoration strategies should be reviewed and, where necessary, modified in light of the findings of the river health assessment. For example, a river health assessment may identify locations where urgent interventions are required, or show that existing strategies have not resulted in the expected improvement in river health or are unlikely to meet the goal and objectives for the programme.

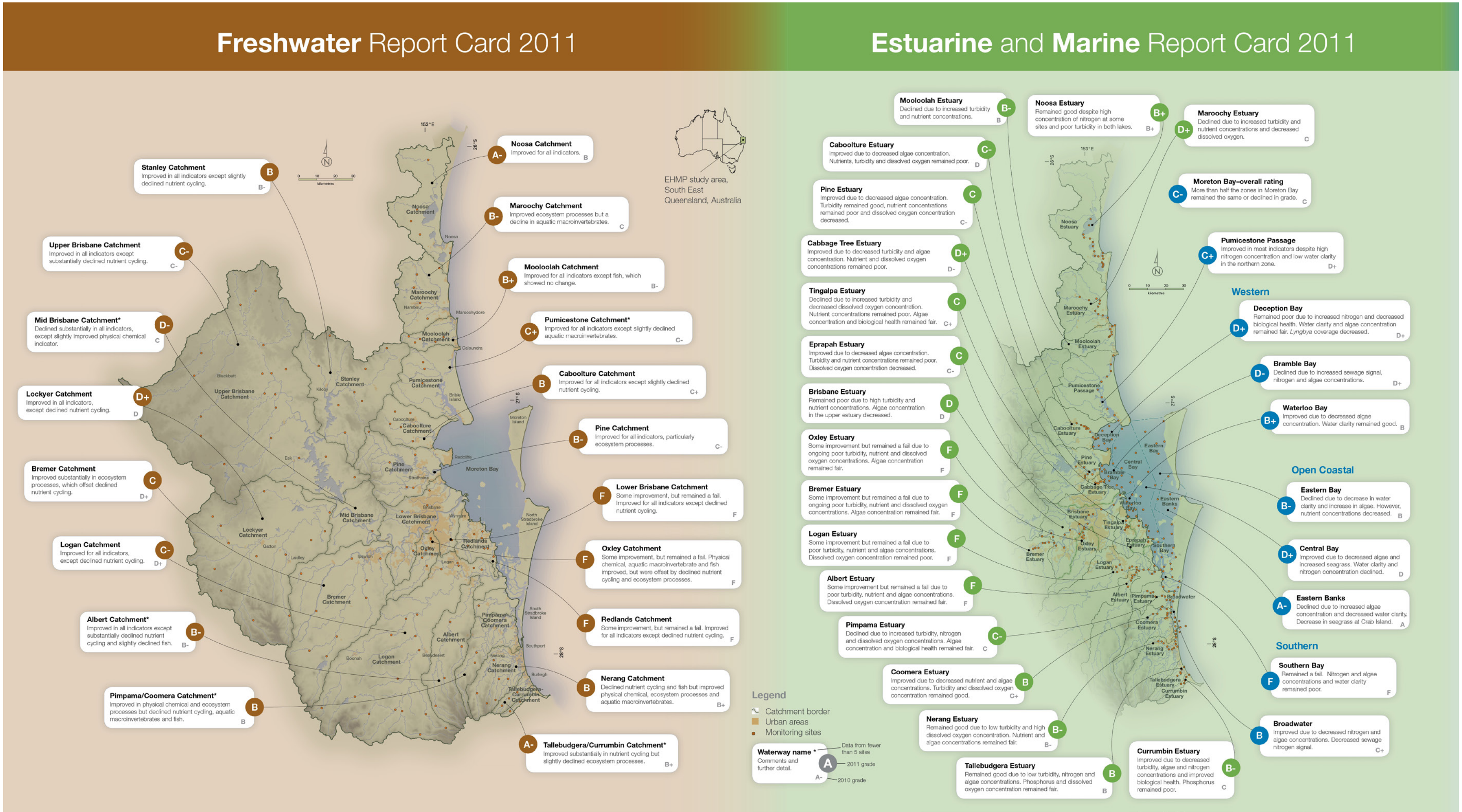
Box 34: Assessing the results and preparing a report card in Southeast Queensland as part of an ecosystem health monitoring programme

The ecosystem health monitoring programme in Southeast Queensland, Australia is based on five indicator groups: fish, aquatic macroinvertebrates, physical/chemical, nutrient cycling, and ecosystem processes, with sampling undertaken twice per year at 135 freshwater sites. A further 254 estuarine and marine sites are monitored monthly. Objectives for different indicator values were set based on the requirements to protect the predefined values.

Scores for each indicator are standardized to produce a score from 0 to 1 (with 1 being derived from a reference condition). These scores can then be aggregated and reported for different sites, indicator groups and catchments. Catchments are graded from A (excellent) to F (fail). The assessment is undertaken annually by an independent scientific panel and the results released publicly via a 'river health report card'. The report cards show clearly whether catchment health has improved or declined over the previous twelve months. The release of the report cards have typically attracted significant media attention, with the release often involving the presentation of the report card by the chair of the independent scientific panel to the Mayor of Brisbane and/or regional mayors.

The ecosystem health monitoring programme has been important in building community support for management interventions, as well as guiding those interventions. The programme identified the sources of high nutrient loads in Moreton Bay, which led to an investment in new wastewater treatment facilities. Studies under the program have also supported targeted action to reduce land degradation in those parts of the catchment that are contributing the bulk of sediment runoff.

Figure 8.4. Ecosystem health report card for Southeast Queensland catchments



Source: Bunn *et al.*, 2010

Box 35: The use of national frameworks for river health assessment

A common objective for national governments in developing national river health assessment programmes is to be able to compare the relative health of different rivers. This allows government to identify priorities for funding restorative action and to assess the relative success of conservation and restoration activities. This can result in pressure to adopt common indicators and reference values across a country. However, natural regional variations in climate, geology and other environmental factors and differences in the range and intensity of land use make the development of a national river health assessment program in any country a major challenge. It can be appropriate to establish a framework to ensure a consistent approach is adopted across different basins, allowing results to be compared and yet still allowing flexibility to meet the specific needs of each region.

A National Framework for the Assessment of River and Wetland Health has been developed in Australia as part of the Australian Water Resources 2005 project being undertaken by the National Water Commission. The Framework for the Assessment of River and Wetland Health proposes six key components for the assessment of river and wetland health:

1. catchment disturbance
2. hydrological change and spatial extent of wetland and temporal change
3. water quality
4. physical form
5. fringing (i.e. riparian) zone
6. aquatic biota.

The Framework for the Assessment of River and Wetland Health allows nationally comparable assessments of river and wetland health. This comparison enables states and territories to include data that are already being collected. The framework does not prescribe which indicators should be selected to represent the six components, but recommends that indicators should be relative to a reference (usually pre-European settlement conditions); linear and range standardised to 0–1, in increments of 0.1; and divided into condition bands.

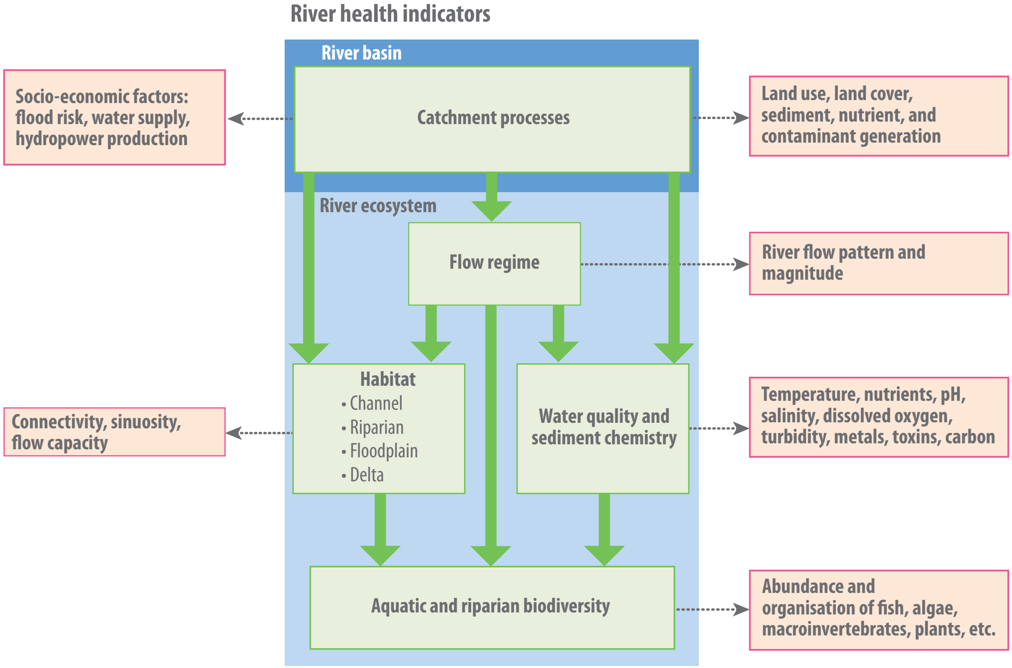
8.4. Indicators of river health

Many different indicators are used in river health assessments. Not all indicators provide meaningful results in all situations, and using a greater number of indicators typically results in a higher cost to undertake the assessment. The indicators selected should (based on Speed *et al.*, 2012):

- quantify threats and assets
- provide easily interpretable outputs
- respond predictably to damage caused by humans
- respond at appropriate time scales – for example, if an indicator takes too long to respond to a change (e.g. a disturbance) in the landscape, then this will reduce its suitability.
- be cost effective to measure
- relate to management goals
- be scientifically defensible.

A river health assessment may assess physical attributes of the river ecosystem (e.g. the flows, water quality, or biota), stressors and drivers of river health, and the benefits derived from the river ecosystem (either directly or based on relevant socio-economic indicators). Figure 8.5 highlights some of the common indicators that are used to assess different elements of a river ecosystem. Table 8.1 includes more detail on a number of different indicators, including information on how each indicator is relevant to a river health assessment and some considerations in using the indicator.

Figure 8.5. Examples of river health indicators relevant to different elements of a river ecosystem



The red boxes show examples of different indicators that can be used to assess the different elements (shown in green boxes)

Table 8.1. Categories of river health indicators

Element of river ecosystem	Indicator category	Why are they relevant/used in river health assessments	Considerations/issues	Examples of indicators
Catchment	Catchment	The catchment and related catchment processes provide the major inputs to a river ecosystem. Monitoring catchment condition provides information in key stressors and drivers of river health.	Studies have shown mixed results when assessing whether local or catchment-wide factors have more of an impact on biotic integrity of streams. (See Lammert and Allan, 1999; cf. Roth *et al.*, 1996)	■ Land use/land cover (e.g. % of catchment that is forested, under agriculture) ■ Level of adoption of best management practice in agriculture (e.g. % adoption by different sectors) ■ Presence of infrastructure
Flow Regime	Hydrology	Hydrologic alteration due to water abstraction and flow regulation are major drivers of change in aquatic ecosystems and impact on river health. The extent of hydrologic alteration can be measured by examining how patterns of flow variability have been altered by water resource development.	■ Easy to calculate but relies on the availability of adequate hydrological data, which is often a serious limitation. ■ Information on relationships between hydrological indices to ecosystem processes is improving but remains a weakness.	■ Flow stress ranking (SKM, 2005) ■ Index of Flow Health (Gippel *et al.*, 2012)
Habitat	Physical form	Physical form is concerned with the morphology and sediment characteristics of the bed and banks and floodplain environment. These characteristics create habitat conditions for the biota. Fragmentation by dams and levees also impacts on the physical environment of the river.	It is difficult to measure the health characteristics of physical form due to the wide range of physical habitat preferences of different biota. Further, stream morphology is ideally in a dynamic state, while too much change, or fast change can have a negative impact on biota. In the field it is virtually impossible to measure the dynamism of physical form.	■ Bank stability indicators ■ Channel form variability (e.g. sinuosity, particle size, channel cross-section) ■ Connectivity (lateral and longitudinal) ■ Direct disturbance (See Gippel *et al.*, 2012)
Water Quality	Water quality parameters	■ Water quality is a key component of aquatic ecosystem condition, and can be both an indicator as well as a cause of poor health. ■ Nutrient and pollutant levels can indicate the likely cause and source of water quality decline, and help identify areas to be addressed by management actions.	■ Most parameters vary significantly according to recent runoff history, which must be considered when interpreting the data. ■ Physico-chemical profiling may identify situations where biotic communities are at risk, but provides no information on the actual damage, if any, to the biota.	A range of parameters are commonly measured, including temperature, turbidity, EC, pH, nutrients, heavy metals
Biodiversity	Benthic macro-invertebrates	■ Benthic macroinvertebrates are found in most habitats, are an important food source, and contribute to carbon and nutrient processing. ■ They have limited mobility and are easy to collect. ■ They are sensitive to short and medium-term disturbances. ■ Different taxa show a wide range of sensitivities to changes in both water quality (of virtually any parameter) and habitats.	■ Most popular choice for use in bio-assessment of stream health globally (Gordon *et al.*, 2013). ■ Compared with other groups of organisms and parameters, they can be more easily and reliably collected, handled and identified. In addition, there is often more ecological information available for such taxonomic groups. ■ Macroinvertebrates are not generally as sensitive to altered river flows as fish.	EPT ratio, Berger-Parker Dominance, Shannon index, SIGNAL (Chessman, 2003), Biotic Index (Lenat, 1993)
	Vegetation	The riparian zone can act as a buffer between the river and activities in the surrounding catchment. Healthy riparian zones are an effective way of achieving a healthy river – helping filter nutrients, trapping sediment runoff, and maintaining food-webs and other important links between the terrestrial and aquatic environments. They are also important environments in their own right, and often harbour a high diversity of plant and animal life such as birds.	A review of existing methods for quantifying riparian vegetation as an indicator of stream health by Werren and Arthington (2002) found that most methods measured structure and failed to consider activity (metabolism or primary productivity), while few considered resilience. They developed a generalized rapid assessment protocol for riparian vegetation that was claimed to address these shortcomings (Gordon *et al.*, 2013).	■ Width and continuity of the riparian buffer zone. ■ Diversity, naturalness of vegetation (riparian and instream)
	Algae (diatoms)	■ Algae are abundant in most streams and respond rapidly to changed conditions. ■ They are relatively easy to sample, and their tolerance to environmental conditions is known for many species due to the wide distribution of many taxa. ■ Algal abundance (e.g. measured as chlorophyll concentration) and isotopic signatures can detect nutrient enrichment and nutrient sources.	Requires technical expertise for laboratory analysis.	■ Biological Diatom Index ■ Specific Pollution Sensitivity index
	Fish	Fish have a range of sensitivities to water quality, hydrology alteration and habitat deterioration. ■ Fish are relatively easy to sample and identify in the field. ■ Their place in the food chain mean fish integrate effects of lower trophic levels, and can be reflective of integrated environmental health. ■ Their mobility and longevity mean they can be used to assess macrohabitat and regional differences, as well as impacts of long-term changes in stream health. ■ Fish are often valued socially and economically.	It is important to establish uniform approaches to sampling. Accessing historical patterns of diversity can be challenging, making the establishment of suitable targets difficult.	Indicators related to species richness; abundance; size or condition of individual fish; % of native species
Other	Socio-economic indicators	Provide more explicit information on the ecosystem services a river is providing.	Historically socio-economic indicators have not been included in many river health assessments. Many of these indicators will be closely related to other indicators discussed above.	Flood risk (related to physical form/habitat) ■ Water supply, including reliability/quality ■ Human health indicators, such as incidence of water-borne disease and healthy babies at birth.

8.5. Setting reference values

Reference values provide the benchmarks against which different river health indicators can be assessed. Reference values can be defined for different indicators to identify what a 'good' score would be (i.e. what would be expected in a healthy river) as well as a 'bad' score (what would be unacceptable in terms of river health).

There are various approaches to setting such benchmarks. In determining the reference value that will be used to indicate 'good' health, common approaches include the use of:

- Natural condition: that is, the value that would be expected in a relatively undisturbed river system. This is the approach adopted in the US under the Clean Water Act, by the EU Water Framework Directive, and in many river health assessment programmes in Australia.
- Minimally disturbed condition: the condition of streams in the absence of significant human disturbance.
- Least disturbed condition: the best conditions that presently exist for the stream (or type of stream) given present day conditions.
- Historical condition: this refers to the condition at some historical point in time. For example, it may be linked to the condition of the river before some major development, such as the construction of a reservoir.
- Best attainable condition: the expected ecological condition of least-disturbed sites if the best possible management practices were in use for some period of time (Stoddard *et al.*, 2006).

Rather than using absolute values, it is also possible to report on trends: that is, whether the score for a particular indicator has improved or worsened over time. For ongoing monitoring programmes, trends over time can often be more important that assessing health against (at times) arbitrary reference values. For instance, the EU Water Framework Directive obliges Member States to ensure that there is no deterioration in ecological status of water bodies, thus requiring monitoring of trends in river health.

In applying reference values, it is important to recognize natural variability in indicator values, including seasonal variability. Many indicators are subject to periodic fluctuations in response to climatic or other events. This can result in rapid (although at times short-lived) changes in values. The likely causes of such changes need to be considered when interpreting the results of monitoring programmes.

There are various ways to develop appropriate reference values. This can include one or more of:

- international or national standards and experience (e.g. water quality guidelines; biotic indices)
- historical data
- the statistical distribution of scores within the relevant basin
- expert judgement (especially where data is scarce).

Finally, and as noted elsewhere, appropriate reference values will vary between different types and sections of rivers. As such, it will often be necessary to define different reference values for different classes of river.

Box 36: Water quality standards in China

In China, the National Surface Water Quality Standard (GB3838-2002) classifies chemical water quality into five water use grades for a range of indices. A number of water quality indicators are used to define these standards, with each parameter having a numerical limit for each grade. State of the Environment reporting for river health is based on the standards. The five grades and corresponding uses are shown in the table below. (COD, NH4-N, and DO refer to permanganate index, ammonium nitrogen, and dissolved oxygen. The unit of water quality concentration is mg/L.)

Grade	Description of water use	COD	NH4-N	DO
I	National conservation reserves, water source protection zones	≤2	≤0.15	≥7.5
II	Drinking water 1st Class; natural habitat for sensitive and rare aquatic species; fish and crustacean spawning; fish rearing	≤4	≤0.5	≥6
III	Drinking water 2nd Class (treatment required); sanctuaries for common aquatic species; fish survival in winter; fish migration; aquaculture; contact recreation	≤6	≤1	≥5
IV	Industrial use; active non-contact recreation	≤10	≤1.5	≥3
V	Industrial cooling only; agricultural irrigation; ordinary (low conservation value) landscape irrigation; passive recreation	≤15	≤2	≥2
VI	Not suitable for any purpose	>15	>2	<2

8.6. Management and operational issues

River health assessments are best supported by river health monitoring programmes that can provide ongoing information on river condition and related trends. Such programmes require that a range of operational and management issues be addressed. In designing a programme, it is important to consider the resources (staff and funds) required for implementation. This will depend in part on the type and number of indicators that will be measured, as discussed above. The number and location of sites and the frequency of sampling and reporting will also be important, and quality assurance and logistical issues must also be considered. These issues are covered in detail by other reports (IWC, 2012).

SITE SELECTION AND SAMPLING REGIME

Regardless of resource constraints, it is important to ensure that there are sufficient sites and measurements to achieve the statistical power required to report on the objectives. For example, sampling of biota relies on a statistical technique to use a number of individual observations from within a population of individual to make predictions across the entire population based on statistical inference. The process of selecting the locations for sampling does, however, have major implications on the results (Gippel and Speed, 2010).

Randomized sampling design provides the best-possible statistical power for assessing and monitoring river health. This increases the capacity to extrapolate the results to sites that were not sampled. However, completely randomized sampling is often unachievable due to constraints imposed by site access and limited resources (Alluvium Consulting, 2011).

Alternatively, it may be desirable to deliberately select particular sites, for example sites with high conservation value, where the program is designed to test the effectiveness of particular management interventions, or where monitoring is to assess the impacts of a particular threat (e.g. a mine or factory).

Ultimately, the approach to site selection will need to be driven by the local context, and particularly the programme objectives. Where a river health assessment programme is designed to assess the effectiveness of management actions – such as a river restoration intervention – then sites need to be selected in such a way that the results can support that overarching objective (see Table 8.2).

Table 8.2. The implications for site selection based on different program objectives

Program objective	Specific objective	Site selection implications
Test and improve effectiveness of management actions	Test effectiveness of, and adaptively manage, specific management actions	Stratified according to where actions are and are not applied
	Test effectiveness of, and adaptively manage, site specific application of management actions	According to location of actions
	Compliance checking against stated limits	Points of compliance
Collect data to inform policy development	Observe spatial pattern and trend in variables related to specific issue of concern	Known sites where issue has been identified
	Provide data to develop policy priorities for specific types of actions	Random over extent of region where actions likely to be applied
	Provide data to develop policy priorities for actions at specific areas (e.g. icon sites, geomorphic zones within basins)	Random within the specific areas
Communication	Raise public awareness of river health as an issue, to support policy implementation	Random over region of interest, or target rivers of main public interest
	Provide comparative data to motivate regional river managers and stakeholders to implement actions to improve river health	Random sites over region of interest, with coverage of most major streams
	Inform the public of the state of river health as part of accountability obligations	Random over region of interest, or target rivers of main public interest

Source: IWC, 2012

QUALITY ASSURANCE PROCEDURES

Large-scale and long-term monitoring programmes require a rigorous quality assurance (QA) program that can be implemented consistently throughout the duration of the monitoring period (Lazorchak *et al.*, 2000).

River health monitoring and assessments should be undertaken in accordance with a quality assurance and quality control (QA/QC) plan. The core elements of such a plan are (see IWC, 2012):

- Data quality objectives: these objectives are used to establish performance and acceptance criteria for field and laboratory measurement processes and set levels of acceptable measurement error. Objectives are usually established for five aspects of data quality: representativeness, completeness, comparability, accuracy, and precision.
- Data generation and acquisition: these elements are quality controls, such as standardized procedures, for use in the field and laboratory.
- Data validation and usability: review the quality of data and make corrections where necessary.
- Data management: includes managing the chain of custody, defined data flow paths, the use of standard field data sheets and laboratory reports, and information management (database) systems. In addition to ensuring the quality of the data, data management systems offer the opportunity for increasing the accessibility and utility of data.
- Auditing: field, laboratory and data management operations tracks compliance with the QA/QC plan.

LOGISTIC ISSUES

Finally, there are significant logistical challenges to be considered to address issues related to project management, scheduling, workplace health and safety, training, data collection and management, and review procedures (Table 8.3).

Table 8.3. Critical elements of a river health monitoring programme

Logistic component	Required elements
Project management	■ Overview of logistics activities ■ Staffing & personnel requirements ■ Communications ■ Reporting
Access & scheduling	■ Sampling schedule ■ Site access ■ Reconnaissance
Safety	■ Safety plan ■ Waste disposal plan
Training and data collection	■ Training program ■ Field operations scenario ■ Laboratory operations scenario ■ Quality assurance ■ Information management
Assessment of operations	■ Field crew debriefings ■ Logistics review and recommendations

Source: Adapted from US EPA, 2004

CHAPTER 9
PRIORITISING RESTORATION MEASURES AND PROJECTS

OVERVIEW AND KEY MESSAGES

This chapter describes considerations and approaches to prioritizing different restoration options as the basis for deciding which restoration measures to implement and in which locations. The key messages from this chapter are:

- Strategic restoration requires that restoration projects be prioritized at the appropriate scale, commonly the basin-level, and over a medium to long timeframe. Prioritization undertaken at a local scale or over a short timeframe can result in significant inefficiencies.
- River restoration measures and projects should prioritized be based on: (i) the principles of catchment processes; (ii) protecting existing high-quality habitats and critical ecosystem services; and (iii) current knowledge of the effectiveness of specific techniques.
- Prioritization of projects should be undertaken based on selection criteria that reflect the overall goals and objectives. These should be used to assess the range of potential restoration opportunities.
- The approach to prioritization needs to be tailored to the situation, taking account of the availability of information on the target river basin. Of the many approaches available, multi-criteria decision analysis is becoming increasingly popular as a method for making assessments that consider a range of factors.

9.1. Introduction

Restoring rivers can be an expensive process and funding is inevitably limited. Consequently, the options available for restoring a river basin need to be prioritized. Decisions about potential interventions need to be made. Such decisions are often based on professional opinion or the preference of local experts or the project proponent (Roni and Beechie, 2013). In other instances, specific restoration projects are selected based on convenience or the path of least resistance (Hermoso et al., 2012). As more public funds are invested in restoration measures, there is growing pressure for restoration processes to demonstrate the greatest value for money in terms of both socio-economic and biodiversity conservation outcomes (Menz et al., 2013). This has resulted in the need for more robust, transparent, and defensible mechanisms for evaluating and selecting restoration projects.[12]

In some instances, prioritizing between different restoration options can be relatively straightforward, for example where the restoration objectives relate to a limited geographic area or addressing a specific threat. This results in a limited number of suitable restoration measures and locations for action. In

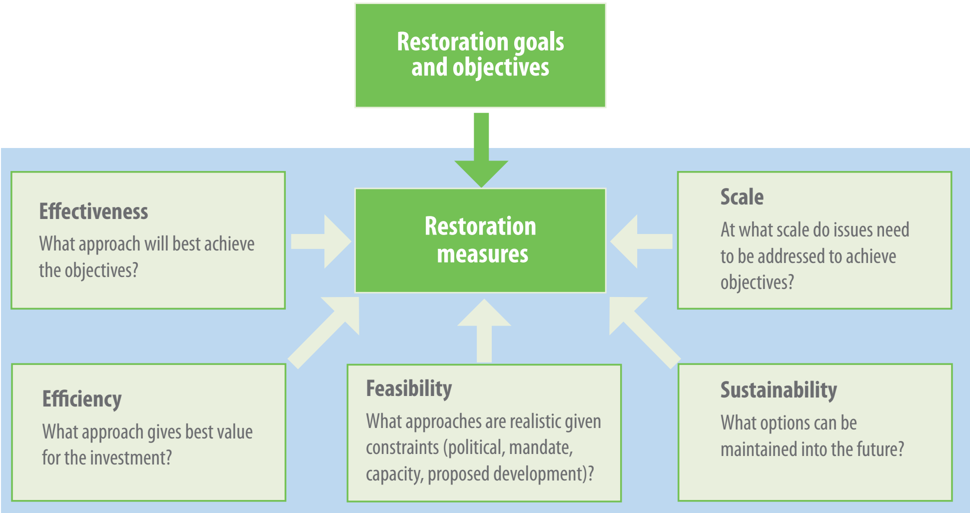
12. We use the term 'restoration measure' to refer to a particular approach to restoration (e.g. the creation of instream habitat, removal of barriers) and 'restoration project' to refer to the application of one or more restoration measures in a particular location.

larger basins, or where the threats, issues, or objectives are more complex, the prioritisation process can be far more challenging.

Prioritizing restoration measures and projects involves deciding where to work, what problems should be addressed, and what to do. This requires consideration of a number of factors as they relate to each potential project (see Figure 9.1):

- **Effectiveness:** how will the river ecosystem respond to different interventions, and which are most likely to be successful in achieving the stated restoration objectives? What interventions are required to address the rate-limiting factors to river health? Will passive restoration be sufficient, or are more active interventions required?
- **Efficiency:** which interventions will achieve the best outcomes per dollar of investment? How do the costs and benefits of different interventions compare, including upfront and ongoing costs and both direct and indirect benefits?
- **Feasibility:** as for setting the goals and objectives, identifying interventions needs to consider the potential constraints in ensuring that the proposed approach is feasible. This includes considering technical feasibility (e.g. technical capacity of staff, availability of data and information relating to the basin and how it functions, legal mandate), political feasibility (e.g. political will, stakeholder support, institutional support), and affordability (i.e. any budget constraints).
- **Sustainability:** which interventions are more likely to be enduring? Are the measures likely to be undermined by other actions in the basin? Which approaches will be most resilient to a range of future scenarios?
- **Scale:** at what scale (basin, reach, local) and in which specific locations, do the issues need to be addressed?

Figure 9.1. Considerations in deciding restoration measures and formulating a strategy



Prioritizing restoration projects requires that these factors be considered for different restoration options, including both individual restoration measures as well as different combinations of measures, and for different locations. Initially this may involve identifying which category of measure (e.g. improving river flows or connectivity, bank stabilization. See Table 3.1) is most suitable. Ultimately, this process needs to identify the nature and scope of the specific restoration projects that will be implemented as part of the strategy, including both on-the-ground actions in defined locations, like re-vegetating part of the catchment or riparian zone or reconfiguring the channel, and any changes to policy or regulations designed to change the behaviour of people and businesses within the basin.

The process of prioritizing restoration measures and projects can be considered in terms of four steps (Beechie *et al.*, 2008). These steps fit within the broader restoration planning process discussed in Chapter 4 (see Figure 9.2). The first step is identifying restoration goals and objectives (see section 4.3). Clearly defined goals and objectives are critical to selecting an approach for prioritizing actions – the outcome must be known to assess the best mechanism for achieving it. As well being a target, goals and objectives also inform the selection criteria for choosing restoration measures, including deciding which specific projects should go ahead.

The second step is determining specific criteria for selecting restoration projects and the approach to assessing those criteria, that is the prioritization approach. The selection criteria should be determined based on the restoration goals and objectives and incorporate the considerations described above (efficiency, effectiveness, feasibility, sustainability, scale). There are many methods available for prioritizing restoration measures, and which is the most appropriate will depend on a range of factors, including the restoration goals and objectives; the data and other information available regarding the river basin; and the time and resources available to complete the prioritization process. There is no ideal approach, and establishing the selection criteria and deciding on the prioritization approach are closely connected (Roni & Beechie, 2013). An overview of prioritization approaches is in section 9.3.

The third step is to determine potential restoration measures and projects. Suitable measures and projects will often be identified based on the situation assessment (see section 4.2) or through information provided by ongoing river health assessment programmes (see Chapter 8). As well as providing information on river ecosystem function and related ecosystem services, and informing the setting of restoration goals and objectives, such assessments can also provide an inventory of potential threats and drivers related to specific functions, which can form the basis for identifying specific restoration interventions (see Table 9.1).

Table 9.1. Information relevant to developing list of potential restoration projects

Ecosystem function	Inventory of relevant threats or drivers	Relevance to identifying potential projects
Sediment transport	Inventory of forest roads; mapping of agricultural sediment sources	Identify sites for catchment restoration to reduce sediment runoff
Environmental flows	Inventory of diversions, dams, and water withdrawals	Identify options for altering the flow regime through changed dam operational rules or abstraction practices
Habitat connectivity	Inventory of barriers and available habitats above them	Identify potential barriers for removal or for retrofitting of fish passages
Waste assimilation	Inventory of development and agriculture patterns; pesticide use by land class	Identify agricultural sectors and locations for introduction of improved farming methods

Source: Adapted from Beechie et al. 2008

Alternatively, or in addition, restoration projects may be identified by stakeholder groups. For example, a restoration programme may involve a call (say from the federal government) for expressions of interest from regional governments or community groups for proposals. These proposals would then be assessed against the selection criteria and funding awarded to the preferred proposals.

The fourth step is to assess the list of restoration projects, based on the prioritization method and criteria. The time and resources required for this step will vary significantly based on the prioritization approach selected and some expertise in river ecosystem functions may be needed for the assessment. The end result is typically a ranking or scoring of different restoration projects. In some instances, rather than ranking the options, the process may divide restoration projects into (for example) high, medium, and low priority groupings.

The ranking or scoring produced at the end of this process will not necessarily be definitive in deciding which projects will go ahead. The prioritization process is simply a tool to inform decision-making and the final decision on restoration projects may be influenced by factors that were not captured or fully reflected in the assessment criteria, for example, political imperatives. Prioritization can also be used to determine sequencing of restoration projects, rather than simply deciding which projects will and will not be implemented (Roni and Beechie, 2013). Regardless, the ranking process offers the potential to provide an objective assessment of different restoration projects, and to improve transparency in the decision-making process.

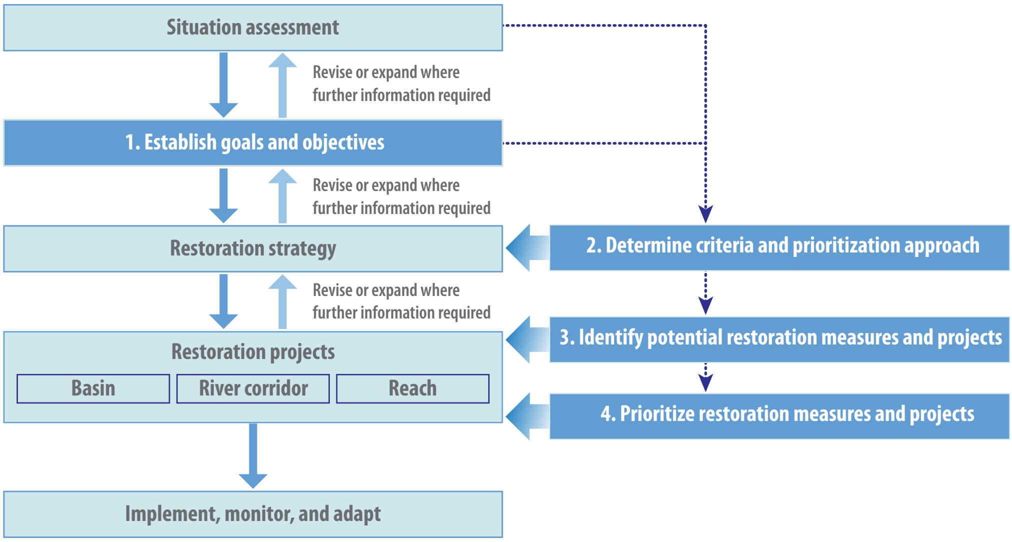
Finally, it is relevant to reiterate, as discussed in section 4.3, that the process of developing goals, the strategy, and identifying individual restoration measures and related projects is an iterative one. This applies also to the prioritization process. Goals may be revised based on a review of the feasibility (including cost) of achieving them, once restoration interventions have been more fully considered. Similarly, while the prioritization process will draw on information collected as part of the situation assessment, further data collection can be required based on the prioritization approach adopted.

CASE STUDY: USING SELECTION CRITERIA TO PRIORITIZE RESTORATION IN THE DANUBE

The first and most significant attempt to assess restoration potential for the Danube River basin was an evaluation developed under the Danube Pollution Reduction Programme (DPRP) in 1999. The evaluation focused on lateral connectivity and morphology along the mainstem and five major tributaries and was undertaken to define priority wetland and floodplain rehabilitation sites. Flood plain restoration had previously been identified as a key intervention to address issues of flooding and water quality.

Floodplain sites were classified according to floodplain type, width and land use. Then the potential for restoration to contribute to nutrient pollution reduction and flood protection was assessed. The end result was listing 17 wetland or floodplain sites across the basin recommended for restoration based on their ecological importance, their nutrient removal capacity and their role in flood protection.

Figure 9.2. The four steps in identifying and prioritising river restoration measures



The floodplain classification process involved GIS data and economic analysis to establish an inventory, assessment and prioritization of restoration sites (WWF-Danube Carpathian Programme, 2010). The Danube basin was mapped according to two flood plain areas: the morphological floodplain (defined as post-glacial terraces) and the active floodplains (within current protection dikes). Most of the proposed restoration areas fell outside of the dikes in a portion of the morphological floodplain. This allowed a direct comparison of natural versus active floodplains, for the identification of restoration sites.

To identify restoration points of greatest potential, 'ideal' selection criteria were initially identified. However, the costs of data collection were considered prohibitive and revised criteria were selected based on available data.

Table 9.2. Ideal and actual selection criteria used to select sites for restoration in the Danube River Basin

'Ideal Criteria'	Available & Useful Data
Flood protection	Land use and habitats (settlements are 'no go' areas)
Groundwater replenishment	Spatial configuration
Sediment and Nutrient retention	Hydro morphological intactness
Water purification	Overlapping protected areas
Resilience and recovery of river ecosystems after accidents	Floodplain function/purpose
River-floodplain products (wood, fish, game, reed)	Land ownership
Cultural Values	Usage concepts (for specific areas)
Recreation and tourism	Feasibility of projects (costs, legal framework, administration)
Climate change buffering capacities	

A matrix was developed based on comparable criteria to identify the restoration potential of each of the proposed areas, ranking on criteria which included: overall hydro morphological intactness of adjacent river stretch, functional flood plain type, land use, protection status and coverage, and area size (Table 9.2). Complementary economic analyses were undertaken to support the restoration arguments and gain stakeholder support, based on pilots and projects. A simple estimation of the financial value of the Danube floodplains was then carried out, considering the following values: fishing, silviculture, grassland farming, recreation, nutrient retention and decomposition, and flood protection. The economic analysis indicated that the 12 major riparian states of the Danube River basin that were included in the study had very different economic and social levels, therefore suggesting restoration projects needed to be specific to the context. Subsequently, many economic analyses of wetlands have been conducted, all with widely varying results.

One lesson from this experience was that data collection and analysis is a vital component of planning. Strong scientific data and analysis allowed for informed decision-making, which in turn translated into effective project implementation. The project is noteworthy for its significant scope for large-scale restoration along the entire Lower Danube (~1,000 km), and the trans-boundary nature of the suggested restoration sites. The project aided in the establishment and implementation of the Danube Lower Green Corridor agreement.

9.2. Spatial and temporal scales

Spatial and temporal scales are highly important to understanding ecosystem function and therefore to effective river restoration interventions (see sections 3.5 and 3.6). As such, decisions on where to restore need to be undertaken within an appropriate spatial framework, and with appropriate consideration of the implications of timing of interventions. Notably, considering and prioritizing projects at the right scale (both spatial and temporal) can have significance for both the cost and effectiveness of restoration measures (see Box 37). Spatial and temporal scales in the context of prioritisation are discussed further in the following sections.

Box 37: Impacts of scale on prioritisation and cost-effectiveness in the Great Lakes Basin, United States

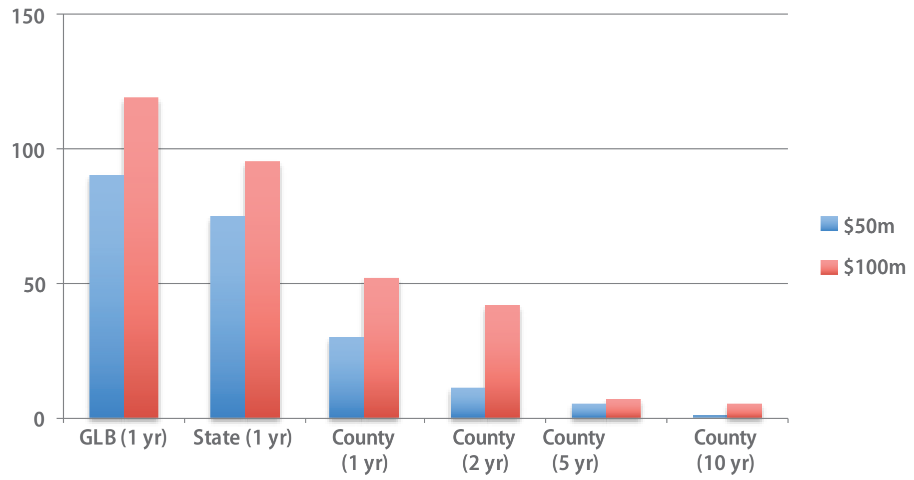
The Great Lakes Basin in the US provides significant ecosystem services to the 33.5 million people that live in the basin, including US $7 billion in economic activity related to recreational fishing. Presently, a range of programs and projects are undertaken at various scales, which fund efforts to remove or mitigate the effects of the hundreds of thousands of dams and road culverts that partially or fully block fish migration.

A study of the Great Lakes Basin considered the potential cost effectiveness of efforts to improve aquatic ecosystem connectivity. The study considered the potential gains from coordinating barrier removal at different spatial scales (including at county, tributary, state, and whole-of-basin) and different temporal scales, comparing funding as a lump sum or allocating the same amount over a number of years. The assessment showed a major benefit from optimizing interventions at the basin scale. For example, an investment of $100 million across a portfolio of barrier-removal projects optimised across the Great Lakes Basin would result in a 119% increase in habitat, compared with only a 14% increase if the optimization was undertaken at the tributary scale. Based on this assessment, nearly 10 times the funding would be required to double the accessible tributary length if decisions were made at the tributary, rather than basin level ($70 million vs $690 million).

The timing of funding was also shown to be highly relevant in some instances. Where funding was divided among the smaller spatial units (e.g. county or tributary level), then a one-off payment was shown to be far more effective than annual funds spread over a number of years. For example, a one-off payment of $100 million at the county level would potentially increase accessible habitat by 52%, compared with a 5% increase if the amount were provided over a 10-year period. This large inefficiency only existed in the case of local-scale planning, and was a consequence of budgets being too small to support removal of key dams (which are expensive) resulting in expenditure on low-cost, low-reward projects.

These figures are shown in the graph below. The graph shows percentage increase in habitat based on a total budget of either $50 m or $100 m. The shows the impact of prioritising at the basin level, state, or county levels. For the county level, the graph also shows the difference between allocating funding in a single year (1x 100%) vs. spreading funding over 2, 5 or 10 years.

Figure 9.3. Increase in habitat based on expenditure of USD $50m and $100m, depending on spatial and temporal scale used for prioritisation



Source: Neeson *et al.*, 2015

SPATIAL SCALE

Determining the best locations to intervene can involve prioritizing at various spatial scales. River restoration interventions can be ranked at national, state, regional, basin, sub-basin, or reach levels (Beechie, *et al.*, 2008). In the case of large-scale restoration (e.g. national or major river-basin), it can be common to first assess and prioritize individual basins or sub-basins, based on their potential for delivering benefits from the restoration efforts (Mitsch *et al.*, 2001). A challenge here can be ensuring that large-scale objectives (e.g. national, basin or regional) are reconciled with local (reach or sub-basin) objectives. This makes a hierarchical approach to planning essential (Sieben *et al.*, 2011).

Prioritizing river restoration interventions based on location may be undertaken prior to, or as part of, the exercise of prioritizing specific projects. The considerations in undertaking spatial prioritization will vary depending on:

- The restoration goals and objectives: the goals and objectives may explicitly define the scale and location (e.g. the programme may be designed to restore a specific wetland). The nature of restoration goals will also be important: different approaches will be suitable depending on whether the restoration programme is focused on specific species, certain habitat types, or particular ecosystem services, and how these are affected by ecosystem functions operating at different scales.
- The overall spatial extent of the restoration effort: for example, large national programmes implicitly require consideration of issues at the landscape and basin levels, whereas more localised efforts may be able to focus on the immediate surrounds.
- The types of threats: for example, a programme aimed at restoring water quality will need to respond differently where the primary source of pollution is diffuse (e.g. broad-scale agriculture) compared with where it is a consequence of a (more limited) number of point sources, such as wastewater treatment facilities.

CASE STUDY: SPATIAL PRIORITISATION UNDER SOUTH AFRICA'S WORKING FOR WETLANDS PROGRAMME

South Africa's Working for Wetlands programme, a national initiative aimed at restoring its wetlands, was established in 2002. After 14 years, the programme had invested approximately US $79 million in rehabilitating 906 wetlands and improving or protecting the health of more than 70,000 hectares of wetland area in the process (Department of Environmental Affairs, n.d.).

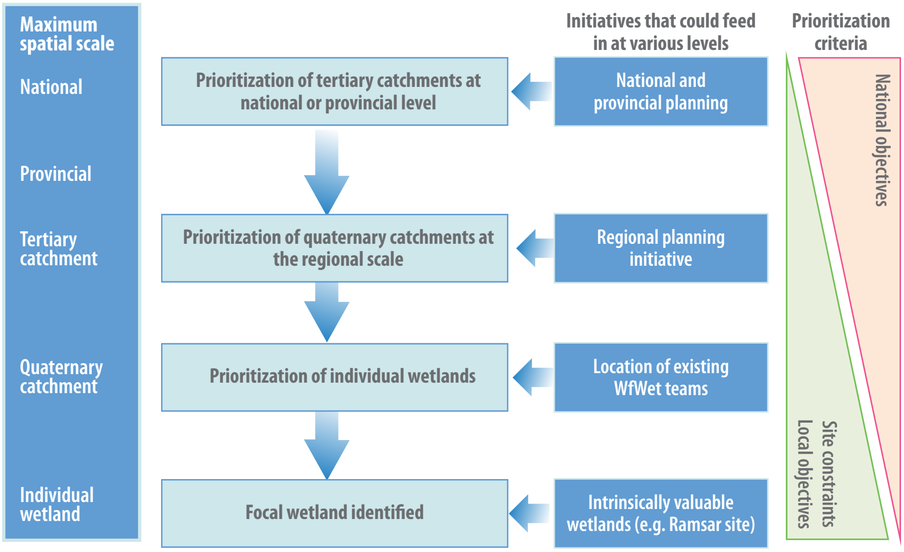
Restoration planning under the programme is hierarchical and focuses largely on improving ecosystem services. A spatial framework was developed to support prioritisation of wetland restoration (Sieben *et al.*, 2011). The framework consists of six spatial scales, at which different prioritisation processes can be undertaken:

1. Tertiary basins
2. Quaternary basins: within tertiary basins
3. Wetland complex: a contiguous wetland area within a quaternary basin
4. Hydro-geomorphic unit: sub-units within a wetland complex, classified based on their hydrological and geomorphological processes, which in turn will guide the types of ecological impacts and restoration responses that can be expected within a unit
5. Habitat type: areas within a wetland with the same environmental conditions for growth
6. Vegetation type: a habitat type may consist of one or more vegetation types.

The prioritization process follows a hierarchical framework to identify individual wetlands for restoration, starting at the national or provincial level to prioritize tertiary basins (those that are water stressed or with reduced water security), and then identifying sub-basins based on national and or provincial priorities related to sub-basin characteristics, as well as local goals (e.g. recreational fishing, ecotourism). More detailed assessments, including of wetland health, are then undertaken at the wetland complex and hydro-geomorphic unit levels to support an assessment of costs and benefits as well as cost effectiveness for restoration of individual wetlands (see Figure 9.4).

This framework was used to prioritize wetlands for restoration in the upper Berg River catchment, in the Western Cape Province. The basin is classified on a national scale as a priority basin due to its importance for water supply. The assessment considered four quaternary basins. Restoration goals for the basin were related to a proposed new water supply dam on the Berg River and associated need to maintain base flows during the dry season. Wetland restoration has the potential to contribute to base flows and sites were prioritized based on their capacity to do so. Wetlands that were not reliant on floodwater from the mainstream of the river (i.e. where water came from elsewhere in the catchment) but would result in increased water retention and hence potentially improve base flows were prioritized. The assessment identified wetlands that met these criteria. These wetlands were then ranked, based on a further set of criteria, including local factors, such as the level of support from local farmers. Ultimately, eight wetlands were identified as suitable for restoration and were ranked (1–8) from highest to lowest in terms of priority for restoration.

Figure 9.4. Prioritisation of wetlands at different spatial scales



Source: Based on Sieben et al., 2011

TEMPORAL SCALE

Timing issues can also be important when prioritizing restoration projects. The most relevant consideration is usually the funding source: funds will inevitably be time-constrained, with requirements that programme or project funds be spent by a fixed date. This then makes considerations around logistics, approvals, and implementation timeframes important issues when prioritizing projects, to ensure that the selected projects can be completed within the funding window.

The timing of funds can also potentially limit the types of projects that are feasible: for example, where funds are spread out over a number of years and only limited funds are available in any given year, this can exclude projects that involve a large one-off cost (see Box 37).

The time involved to implement a project, as well as the time for the benefits of a project to become apparent, can also have political implications, especially where the nature of a particular approach means that its implementation or outcomes will only occur beyond the current electoral cycle.

9.3. Approaches to prioritization

At a high level, river restoration measures and projects should be prioritized based on three elements:

1. the principles of catchment processes (in recognition of the importance of restoring natural processes)
2. protecting existing high-quality habitats and/or critical ecosystem services, and
3. current knowledge of the effectiveness of specific techniques (Roni *et al.*, 2002).

While there are various ways to categorize the approaches to prioritization (Beechie *et al.*, 2008; Roni and Beechie, 2013), the broadly fall into two groups (Beechie *et al.*, 2008). The first group use simple 'logical' tools to prioritize projects. As a result these approaches require relatively little data about how the river basin functions and how different drivers and pressures have impacted on the health of the river. Rather they are based on simple principles or the basic premise that certain restoration measures are expected to be most effective. The second group of approaches adopt a more 'analytical' approach, for example by prioritizing based on an analysis of habitat loss or change in catchment processes and the significance for one or more target species or ecosystem services. These approaches require a greater understanding of river ecosystem function.

We describe six different approaches to prioritizing restoration measures and projects (adapted from Beechie *et al.*, 2008 and Roni & Beechie, 2013). The first two (project type and refugia) are considered 'logic' based approaches. The next three (individual species and habitat needs; cost effectiveness and cost–benefit; and optimization and conservation planning tools) are analytical approaches. Multi-decision criteria analysis (the last of the six approaches) can incorporate both logic and analytical elements.

1. **Project type:** using this approach, projects are prioritized by giving preference to projects that adopt a particular restoration measure, or based on a hierarchy of measures. For example, projects that protect high-conservation value habitat might be given the highest priority, followed by projects that remove instream barriers to allow access to intact habitat, followed by projects that restore catchment

processes, such as environmental flows or sediment transport (Roni *et al.*, 2002). The hierarchy of measures is developed based on the overall restoration goal and objectives, and an understanding of which restoration measures are most likely to be effective. Such approaches are simple to apply, but do not necessarily respond to basin or location specific issues and may not help identify optimal locations for action.

2. **Refugia:** this approach prioritizes (firstly) projects that protect intact freshwater habitat that are supporting existing, high-priority biota and (secondly) projects that aim to restore habitat in close proximity to the intact habitat, on the basis that there will be an existing population that is capable of colonizing the restored habitat.
3. **Individual species and habitat needs:** this category focuses on priority biota and their habitat requirements. This can involve simply ranking projects based on the predicted increase in number of priority biota (e.g. a particular fish species) or the length or area of habitat that will be restored. More sophisticated approaches can involve focusing on those habitats that are the limiting factor to production of the priority species, and using life cycle models to prioritize that habitat for restoration. These types of approaches can be straightforward for some restoration measures: for example, where projects involve directly reconstructing instream habitat or reconfiguring of the channel, the restored area is easily determined. However, other measures (catchment restoration, introduction of environmental flows) are not as readily converted into scores related to population number or habitat extent. More sophisticate approaches using life-cycle assessments can provide more robust and defensible recommendations, but in turn rely on greater understanding of the priority species.
4. **Cost effectiveness and cost–benefit:** increasingly, restoration programmes and projects are being required to demonstrate that they represent value for money (see for example QAO, 2015). Prioritization of projects may therefore be undertaken based on an assessment of the cost effectiveness of different restoration interventions. This typically requires that restoration outcomes be quantified for each project, as against the restoration objectives, allowing an assessment of cost per 'restored unit': for example, the cost per increase in number fish or cost per kilometre of restored habitat. Alternatively, the assessment may involve consideration of the net economic benefit based on a cost–benefit analysis. Cost–benefit analysis is founded on quantitative assessment of economic costs and benefits, and has an extensive technical literature to accompany it. The drawback of cost–benefit analysis is that, as it is based on quantitative economic valuations, it can struggle to fully capture the environmental, social and political considerations relevant to different restoration interventions.
5. **Optimization and conservation planning tools:** a number of software tools are now available to support conservation and restoration planning (e.g. Westphal & Possingham, 2003; Ball *et al.*, 2009; Lethbridge *et al.*, 2010). The majority of these tools have been developed with a focus on terrestrial ecosystems, but a number have now applied to freshwater systems (Fullerton *et al.*, 2010). Tools like Marxan, arguably the most widely used conservation planning software, can balance cost and benefit and optimize conservation or restoration outcomes, based on defined objectives (e.g. habitat area, connectivity, ecosystem services, see section 9.4). Models can also be used to identify optimal approaches to implementing a specific restoration measure, such as water (re)allocation scenarios to support restoration via changes to the flow regime (e.g. Yang, 2011) or removal of barriers to improve connectivity (O'Hanley *et al.*, 2013). Such tools are more suitable for ranking projects based on a specific restoration measure, or for ranking basins or sub-basins than they are for individual restoration projects (Roni & Beechie, 2013). The use of complex models has the drawback of reducing transparency, and where the prioritisation process occurs within a 'black box' this can be a barrier to stakeholder understanding and, ultimately, support.

These five categories are neither exhaustive nor exclusive, but rather represent a continuum of approaches. As is evident from the descriptions above, a number of the approaches are useful for prioritizing certain aspects of the restoration process but not others. Prioritization by project type can be useful for identifying the preferred restoration measures, but may not help identify where projects should be implemented; the refugia approach can help identify priority locations for restoration (i.e. close to intact habitat and viable populations of key species) but may not help identify what measures are most appropriate in those locations. As or more importantly, many of these approaches are focused on restoring biodiversity, and many do not assess the implications of different restoration alternatives for the provision of ecosystem services.

6. **Multi-criteria analysis:** As the name suggests, this method allows for the assessment and prioritization process to consider a number of criteria. This can involve the use of one or more of the approaches described above to assess some of the criteria. MCDA has a long history of application and there are many guides to its application (Corsair *et al.*, 2009). At a high level, this approach is based on (Pegram *et al.*, 2013):
   - identifying the different criteria to be assessed (e.g. increase in fish number or habitat; cost-effectiveness or cost benefit outcome; project type)
   - weighting the criteria to identify a weighted score that can be compared for each option (e.g. for each project being considered)

- inferring relative priorities of the criteria to enable the reduction of options that are inferior to others
- identifying thresholds for the criteria to enable the exclusion of options that do not achieve the minimum requirements, or providing a user-friendly protocol to assist stakeholders with explicitly defined (or implicitly assumed) interests or priorities around these criteria to move towards consensus.

CASE STUDY: PRIORITIZING RESTORATION SITES IN THE COLUMBIA RIVER, UNITED STATES

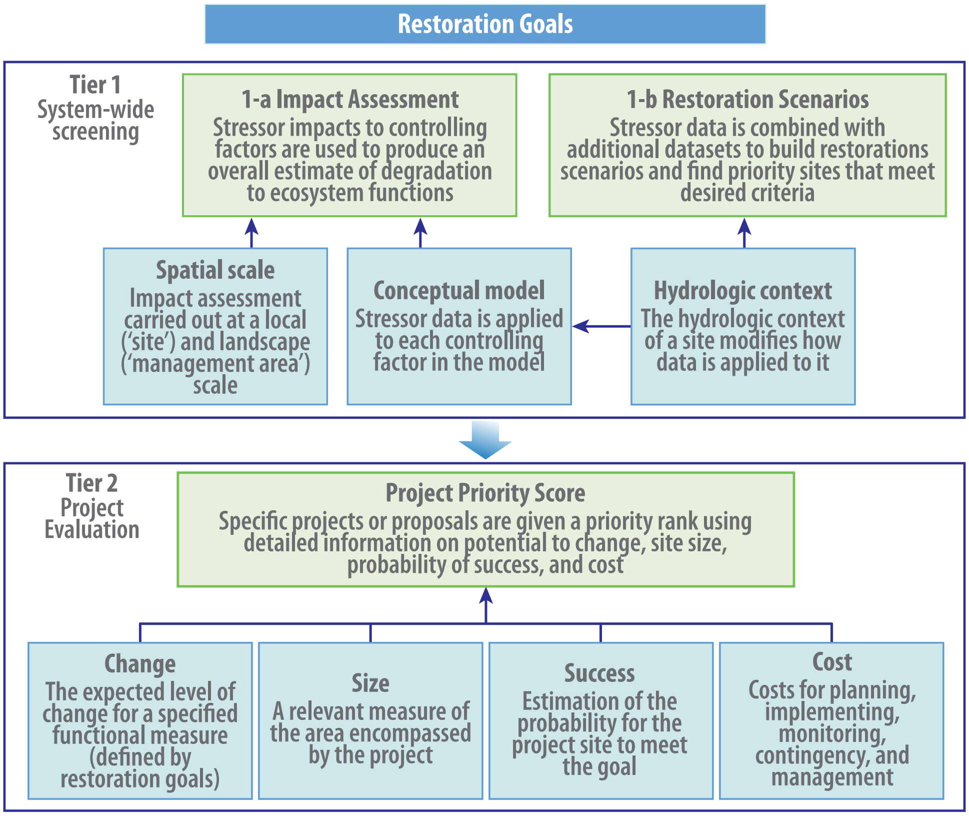
Restoration activities in the Columbia River, US are guided by a series of 58 sub-basin plans, which identify priority restoration and protection strategies for habitat and fish and wildlife populations. A framework was developed for and used by the Lower Columbia River Estuary Partnership to help prioritize potential habitat restoration projects.

The framework uses a conceptual model to assess the impact of different alternatives on ecosystem function. The conceptual model assumes that physical controlling factors (e.g., light, temperature, hydrology) drive the formation and maintenance of habitats and their ecosystem functions, and that stressors act on the controlling factors. The framework assesses restoration interventions at different spatial scales:

- Management-area scale, which represent groupings of sites with similar landscape qualities. Groupings were primarily based on hydrologic boundaries (large tributaries).
- Site scale, which were delineated based on topography, hydrologic factors and anthropogenic factors. There were an average of 35 sites per management area.

The framework is two-tiered (see Figure 9.5). Tier I involves system-wide screening and uses a GIS-based approach to evaluate the impacts of human 'stressors' (e.g. agriculture, barriers to flow). Priority scores are derived (for management areas and sites) and spatially linked, allowing all of the data and tools to be analysed and queried in a geospatial context. This component of the framework also allows for hydrologic connectivity and existing function to be assessed as part of the prioritization process. Tier II is used to evaluate specific restoration project proposals, based on cost, expected functional change, site size, and predicted probability of success. The end result is a framework that allows for areas and projects to be prioritized and evaluated based on ecological criteria (Thom *et al.*, 2011).

Figure 9.5. Framework for prioritizing projects in the lower Columbia River



Source: Adapted from Thom et al., 2011

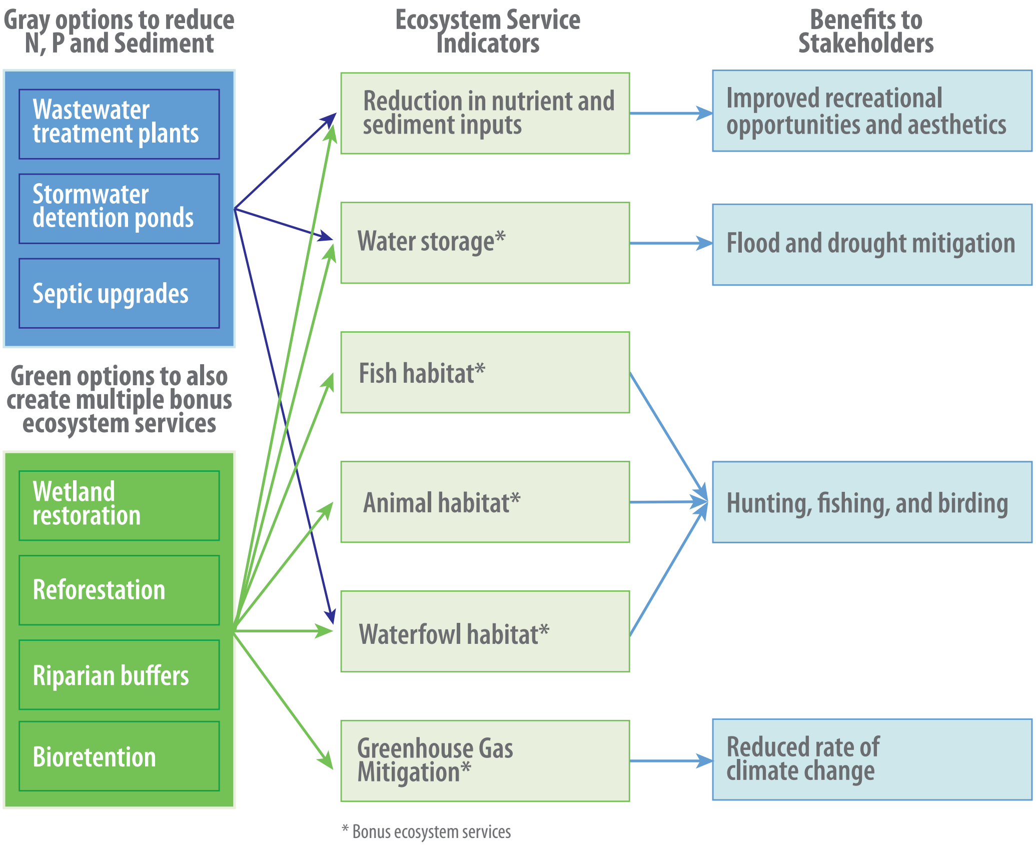
CASE STUDY: PRIORITIZING FOR MULTIPLE OBJECTIVES IN THE CHESAPEAKE BAY, UNITED STATES

In the Chesapeake Bay, located in the north-eastern United States, the US Environmental Protection Agency (EPA) has set 'total maximum daily loads' for pollutants. The loads include nutrient and sediment load allocations for the major tributaries of the bay. These are to be achieved by 2025 and will require significant river restoration measures.

To support this restoration work, the EPA developed an analytic framework to assess (i) the mix of pollution-control projects that provides the least costly way to achieve water quality goals and (ii) how consideration of bonus ecosystem services – i.e. ancillary societal benefits above and beyond the pollution control targets – can affect the desired mix of projects. The seven steps undertaken were as follows.

- **Step 1 –** Define the aggregate nutrient and sediment load reduction targets of interest.
- **Step 2 –** Create a spatial inventory of the main point and nonpoint sources in the watershed and identify control projects (grey or green infrastructure) for reducing nutrient and sediment loads from these sources.
- **Step 3 –** Develop estimates of the annual costs and effectiveness of each pollution-control project.
- **Step 4 –** Develop estimates of the bonus ecosystem services associated with each of the pollution-control projects.
- **Step 5 –** Apply an optimization model to identify the combination of grey and green treatment projects that achieves the specified nutrient and sediment load-reduction targets in each basin at the lowest total cost.
- **Step 6 –** Estimate the net costs associated with each project for all projects in the inventory, i.e. costs of the project minus its monetized bonus ecosystem service benefits provided by the project.
- **Step 7 –** Rerun the optimisation model to identify the combination of grey and green treatment projects that achieves the specified nutrient and sediment load-reduction targets in each basin at the lowers total net cost.

Figure 9.6. Schematic showing grey and green options to reduce pollution, and links to ecosystem service indicators and the benefits to stakeholders from those services



Source: Adapted from US EPA, 2012

Among the findings, the assessment showed:

- Green infrastructure options would contribute substantial offsetting ecosystem values to the cost of achieving the TDML targets. This compares with grey infrastructure options, which in fact contribute ecosystem service dis-benefits.
- Including the monetized value of ecosystem services would result in restoration of a larger number of non point-source controls, primarily natural re-vegetation of farming land.
- The cost of reducing pollution loads using agricultural or stormwater best management practices BMPs was significantly impacted by uncertainty around their effectiveness. Better information on the performance risks would change the outcomes of the analysis and hence prioritisation recommendations.
- The cost of achieving the overriding water quality objectives would be less if basin-specific load targets were replaced with bay-wide targets, which would allow greater flexibility in responses, while changing the spatial distribution of load reductions in the basin. This last point highlights again the relevance of the spatial framework used for setting objectives and prioritising projects.

Source: US EPA, 2012

CASE STUDY: OPTIMISING RESTORATION IN SOUTHEAST QUEENSLAND CATCHMENTS, AUSTRALIA

In southeast Queensland (SEQ), restoration targets are set out in the SEQ Healthy Waterways Strategy. The strategy identifies a series of 'resource condition targets' (primarily related to water quality and other river health indicators) and five 'management action outcomes' that are required to achieve the resource condition targets (see Box 12). These outcomes include achieving a 50% reduction of diffuse loads in priority catchments through riparian restoration, instream rehabilitation, and best management practices.

The need for evidence on the costs and benefits of different interventions has driven a major scientific effort to identify the sources of key pollutants (e.g. sediments, nutrients), the costs associated with pollution (e.g. increased drinking water treatment costs), and options for reducing pollutant loads. Sediment sourcing studies have confirmed diffuse rural pollutant loads are the main issue for waterway health in SEQ (Caitcheon *et al.*, 2001). This study also found that less than 30% of the catchment produces 70% of the total pollutant load (Figure 9.7).

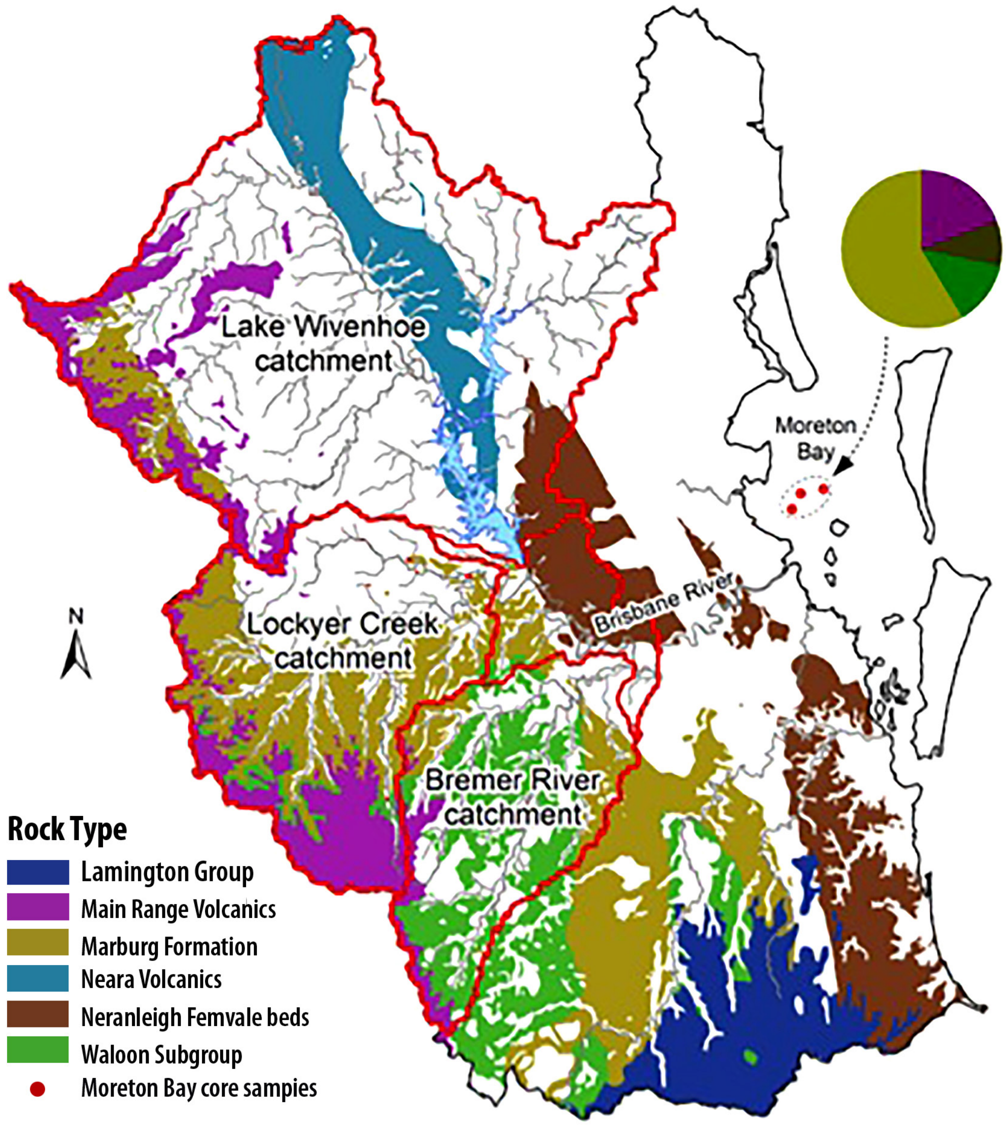
This data suggests that a strategic investment of funds for management actions within the areas of high export would result in a significant reduction in pollutant loads. Other studies have shown the dominant sources of sediment in the priority areas are from river channel bank and gully erosion processes and as such the sources of sediments and nutrients and the key processes of their transport through the catchment are now well understood. Published research suggests the re-instatement of riparian vegetation to degraded areas is an appropriate management action to reduce the rate of erosion and movement of these pollutant loads. Recent studies have also used predictive modelling, river health monitoring data trends and analysis of rainfall event-based data collected over the past eight years to show the effect of vegetation cover on sediment/nutrient movement in the catchment.

Studies showed that sediment yield per unit area from a catchment containing no remnant vegetation is predicted to be between 50 and 200 times that of a fully vegetated channel network; total phosphorus between 25 and 60 times and total nitrogen between 1.6 and 4.1 times (Olley *et al.*, 2014) and that that at least 80% riparian forest cover is required in hydrologically active near-stream areas to obtain excellent aquatic ecosystem health (Sheldon *et al.*, 2012).

Building on this knowledge, a comprehensive understanding of cost and benefits for river restoration on a catchment scale has been developed to spatially optimize investment for a targeted reduction in sediment loads to the waterways and Moreton Bay (Hermoso *et al.*, 2012). The assessment was a response to concerns that earlier restoration planning lacked consideration of driving factors at a scale adequate to capture the ecological processes involved. This concern, together with an insufficient incorporation of socio-economic aspects, led to poor ecological outcomes from past restoration activities. In light of this, the assessment adopted a systematic planning approach, which assessed a range of alternatives through predictive modelling. The modelling used cost-effectiveness analysis and incorporated an understanding of local ecosystem processes. In incorporating socio-economic constraints, the model captured not only the cost of restoration but also the implications of restoration for local economies (i.e. in terms of opportunity cost).

Rather than simply presenting outcomes for a series of scenarios, the model employed an optimization function, which allowed it to assess a much larger number of combinations of different restoration measures and then provide a (more limited) number of optimised options to stakeholders for their consideration. The outputs of the optimization model, together with feedback from stakeholders, were then used to select restoration priorities (see Figure 9.8).

Figure 9.7. Map of South East Queensland catchments showing the source of sediments entering Moreton Bay

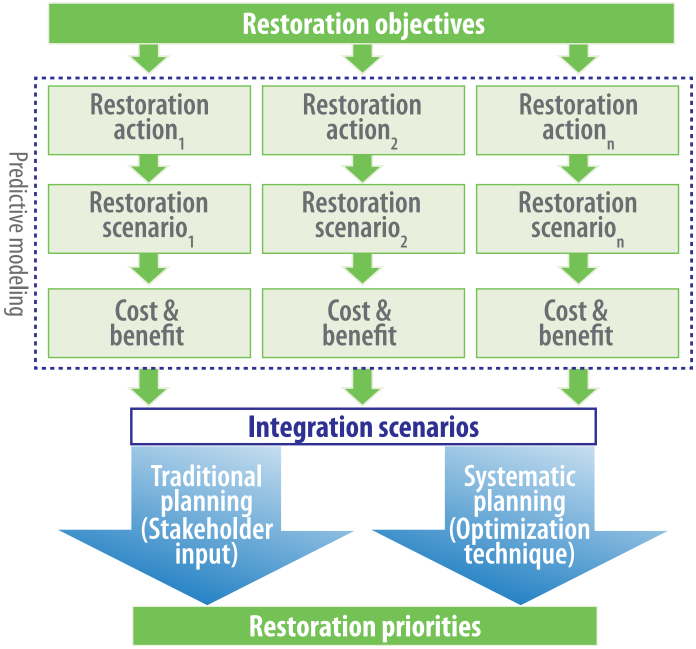


Source: Caitcheon et al., 2001

9.4. Prioritizing for ecosystem services

As discussed in section 2.3, while many early restoration efforts were focused on biodiversity goals, river restoration increasingly aims to protect and enhance the provision of freshwater ecosystem services. While biodiversity can be a proxy for the provision of ecosystem services, (Benayas *et al.*, 2009), there is a need for prioritization approaches that specifically identify and rank interventions based on their capacity to provide ecosystem services. For example, in the case of restoring wetlands, while one wetland complex or site might be most appropriate for restoration to maximize biodiversity outcomes, other locations are likely to be preferred if the objectives relate to flood retention, livelihoods, cultural benefits, or improving water quality (see Table 9.3).

Figure 9.8. Establishing priorities for restoration in SEQ



Source: Adapted from Hermoso et al. 2012

Table 9.3. Considerations in prioritising wetlands, based on different ecosystem services

Targeted ecosystem services for restoration	Possible priority wetland
Habitat conservation	Wetlands with potential habitat for target species; wetlands within or at close proximity to nature reserves
Reducing soil loss	Wetlands in subcatchments that have steep slopes, erodible soil or a large proportion of hardened surfaces
Water quality	Wetland types which can improve water quality and are downstream of major sources of pollution
Maintenance of base flows/ Water retention	Wetlands downstream of large dams and preferably those that store large quantities of water (mostly permanent wetlands)
Flood retention	Wetlands upstream of major population centres and properties that are vulnerable to flooding
Livelihoods	Wetlands close to poverty nodes where communities harvest wetland species or are dependent on grazing or other goods and services
Cultural/Scenery	Wetlands close to national roads or on major tourist routes, or those with high cultural values

Source: Sieben et al., 2011

A number of the prioritization approaches (section 9.3) can be applied using criteria that relate to ecosystem services. Two examples are provided below.

PRIORITIZING RESTORATION IN A SEMI-ARID MEDITERRANEAN RIVER BASIN

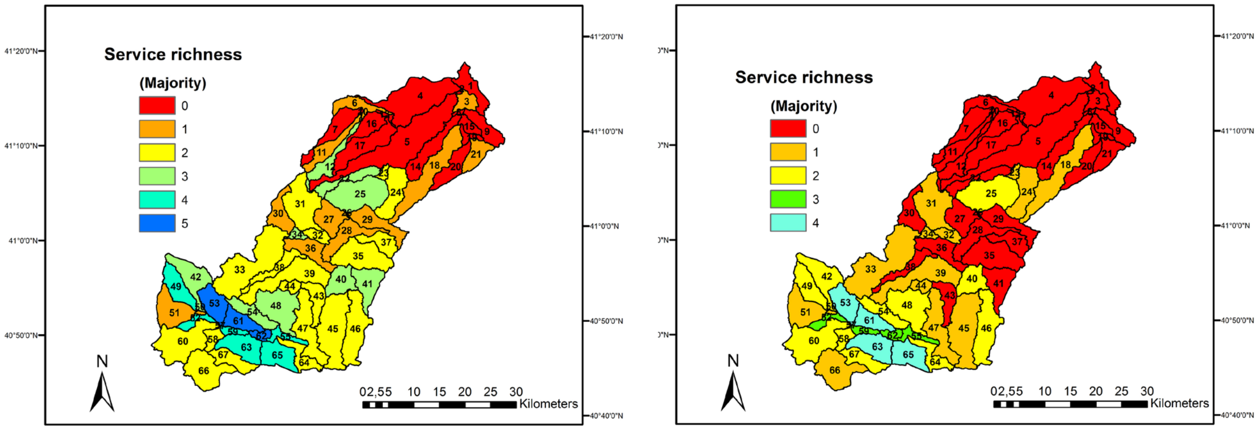
The Martin River sub-basin is located in the Ebro River Basin in north-eastern Spain. The region is primarily used for rain-fed agriculture and cattle grazing. It was previously the site of significant coal mining activity. The landscape has been significantly degraded as a result of natural and human factors and the basin lies in a region that is highly susceptible to desertification.

An assessment was undertaken to identify and map ecosystem services and the relationship between ecological functions and services, as a basis for supporting and prioritising restoration actions (Trabucchi *et al.*, 2014).

Ecosystem services maps were developed for five services: erosion control, maintenance of soil fertility, surface water supply, water regulation, and carbon storage in woody vegetation. These were considered vital services that are threatened by soil erosion. The study also considered recreation/ecotourism services.

The maps for each service classified the basin spatially into five classes (very low to very high) based on the importance of different regions for each service. For example, in mapping the importance of different parts of the basin for surface water supply, total runoff data was used as a surrogate for surface water supply.

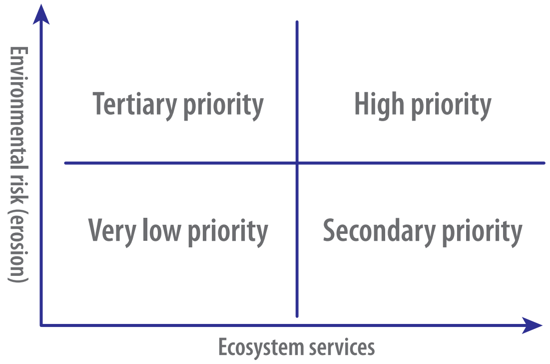
Figure 9.9. Number of overlapping ecosystem services per sub-basin (left) and number of overlapping hotspot services per sub-basin



Source: Trabucchi et al., 2014

Hotspot maps were developed to identify high-service areas, both for individual ecosystem services and for where services were combined (Figure 9.9). A total of 67 sub-basins were identified. In addition, the study looked at the vulnerability of different sub-basins to environmental degradation, based on the mean erosion value. This ultimately allowed for sub-basins to be prioritized based on a combination of ecosystem service delivery and environmental risk of erosion (see Figure 9.10).

Figure 9.10. Combined ecosystem services and environmental risk criteria as basis for establishing priority areas for restoration



Source: Trabucchi et al., 2014

PRIORITIZING MANGROVE RESTORATION BASED ON ECOSYSTEM SERVICES

Mangrove ecosystems provide a range of ecosystem services, including improving the water quality of creeks and rivers adjacent to them, sequestering carbon, and stabilizing coastal zones by protecting them from wind, waves, and flooding.

Marxan, a conservation planning model, was used to identify cost-effective areas for mangrove restoration on the Yucatan Peninsula, Mexico, based on a combination of biodiversity and ecosystem services targets. Current stressors to the mangroves in the region include water pollution, hydrological modification, and erosion.

Initial assessments were made to identify indicators of potential for improvements in ecosystem services. For example, the potential for water depuration is greatest where water quality is poor and tree biomass is high. However, high nutrient levels have been shown reduce success, due to low production and high mortality of resident trees. As a result, priority for restoration was given to locations where tree biomass was high and nutrients were intermediate.

The model was used to identify priority areas for restoration for different ecosystem services: water quality; carbon sequestration; and coastal protection. The model was also able to identify the improvement in ecosystem services for (say) coastal protection, as a result of restoration that was primarily focused on improving water quality, thus allowing consideration of the multiple benefits that a particular project might realise (Adame *et al.*, 2014)

CHAPTER 10
URBAN WATER MANAGEMENT AND RESTORATION OF URBAN RIVERS

OVERVIEW AND KEY MESSAGES

This chapter discusses some of the key considerations related to urban rivers, particularly how urban environments impact on rivers, what urbanization means for setting restoration goals, and which measures are most likely to be appropriate for improving the health of urban rivers.

- Urbanization within a river basin can have significant negative impacts on the relevant river ecosystem. Notably, where a significant percentage of the basin surface is impervious to water (e.g. as a result of roads and buildings) this is likely to be detrimental to river health.
- Urban rivers offer significant challenges as a result of the large population within the catchment, greater pressures on the resource, the high cost of land, and uncertainty as a result of land use change.
- Urban rivers also provide opportunities due to their proximity to people, and the potential for political interest and funding that this brings with it.
- Best practice urban water management offers the potential to reduce the impacts of urban regions on neighbouring waterways.

10.1. Introduction

Urban rivers are an important part of the physical and cultural landscape. They are central to the identity of many towns and cities, and riparian zones can be desirable areas for urban development and gentrification (Francis, 2012; Chang and Huang, 2011). Locally generated ecosystem services have a substantial impact on quality of life in urban areas. Urban freshwater ecosystems, including wetlands, rivers, and lakes, can provide many local and direct ecosystem services. These include air filtering, microclimate regulation, noise reduction, rainwater drainage, sewage treatment, and recreation and cultural values (Bolund and Hunhammar, 1999). These are of course in addition to services such as water supply, flood mitigation, transport, and hydropower production, which all rivers (potentially) can supply. Urban rivers, streams, and lakes also constitute the aquatic ecosystems that the majority of urban populations most commonly see and reflect upon in their daily lives (Gabr, 2004).

Urban developments are a significant stressor on river ecosystems (Sprague, 2006) and significant relationships have been demonstrated between the extent of catchment urbanisation and river health (see for example Klein, 1979; Gergel *et al.*, 2002).

With more than 50% of the world's population now living in cities and towns, and with a further 2.5 billion people expected to join the world's urban centres by 2050 (UN, 2014), there will be an increasing proportion of rivers and freshwater ecosystems impacted by urbanisation. At the same time, a larger fraction of the human population than ever before will rely on river ecosystems that have been degraded by urban impacts (see for example Violin *et al.*, 2011). In many rivers, urbanisation has already resulted in changes in hydrology, increased flood risk, and the loss of biodiversity. It can also result in poor water quality and mean that rivers are no longer suitable for recreational purposes. Indeed, many urban rivers have now degraded to the extent that they have ceased to provide the very services that originally resulted in settlement along the river's banks (Groffman *et al.*, 2003; Grimm *et al.*, 2008).

River restoration has become a common response to such issues, with a greater share of resources being allocated to restoring urban rivers relative to other rivers (Bernhardt *et al.*, 2005). This may reflect the greater level of degradation experienced by urban rivers, the higher cost associated with restoring them, or political imperatives (Bernhardt and Palmer, 2007).

The principles, approaches and measures for river restoration discussed elsewhere in this book apply equally to the urban context. However, the additional challenges and opportunities urban rivers present can require refinements to the process of planning and implementing river restoration.

Box 38: Urbanized catchments

Total impervious area (TIA), the proportion of a basin's area covered by surfaces impermeable to water, such as roofs and roads, has commonly been used to measure urban density, based on the observed relationship between TIA and river health. Studies suggest that degradation is inevitable above a certain TIA, such as 10% (Center for Watershed Protection, 2003; Walsh *et al.*, 2004a). As a consequence, some commentators have defined an urban river as one where more than 10% of the catchment has impervious coverings (e.g. Findlay and Taylor, 2006).

An alternative to TIA that has been shown to be a better predictor of river condition is effective impervious area (EIA). EIA refers to impervious surfaces that are directly connected to rivers by pipes or sealed drains (Booth and Jackson, 1997) and a number of studies have shown that EIA has a stronger correlation with river health than TIA (e.g. Taylor *et al.*, 2004; Hatt *et al.*, 2004). While other indicators have been proposed, such as the percentage of urban landuse in the basin (Morley and Karr, 2002), these indicators have not been shown to provide a better indication of river health than TIA and EIA.

10.2. Evolution of urban water management

Despite their obvious and noted importance, for much of human history little regard has been paid to the health of urban rivers. The traditional European approach to urban river management was to '...bury them, turn them into canals, line them with concrete and build upon the (now protected) floodplains' (Eden and Tunstall, 2006, pg. 662). Indeed, most urban development has historically involved transforming rivers into drains or sewers. Through the 20th century, urban river management expanded to include safeguarding people from floods and disease (Walsh *et al.*, 2005). While these remain important goals, modern approaches to urban design and river management show potential for balancing these goals with improved amenity and the ecological health of urban rivers (Lloyd *et al.*, 2002).

This type of transition in management approach is described in a framework developed by Brown et. al. (2009a), which provides a typology of the attributes of past and present hydro-social contracts (Lundqvist *et al.*, 2001), and which reflects an evolutionary process as cities mature and as water becomes more limited. A 'hydro-social contract' describes 'the pervading values and often implicit agreements between communities, governments and business on how water should be managed' (Brown *et al.*, 2009a).

Based on a review of Australian cities, the framework describes a typology of six city states, namely:

1. Water Supply City – where water management is focused on providing safe and secure water supplies, usually through a centralised water supply system, for a growing urban population.
2. Sewered City – in these cities management involves the development of reticulated sewerage systems to dispose of waste effluent. Examples of sewered cities first emerged in Australia in the mid to late 1880s.
3. Drained City – in these cities water management expands to include a focus on the rapid and efficient conveyance of stormwater out of cities. Drained cities emerged in Australia after the Second World War.
4. Waterways City – where water management includes measures to address point source pollution, and urban planning recognizes the amenity value of waterways. Such approaches commenced with the rise of environmentalism in the 1960s and 1970s.
5. Water cycle City – where urban management is based on an integrated or total water cycle approach, which involves water conservation and diverse water supplies (matched to the most appropriate uses) at a range of scales that are also sensitive to the energy and nutrient cycles and ultimately contingent on protecting waterway health.

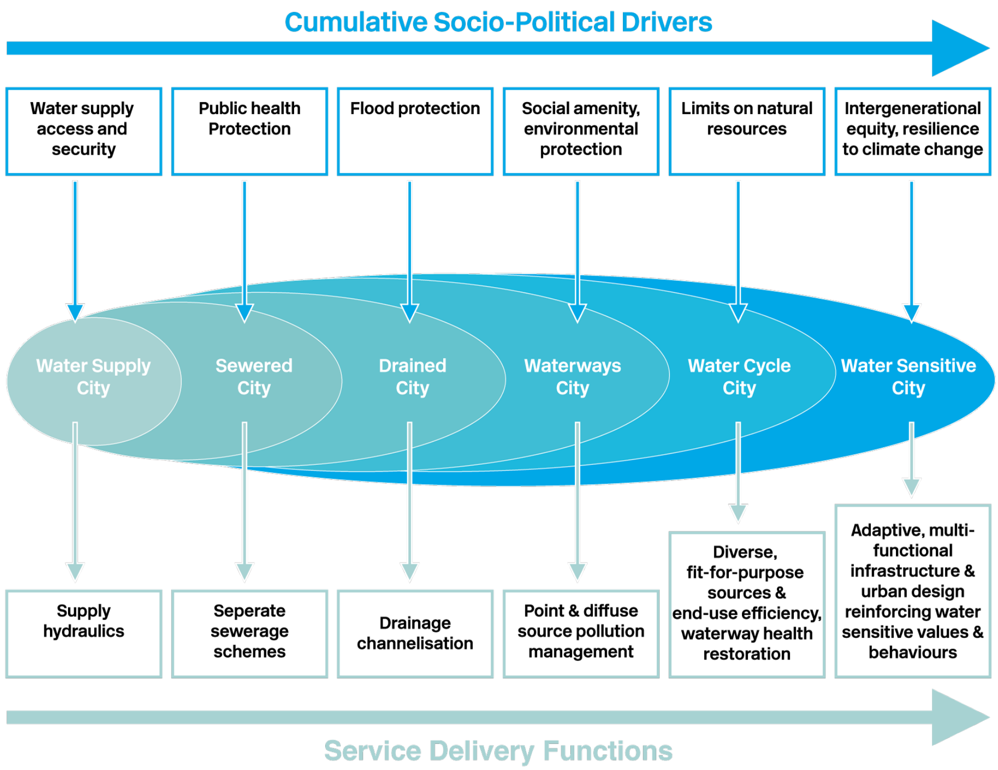
6. Water Sensitive City – an idealistic state, where environmental repair and protection, supply security, flood control, public health, amenity, liveability and economic sustainability and all considered in urban and water management. Communities would also be driven to protect intergenerational equity with regards to natural resources and ecological integrity, and to ensure resilience to climate change (Brown *et al.*, 2009a).

The framework recognizes the different contexts that a city transitions through as it moves towards a sustainable urban water condition. Each city state is linked to a range of socio-political drivers, and with that different functions that are required of the city and its waterways (see Figure 10.1).

The framework is designed to provide a benchmark for setting targets and measuring progress in improving urban water management. Despite significant efforts, no Australian city is regarded as fully meeting the requirements of a water cycle city, and there is currently no example anywhere in the world of a water sensitive city. While sustainable urban water management and water sensitive urban design offer alternative approaches, urban water strategists still lack a clear vision or goal for the attributes of a sustainable water city (Brown *et al.*, 2009a).

While related, urban water management and urban river restoration are not the same the same thing. Poor practices in urban water management have of course been a significant contributor to the degradation of urban rivers. At the same time, implementing best practice approaches to urban water management, including retrofitting existing urban areas, is a critical tool for reducing the drivers of poor health in urban rivers.

Figure 10.1. Typology of different city states in transition towards sustainable urban water management



Source: Brown et al., 2009a.

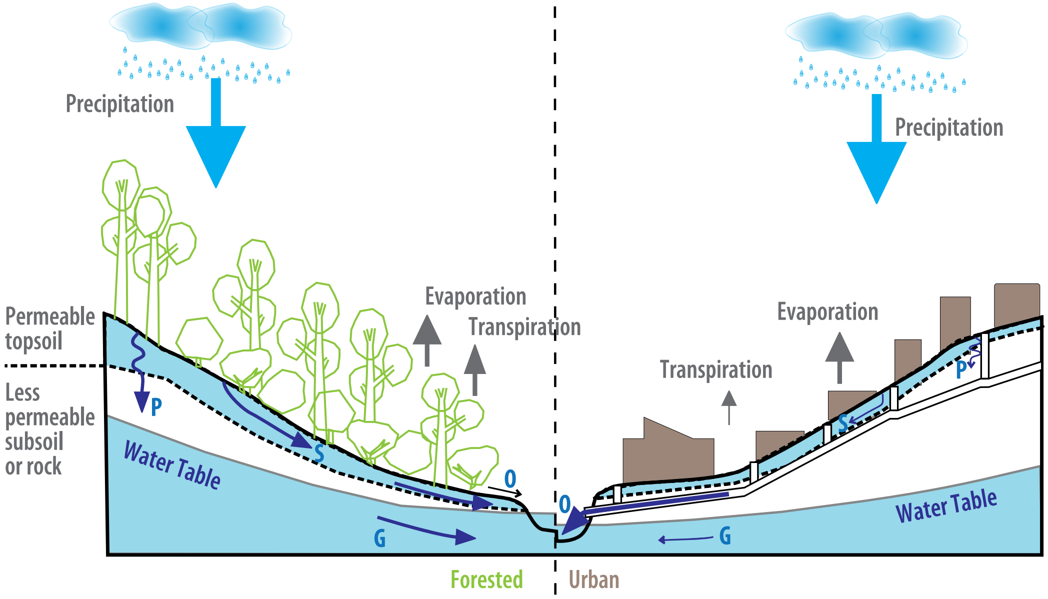
10.3. Urbanization and river health

Urbanization impacts, directly or indirectly, all elements of a river ecosystem. Understanding the nature and consequence of these impacts is of course vital to effective restoration of urban rivers. The impacts of urbanization on the ecosystem structure and function of rivers is well documented (Paul & Meyer, 2001; Walsh *et al.*, 2005). Some of the most significant impacts are described below.

CATCHMENT PROCESSES

Urbanization fundamentally changes a number of key catchment processes, and hence critical inputs into a river ecosystem. Foremost among these changes are large areas of impervious surfaces (such as roads and rooftops) within the catchment. Stormwater runoff from impervious surfaces is now widely recognized as the paramount stressor to urban rivers, and the primary driver behind the correlations between river health and catchment imperviousness (Walsh *et al.*, 2005). Impervious surfaces also reduce sediment mobilization and can result in changes in sediment sources in urban catchments, with mining, road-deposited sediments, industrial point sources and wastewater the major sources of sediment. As a consequence contaminants occur in high concentration in urban river sediments (Taylor and Owens, 2009). Finally, catchment imperviousness can lead to diminished groundwater recharge, which in turn impacts base flows (Lerner 1990), and can result in a reduction in hyporheic flow (Grimm *et al.*, 2005).

Figure 10.2. The water cycle in a forested catchment and an urbanised catchment



The size of the arrows indicates the qualitative differences in the relative size of annual water volumes through each pathway in a typical south eastern Australian coastal catchment.
Source: Walsh et al., 2004a

FLOW REGIME

The impact of the urban catchment on hydrology will often be the primary determinant of how the system as a whole responds to urbanisation (Findlay and Taylor, 2006), with changes to hydrology affecting a river's water quality and geomorphology, and habitat. The impervious nature of urban catchments increases the volume and reduces the time for runoff to reach the river channel. This results in a 'flashier' flow regime (Gurnell *et al.*, 2007) with wide and rapid variations in discharge (Olivera and DeFee, 2007). This flow regime can result, for example, in a 1 in 5 year event occurring every 2 years (Wong *et al.*, 2000), which can increase the risk of flooding. Urbanization can also result in increased risk of drought, reduced groundwater recharge and lower base flows (Lerner 1990; Paul and Meyer, 2001).

WATER QUALITY

Urban rivers are subject to increased likelihood of pollutant loadings (Clifford, 2007). Levels of point source pollution are typically greater in urban areas. Even where, for example, wastewater treatment facilities exist, these can be inadequate during major rainfall events, resulting in overflows entering river system, or can be unable to treat or remove many non-traditional pollutants, such as hormones or antibiotics (Behera *et al.*, 2011). As a result, water quality can deteriorate, with common changes including an increase in oxygen demand, conductivity, suspended solids, ammonium, hydrocarbons, nutrients, and metals (Paul and Meyer, 2001). Of these, pollutants, studies suggest that the most important urban pollutants are oil, PAHs, toxic metals, nutrients, and faecal indicator organisms, as well as suspended matter (D'Arcy *et al.*, 2000; Mitchell, 2005). In addition to point source pollution, streets and parking lots can also contribute large quantities of heavy metals, largely the result of automobiles (Bannerman *et al.*, 1993), and cities often contribute significant physical litter). Water temperature can also be increased as a result of runoff absorbing heat from rooftops and road surfaces, combined with loss of vegetation and high width/depth ratios. While inconclusive, there is also evidence that urbanisation can result in reduced nutrient uptake, for example as a result of reduced fine benthic organic matter, reduced channel complexity, and (possibly) reduced primary productivity (Walsh *et al.*, 2005).

HABITAT

Urbanization has a number of consequences for fluvial geomorphology and instream habitat. Urbanization can involve direct changes to the river channel, for example as a result of dredging, or the construction of infrastructure, like roads and bridges, or flood protection structures. Urban development will often lead to the loss of the riparian zone, with urban river corridors generally narrow, if they exist at all.

Changes to the hydrology and the sediment regime can result in channel enlargement (Gurnell *et al.*, 2007), or channel narrowing as land is reclaimed for development. Reduced sediment entering the system as a result of impervious surfaces in the catchment can result in rivers being starved of sediment. This can lead to erosion of the bed and incision of the channel (Niezgoda and Johnson, 2005; Booth and Henshaw, 2001) and channel instability (McBride and Booth, 2005). The geomorphological response to urbanization is, however, variable (Chin, 2006). Evidence suggests that urban rivers undergo an adjustment phase that typically involves increased rates of erosion but ultimately leads to a new state of equilibrium (Neller, 1988).

Other impacts include:

- reduced instream vegetation, including as a result of active removal of vegetation to improve the conveyance of water
- simplification of the channel, and hence loss of habitat, through dredging, removal of woody debris (Violin *et al.*, 2011)
- reduced connectivity to the floodplain and generally more confined due to infrastructure such as culverts, bridges, and dams, all of which alter the hydraulics, and rivers being more fragmented and offering less storage and attenuation potential (Clifford, 2007).

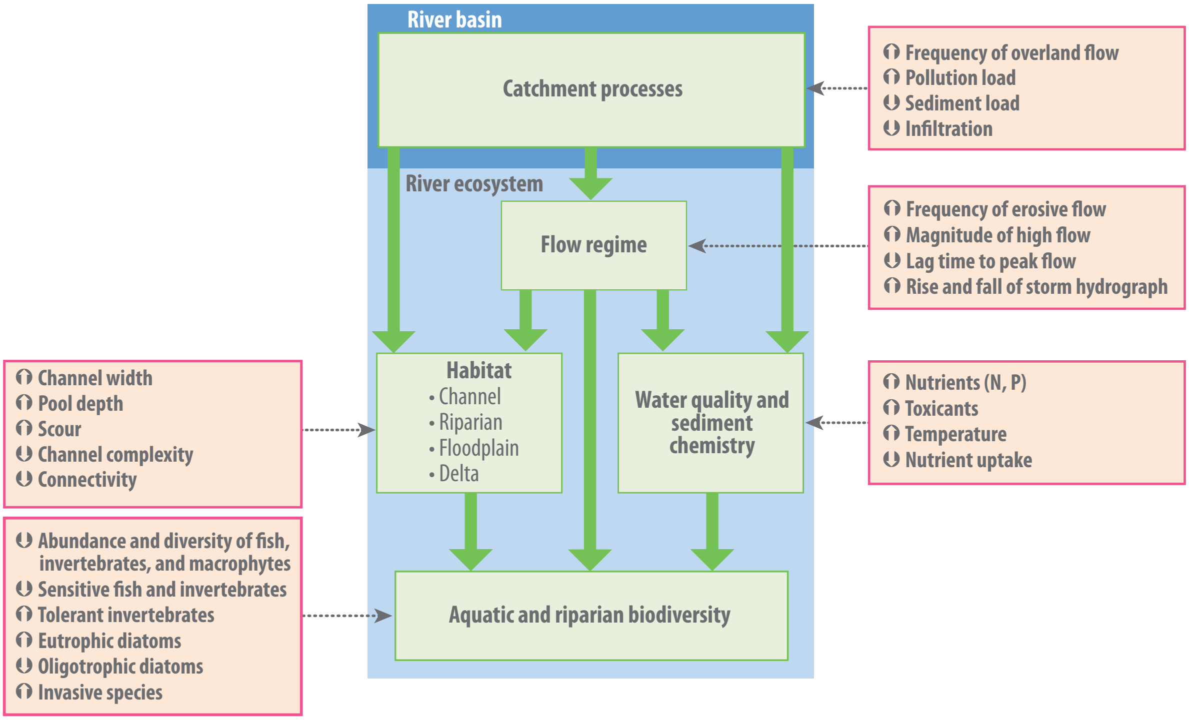
AQUATIC AND RIPARIAN BIODIVERSITY

The factors described above result in significant changes to aquatic and riparian ecosystems and their ability to adapt to extreme events (e.g. Brown *et al.*, 2009b). Urbanization can result in declines in the abundance and diversity of fish (Wang *et al.*, 2000), invertebrates (Chadwick *et al.*, 2006) and macrophytes (Suren, 2000). Urbanization can also increase the establishment and spread of invasive plant species, both terrestrial and aquatic (Cockel and Gurnell, 2012), which can lead to an increase in total abundance and diversity of species.

URBAN RIVER SYNDROME

Collectively, these changes to a river ecosystem result in what is sometimes referred to as 'urban river syndrome', the consistently observed ecological degradation of streams draining urban land (Walsh *et al.*, 2005). Figure 10.3 presents many of the changes to key elements of a river ecosystem as a result of increased urbanization in the catchment.

Figure 10.3. Impacts of urbanisation on the elements of a river system. The figure shows those factors that increase (↑) or decrease (↓) as a result of urbanisation



10.4. Special considerations in urban restoration

CHALLENGES AND OPPORTUNITIES

Urban rivers present particular challenges to river restoration. Firstly, the urban context heightens the conflicts between water resources management and river restoration. The larger number of people and range of enterprises that operate in urban catchments mean that urban rivers are, almost inevitably, heavily contested environments, and managing them requires addressing a broad range of potentially conflicting social, cultural, economic, and environmental factors.

Secondly, urban catchments are likely to be more dynamic (in socio-economic terms) than rural catchments. As such urban rivers are likely to be subject to a greater rate of change and as a result are subject to greater uncertainty regarding future pressures and states.

Thirdly, the urban context can constrain the restoration opportunities that are available, including financial, practical or political reasons. The demand in urban centres for land and water resources can increase the cost of river restoration: buying land or water rights, or changing land use practices, to improve river health is likely to be more expensive in an urban setting compared with a rural one. Practical constraints can exist as a result of existing levels of development. For example, reconnecting a river with its floodplain may be practically (or politically) impossible where urban growth has spread across the floodplain. Allowing for any perceived increase in risk of flooding of people's homes is far less likely to be acceptable than flooding of agricultural land.

Fourthly, urban river catchments (again by definition) have higher human populations. As such, they are more likely to have a higher profile with the broader public, although in some instances rivers have been so consumed by the urban environment that people can be completely unaware of their existence (see for example http://www.londonslostrivers.com/). In either case, restoration of urban rivers is likely to affect and involve a larger number of people, and therefore garner greater political attention. A larger population is likely to mean a broader range of stakeholders, demanding a more comprehensive programme of consultation and engagement.

Urban rivers offer significant challenges, but they also offer opportunities. Their proximity to people means that benefits such as improved human health and amenity values may be proportionally greater for urban rivers than rural rivers. Restoration can increase the value of riparian land, with one study showing a 17% increase in value of properties adjacent to a restored river in Perth, Australia compared with other properties (Torre and Hardcastle, 2004). These types of benefits alone can outweigh the costs of restoration measures (see Box 39). Where the benefits and beneficiaries of urban river restoration are clearly identifiable, funding opportunities can emerge. For example, in China, the central government has mandated that a percentage of funds raised by local governments by releasing riparian land to developers must be set aside for rural water projects, such as irrigation development (GIWP). While these funds are not directed to river restoration activities, the example highlights the financial windfall that a restored urban river can deliver.

Box 39: Benefits of water sensitive urban design

Water sensitive urban design (WSUD) is an approach to planning and design that aims to ensure urban development is sensitive to natural hydrological and ecological cycles by conserving water supplies, minimizing wastewater, and managing stormwater quality and flows (see section 10.5 and Box 41). A cost–benefit analysis of the adoption of WSUD determined that the benefits of achieving best practice stormwater management for typical residential, commercial and industrial developments in Queensland were likely to outweigh the costs:

- the value of reducing total nitrogen was estimated to be worth more than the life cycle cost of WSUD assets
- the avoided costs of future river restoration was estimated to be worth around 70% of the life cycle cost of WSUD assets
- the potential property premium for riparian lands was estimated to be around 90% of the capital cost of WSUD assets.

Source: Water by Design (2010)

Evidence suggests that the public perceive there are greater benefits in restoring urban rivers compared with other rivers (Tunstall *et al.*, 2000) and restoration of urban rivers may offer benefits beyond those that might exist elsewhere. Recreation and education benefits are increasingly being used to justify urban restoration (Everard and Moggridge, 2012). There is a community perception that river restoration can improve safety for children, and restored urban rivers can be highly valued by communities and can be a source of local pride (Tunstall *et al.*, 2000). Urban restoration can also have a strong social justice component, argued by some to be a response (at least in the US) to failed urban renewal policies that cleared slums (Kibel, 2008).

The significance of some these and other dimensions of urban rivers for river restoration are discussed further.

UNDERSTANDING THE SYSTEM, DRIVERS AND STRESSORS

As noted in section 4.2, effective river restoration relies on an understanding of river system function, the drivers and stressors of river health, and how a river ecosystem is likely to respond to different interventions. Urbanization of a river catchment adds additional complexity to what are already highly complex systems. Restoration demands a science-based management strategy, but the environmental science of urban rivers is new. The impacts of towns and cities on aquatic ecosystems are complex, and the scientific community has only recently reached a degree of consensus on the principle stressors of urban rivers (Walsh *et al.*, 2005). While ecological research on urban rivers is increasing (Francis, 2014), there remain significant knowledge gaps.

The greater complexity and more limited scientific understanding of urban rivers increase the importance of an adaptive management approach to river restoration. Adaptive management should be used to adjust restoration measures overtime in response to improved understanding of urban river system dynamics. This requires ongoing funding and continued involvement of scientists and policy makers (Wenger *et al.*, 2007, also see Chapter 5).

A further complexity for urban rivers is the creation of novel ecosystems. The presence of non-native species, hard engineering, chemical contamination, and urban and industrial debris will often create systems that are not found in any natural biome. This biotic and abiotic novelty in urban streams represents a particular challenge in understanding how newly created river ecosystems will behave (Francis, 2014).

Box 40: A holistic approach to conservation in an urban water river: the case of the Etowah River, United States

The Etowah River, part of the Mobile River basin, is located in the State of Georgia in the south-east of the US. The river is a global hotspot for fish endemism, including three species of darter fish that are listed under the US Endangered Species Act. A Habitat Conservation Plan to protect these species began in 2002, led by county and municipal governments by implementing land use and regulatory policies to manage urban impacts on the three listed species. Developers and landowners were required to comply with the policies. The planning process involved building a science-base to identify specific stressors for the listed species and the sources of those stressors, and then identify management policies to address each source. In a number of instances, a single management policy, for example stormwater management, was able to respond to multiple stressors (e.g. sedimentation, hydrologic alteration, contaminants) and sources. The table below summarizes some of the key stressors, sources, and management policies. Scientific assessments suggest that, without the stormwater management provisions proposed under the Habitat Conservation Plan, populations of the three darter fish species would decline by between 43% and 84%, placing the persistence of two of the species in doubt.

Stressor	Sources	Management Policy
Sedimentation	Construction sites Channel erosion Utility and road crossings	Erosion and sediment control Stormwater management policy Utility crossing policy
Hydrologic alteration	Stormwater runoff Reservoirs Water withdrawals	Stormwater management policy Water supply planning protocol
Extensive riparian buffer loss	Agriculture, golf courses, other construction	Riparian buffer ordinance
Contaminants (heavy metals, pesticides, etc.)	Point sources, stormwater, agriculture, forestry	Stormwater management policy
Movement barriers	Natural barriers, road crossings, reservoirs and points	Road crossing policy Water supply planning protocol
Temperature alteration	Loss of riparian buffers Stormwater runoff Reservoirs, water withdrawals Point sources	Stormwater management policy Water supply planning protocol Riparian buffer ordinance

Source: Wenger and Freeman, 2007; Wenger et al., 2010

DETERMINING ATTAINABLE GOALS

Many river restoration programmes no longer aim to return rivers to a pre-development state (see section 2.2). This shift is more apparent or applicable than in the case of urban rivers. Indeed, Eden *et al.* (2000, p. 269) argue that the outcome in terms of restoring to 'natural' is an 'indistinguishable and irrelevant categorisation'.

Urban rivers are often so highly modified that returning them to anything resembling a natural system is highly unlikely while maintaining the societal functions expected of the system (Francis, 2014). As a result urban restoration projects focus more on societal benefits, rather than ecological improvements (Rhoads *et al.*, 1999; Findlay and Taylor, 2006).

Some have even argued that the irreversible nature of many of the drivers of poor river health in urban rivers mean that conservation efforts would be best spent focused on less disturbed areas (e.g. Findlay and Taylor, 2006). However, rivers in good condition in areas with moderate levels of urbanization have been reported in many regions, suggesting that 'protection of ecological structure and function is possible at this and lower levels of urbanization' (Walsh *et al.*, 2005). Moreover, river restoration in urbanized settings can help bring about wider socio-economic benefits including urban regeneration, as was the case in the Mersey Basin (see section 2.4).

While the factors that should inform the setting of river restoration goals and objectives (see section 4.3 and Figure 4.9) are generally the same for both urban and non-urban rivers, urbanization creates a different context for each of these factors. For example:

- urban rivers are more likely to have experienced significant physical and ecological change over time (historic trajectory of the river ecosystem)
- urban rivers are more likely to be subject to degradation (the current condition)
- catchments subject to urbanization are likely to be subject to a greater degree of uncertainty regarding their future state, given the rapid rate of change commonly associated with urbanization (future state).

However, perhaps most significant for urban rivers will be the priorities of government and communities for the river, as well as the constraints on potential restoration. Where trade-offs are required, urban regions are more likely to prioritize development over conservation. The need to recognize existing land use and development plans in the urban context is particularly important in setting goals. This includes giving due consideration the impacts on the flow regime, water quality, and other aspects of river health that can be expected from future development.

The high cost of land can financially constrain restoration goals. The high density of human development and associated infrastructure can limit the spatial extent of restoration options. Stormwaters and associated sediment and pollutants can limit the potential for restoration to improve river health (Bernhardt and Palmer, 2007). River managers need to ensure that rivers (and river restoration) do not destabilize infrastructure, such as bridges. This creates challenges in balancing between natural functions (e.g. flooding) with minimizing impacts on human populations and assets. One example of the challenge of urban rivers relates to restoring connectivity – lateral, longitudinal or hyporheic – that can require giving substantial amounts of land back to the river, which would be expensive and may not be possible in the face of other objectives, such as flood control (Francis, 2014).

Ultimately, these factors can require that restoration goals be pragmatic, focusing on what is possible, rather than what might be ideal (Francis, 2014).

ENGAGING STAKEHOLDERS[13]

Population density in urban river basins is, by definition, significantly (if not massively) higher than in rural areas and the human population is a critical factor in restoring and conserving urban rivers (Booth, 2005), including the population's role in contributing to declines in river health, identifying goals for the condition and use of the river, and implementing solutions. Effective management of urban rivers requires a broader perspective than river ecology to include social, economic, and political dimensions (Walsh *et al.*, 2005).

One advantage of restoring urban rivers is the increased abundance of resources (both people and funds) that are likely to accompany the larger population (Ladson, 2004), as well as the potential for greater political interest. Urban river restoration can also benefit from closer proximity to research centres, and to greater opportunities for citizen science (see Box 19).

Urban restoration will typically involve a wider range of different agencies and stakeholders, including riparian landowners, environmental regulators, planning authorities, and community groups. Consultation can require engaging people and groups from a wide range of backgrounds and perspectives, and it can also bring together a wide range of expertise and experiences of the river environment (Shuker *et al.*, 2012). Further, engaging people in the restoration process can change the way people perceive rivers. This may ultimately increase the value people attribute to urban rivers (Tapsell *et al.*, 2001).

In densely populated urban areas, it has been argued that it is not possible to have ecological restoration without strong public support (Van Diggelen *et al.*, 2001), because among other reasons, policies that affect actions on private lands are more likely to result in landowner opposition (Langpap and Wu, 2004).

Selecting sites for restoration is one area where community engagement can be particularly important. While technical assessments may be able to identify those locations where restoration is (from a technical perspective) most likely to be effective, community considerations should also be paramount. For example, where restoration sites are inaccessible, unknown unused by the public, generating public interest and support for restoration can be more problematic (Tunstall *et al.*, 2000). In developing a plan for restoring the Tame River in the UK (specifically the part of the river located within the City of Birmingham) the planning process concluded that if sites were selected based on a technical appraisal alone, this would neither embed river restoration in a broader environmental management context nor potentially understand public priorities for restoration of their local environment (Petts, 2007)

Local residents attach importance to public consultation and expect to be consulted about restoration works (Tunstall *et al.*, 2000). Tunstall *et al.* (2000) have identified a number of important lessons for undertaking this type of consultation:

- Consultation should be at different levels, and using multiple mechanisms, to ensure the process engages a wide range of people.

13. Stakeholder engagement is also discussed in section 7.5.

- The public can have misconceptions about the impact of restoration. For example, the public may view 'soft engineering' restoration as increasing flood risk, even though it may in fact reduce the risk.
- The benefits that the public want, such as tidiness, improved access or improved safety may have little to do with scientific aims of restoration.
- Consultation should be used as an opportunity to manage people's expectations, ensuring that the public are realistic about the likely outcomes from the restoration process.

10.5. Measures for urban river restoration

This section discusses issues with applying the restoration measures outlined in section 3.7 in an urban context. There are many detailed technical manuals and guidelines on techniques for urban river restoration (see Box 42). This section does not attempt to replace those documents, but highlights key considerations in deciding on the type of approach tobe adopted.

IMPROVING HABITAT

Measures aimed at improving habitat are common in urban river restoration. A study of 65 restoration projects in the Thames catchment, UK, between 1979 and 1999 (Robinson, 2003, cited by Clifford, 2007), found that more than 90% of projects were driven by improving habitat diversity. Projects included re-profiling the channel, importation of gravel, creation of bedforms and planting of vegetation. In the US, replanting riparian vegetation is one of the most common approaches to restoring both urban and non-urban rivers (Bernhardt *et al.*, 2007). Increasingly, restoration of habitat in urban rivers tends to be linked to improving aesthetic values (Sung *et al.*, 2009) or for educational and recreational purposes (Clifford, 2007). Measures may also aim to stabilize incising streams, often to protect property and infrastructure (Nilsson *et al.*, 2003).

Despite their popularity, there is little evidence that such measures are likely to restore biodiversity (Walsh *et al.*, 2005) or generally improve stream health (Ladson, 2004; Booth, 2005; Violin *et al.*, 2011), due to the more significant effects of catchment-scale disturbances on hydrology and water quality. Rather, localized instream modifications are likely to be self-sustaining only where catchment-scale processes are also addressed (Booth, 2005).

There is, however, some evidence that directly enhancing instream habitat complexity can have ecological benefits:

- The extent of intact riparian vegetation has been shown to have a positive effect on urban stream macroinvertebrate taxa richness (Moore and Palmer, 2005). While riparian buffers by themselves are insufficient to maintain healthy fish assemblages in an urban context (for example, due to stormwater runoff often bypassing the buffer), riparian vegetation can contribute to bank stability and buffers are an essential component of stream ecosystem protection (Wenger, 1999).
- Improving instream habitat may benefit mobile taxa by providing refugia during high-flow events (Bernhardt and Palmer, 2007).
- Creating and maintaining debris dams (Groffman *et al.*, 2005) or re-grading the river banks to reduce incision and increase flows through the upper layers of the riparian upper soil (Bernhardt and Palmer, 2007) may improve de-nitrification and the capacity for nitrogen removal. However, such approaches rely on supporting measures to effectively manage stormwater and mitigate their potential impacts, such as on a debris or reshaped channel (Bernhardt and Palmer, 2007).

Table 10.1. Examples of approaches and purpose for establishing riverine habita

Approach	Purpose
Creation of ledges on steel poling river walls (Depford Creek, UK)	Trap sediment and seeds and form habitat for plant establishment and invertebrate colonization
Install wood planks in sheet poling within a former harbour (River Elbeg, Germany)	To create sheltered gaps and interstices between metal wall and wooden planks
Shallow bankside littoral zone with planted vegetation created behind a sheet poling screen (River Spree, Germany)	To create a shallow water zone for macrophytes and other species, sheltered from wave action
Placement of large wood in channels (Puget Sound, US)	Creation of geomorphological complexity and provision of habitat for invertebrates and fish
Installation of floating islands or rafts in urban docks of the River Thames (UK)	To provide resting and nesting sites for birds, as well as a substrate for plant establishment
Installation of floating islands (River Elbe, Germany)	To provide habitat for a range of taxa, as well as sheltered areas for fish spawning

Source: Modified from Francis, 2014

PROTECTING AND ENHANCING BIODIVERSITY

The nature of urban rivers means that it is not feasible to protect endangered species through preservation alone, unless the species has an exceedingly small natural range or exceedingly large sums of money are dedicated to the purpose. Successful aquatic species management plans need to include provisions to reduce the impacts of private urban land (Wenger *et al.*, 2010), as well as wastewater treatment and other broad issues.

A further challenge is that disturbance and the presence of invasive species means that urban rivers are often devoid of most sensitive and rare species (Naiman and Décamps, 1997). Creating favourable conditions for key species may not be sufficient on its own – it can be necessary to either reintroduce species or to reconnect the river system with river sections where relevant species are present, to support re-colonization (Palmer *et al.*, 1997).

IMPROVING WATER QUALITY AND THE FLOW REGIME

The management of wastewater and legacy pollutants is one of the primary requirements for reversing urban-stream syndrome and in the developing world these stressors are major barrier to establishing rivers that protect human health (Walsh *et al.*, 2005).

In urban areas where point sources are well managed, most pollutants will be transported to streams as part of urban stormwater. A range of measures has been developed for reducing the impacts of stormwater on both water quality and catchment hydrology. Such measures are referred to as best management practices and have potential to achieve significant ecological improvements in urban streams (Booth, 2005; Walsh et al., 2005). Best management practices are often incorporated as part of low-impact urban design, sustainable drainage system (or sometimes sustainable urban drainage system), or water sensitive urban design, with different terms primarily reflecting different regional nomenclature, rather than different approaches or practices.

Box 41: Best management practices for urban stormwater management

Best management practices are a response to the impact of impervious surfaces on the condition of urban rivers and rely on replacing stormwater drains and pipes with alternative drainage systems, which promote retention and infiltration of stormwater (Walsh *et al.*, 2004b).

Stormwater best management practices can be implemented to address flow control, pollutant removal, and pollutant source reduction. Best management practices can be:

- Structural: engineered and constructed systems, designed to improve quality and or control the quantity of runoff. Examples include sediment basins, detention ponds, constructed wetlands, swales and buffers, green roofs and roof gardens.
- Non-structural: institutional, educational or pollution prevention practices designed to reduce the amount of pollutants contained in the runoff. These could include preventive measures against nutrient accumulation on impervious surfaces such as street and road sweeping, and proper lawn and park management to prevent fertilizer, soil and debris entering waterways.

Figure 10.4. Examples of best management practice in urban stormwater management

Photo credit: Shaun Leinster
Source: U.S. EPA, n.d.; NWC, 2009; Barron *et al.*, 2010

Selecting and implementing best management practices needs to be tailored to the specific situation. Studies have found that bioretention areas can remove nearly 100% of metals (Davis et al., 2003). Infiltration areas have been shown to effectively trap heavy metals and other pollutants, with little risk to groundwater (Barraud *et al.*, 2005). However, infiltration areas may be less effective at removing nutrients (Wenger, 2010). Constructed wetlands have been shown to reduce faecal indicator bacteria by 80% (Sung, 2009); however, their effectiveness can be far lower during times of high rainfall, requiring other measures to address pollutants associated with those events.

The extent to which constructed wetlands are effective in improving water quality can vary. Wetlands may be effective in reducing total loads of total suspended sediments, total phosphorus and total nitrogen. But during storms, wetlands may in fact make the quality of base flows worse (Ladson, 2004). For example, some pollutants may be temporarily stored in wetlands, rather than being removed, and the bioavailability of toxicants may be increased (Helfield and Diamond, 1997).

Best management practices also contribute to reducing the impacts of urban catchments on stream hydrology, through detaining or retaining flows, or increasing infiltration. Best management practices tend to focus on small rainfall events because they tend to be the main source of hydrologic alteration (Walsh *et al.*, 2005).

Different types of best management practices will be appropriate for different types of land use. For example, different measures might be more or less suited to:

- individual house lots
- medium and high-density housing
- commercial and industrial sites
- subdivisions.

The practicality and cost-effectiveness of measures will also vary between new developments and retrofitting into an existing urban landscape. Several reviews have considered the suitability of different measures for different situations (e.g. BMT WBM, 2009).

CHAPTER 11
COMMON MEASURES FOR RIVER RESTORATION

OVERVIEW

This chapter presents information on a range of different restoration measures. For each measure, the chapter discusses what the measure is trying to achieve, what is involved in implementing the measure, important considerations in applying the measure, and a case study example. Further reference material is also identified.

11.1. Introduction

In setting out a framework for river restoration, Chapter 3 includes a typology of different measures for restoring river ecosystems. The typology divides restoration measures into 12 different categories and is based on a methodology developed as part of a synthesis of US restoration measures (see Bernhardt *et al.*, 2005).[14] The categories of measures under the typology are:

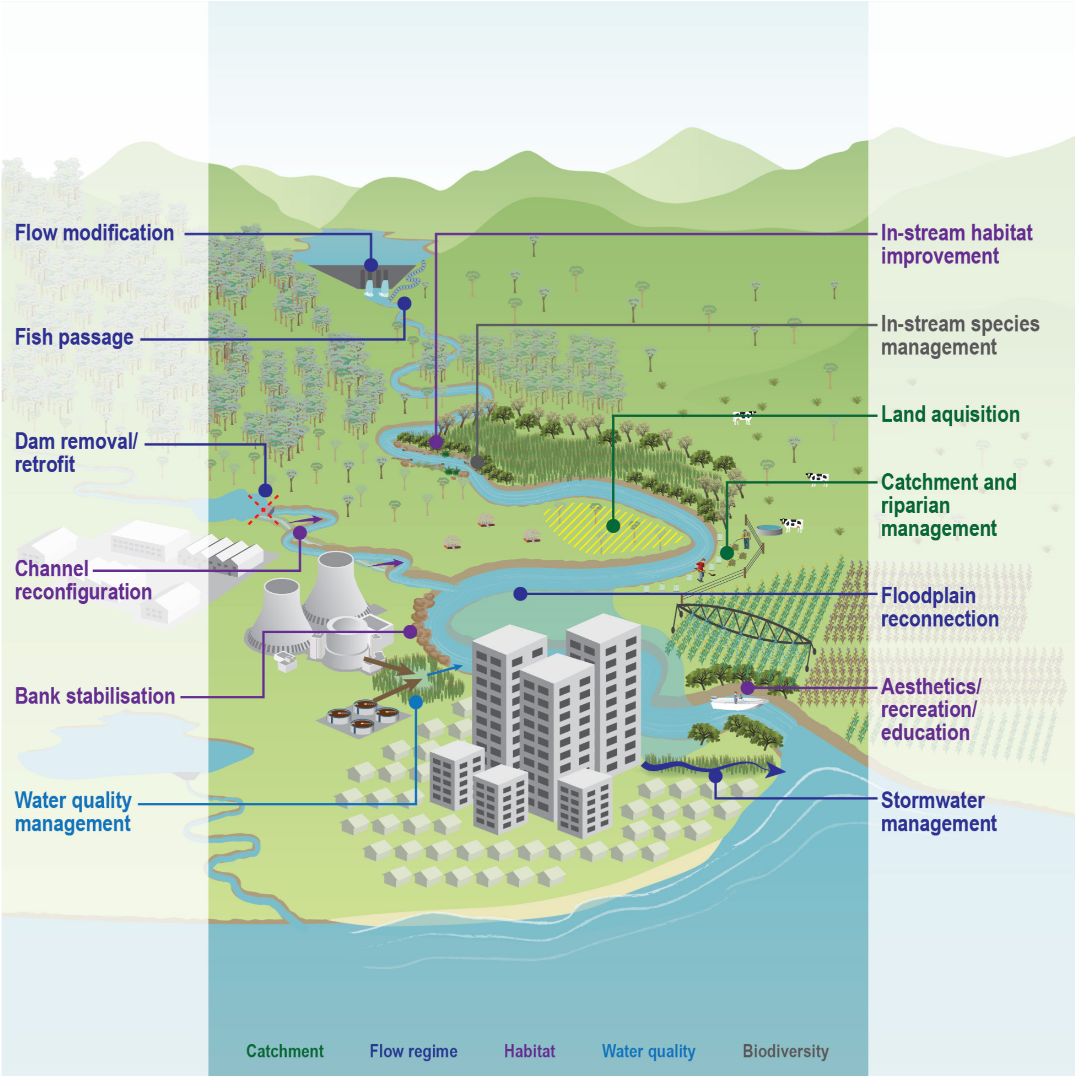
1. Catchment management
2. Flow modification
3. Dam removal or retrofit
4. Stormwater management
5. Floodplain reconnection
6. Riparian management
7. Habitat removal
8. Bank stabilization
9. Channel reconfiguration
10. Water quality management
11. Instream species management
12. Aesthetics, recreation and education

These measures are shown in the conceptual model in Figure 11.1.

There are many ways that restoration measures can be categorized and in this typology a number of the categories are closely connected and some inevitably overlap. For example, stormwater management will influence both flows (and is a subset of 'flow modification') and it can also be designed to manage water quality in the receiving waters. Measures within a number of categories will impact water quality, including measures related to riparian and catchment management. The category of 'water quality' focuses primarily on measures directly aimed at managing water quality through inputs to the river system, particularly from point-source pollution. Riparian management, such as planting of vegetation in the riparian zone, will often contribute to improving bank stability, therefore, there are overlaps between these two categories. Similarly, there are boundary issues between measures related to riparian management and (broader) catchment management.

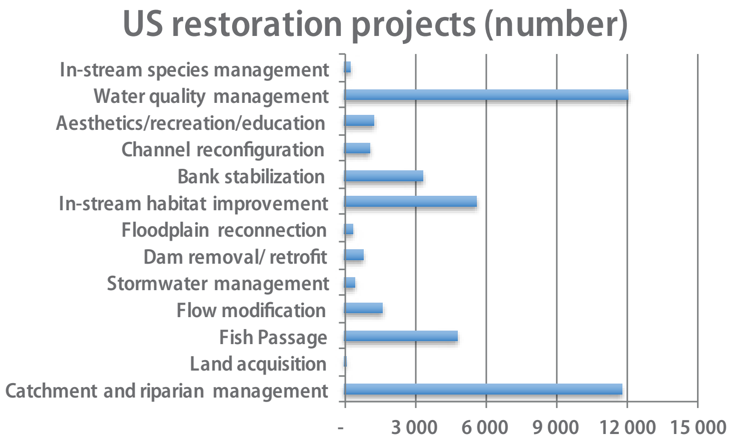
14. Several adjustments have been made to the original categorization used by Bernhardt *et al.* (2005). For example, a new category, catchment management, has been added and some of the definitions used by Bernardt *et al.* (2005) have been modified.

Figure 11.1. Conceptual model of a river basin, showing different river restoration measures



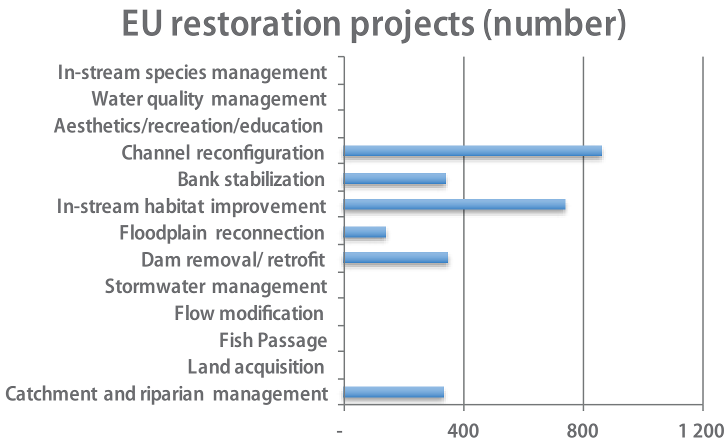
Data on restoration projects shows that a limited number of measures are applied in the majority of restoration projects globally (see Figure 11.2, Figure 11.3, and Figure 11.4), with the most common measures being those related to water quality management, instream habitat improvement, bank stabilisation, and riparian and catchment restoration.

Figure 11.2. Number of U.S. river restoration projects based on type of restoration measure adopted



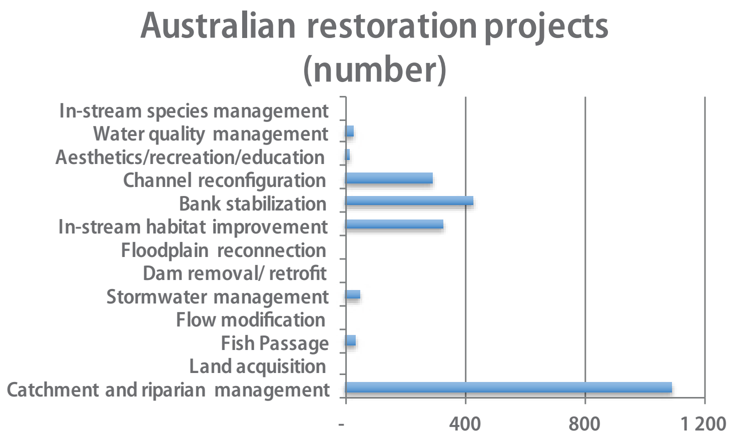
Source: Bernhardt et al., 2005

Figure 11.3. Number of EU river restoration projects based on type of restoration measure adopted



Source: UK River Restoration National River Restoration Inventory (http://www.therrc.co.uk/river-restoration) and the EU RiverWiki (https://restorerivers.eu/wiki/index.php?title=Main_Page)

Figure 11.4. Number of river restoration projects in Victoria, Australia based on type of restoration measure adopted



Source: Brooks and Lake, 2007

This chapter provides a more detailed description of these measures. For each category, the relevant section describes the purpose of the measure, what is involved in implementing it, and some key considerations, along with one or more case study examples.[15]

For each category, measures may include:

- passive restoration: primarily policy-based approaches that are aimed at changing human behaviour (e.g. through education or regulation) to reduce or alter the nature of human impacts
- active restoration: direct (physical) interventions to change the river ecosystem and its surrounds.

In describing these different measures, this book does not attempt to replicate the many technical guidelines and manuals that provide detailed descriptions on how to implement river restoration projects. Box 42 identifies a number of these existing guidelines and manuals. In addition, each of the individual measures described in the following sections includes reference to further detailed guidelines or manuals relevant to those measures.

Box 42: Existing river restoration guidelines and manuals

Stream Corridor Restoration: Principles, Processes and Practices (FISRWG, 1998) provides detailed technical guidance on river restoration measures relevant to the river corridor, based primarily on experiences in the US.

A Rehabilitation Manual for Australian Streams (Rutherfurd *et al.*, 2000) sets out detailed procedures for undertaking rehabilitation project. As the name suggests, the emphasis of the manual is on streams, rather than larger watercourses. The manual focuses on physical rehabilitation of streams, with a particular emphasis on stream stability and stream habitat.

15. Separate subsections are not included for measures related to land acquisition and aesthetics, recreation and education.

Reference Guideline for Restoration by Eco-Compatible Approach in River Basin of Asia (ARRN, 2012) sets out basic principles, policies and measures relevant to restoring rivers in Asia. The guideline also includes a number of case studies from China, Korea and Japan.

Manual of River Restoration Techniques (RRC, 2013) provides detailed descriptions of the application of a number of river restoration methods, primarily related to physical restoration in U.K rivers.

The Handbook for Management and Restoration of Aquatic Ecosystems in River and Lake Basins (GWP, 2015) provides a high-level guide to approaches to restoration for aquatic ecosystems.

Active Beautiful Clean Waters Design Guidelines (PUB, 2011), provides planning and design considerations for various urban water management measures, including surface water drainage and stormwater quality management

Water Sensitive Urban Design Guidelines There are various detailed guidelines for implementing best practice urban water management, including those prepared by SEQ Healthy Waterways (www.waterbydesign.com.au/techguide/ and Melbourne Water (www.melbournewater.com.au/wsud)

11.2. Catchment management

Catchment management captures measures that aim to improve aspects of river health, including water quality and the flow regime, through improved management of a river's catchment. Catchment management includes direct interventions to modify the condition of the catchment such as re-vegetation, as well as policy approaches such as regulatory controls over land use.

PURPOSE OF CATCHMENT MANAGEMENT

Surface water run-off and the nature and composition of flows entering a river can vary as a result of the topography, geology, land cover and the position in the river network, as well as in response to climate (Poff and Zimmerman, 2010). Notably, catchment degradation can influence the delivery of water resources (Le Maitre *et al.*, 2007). Most river degradation is directly attributable to land use practices or hydrologic modification at the catchment level (FISRWG, 1998). Management and restoration of a river's catchment aims to address factors in the catchment that have changed the quantity, composition and timing of the water, sediment, and other materials that enter a river system. Just as degradation of the catchment can be a major contributor to declining river health (e.g. Bunn *et al.*, 1999; Young and Collier, 2009), restoration of the catchment has the potential to bring substantial improvements in river health and related ecosystem services (Gilvear *et al.*, 2012).

THE NATURE OF CATCHMENT MANAGEMENT

Catchment restoration may include (Glendell and Brazier, 2014):

- direct interventions to improve the condition of existing land, including land and water conservation strategies, such as re-vegetating the catchment or rehabilitation of gullies and erosion prone zones
- policy and planning measures to restrict land use change, such as controls over clearing of vegetation, conversion of land to intensive agriculture, or urban and industrial development
- conversion of arable land to permanent grasslands to reduce sediment and nutrient delivery to downstream water bodies
- catchment flood risk management measures in the upper and middle areas of the catchment, to retain water and reduce rapid run off in to rivers
- creation of wetland habitats through temporary flood storage and water retention areas
- preserving the green cover by improved grazing land management to reduce fine sediment yields in the catchment.

Many of the approaches to catchment restoration involve direct action at the farm-level to reduce diffuse agricultural pollution, such as nutrient runoff and sediment loss. Examples include:

- filtering ditches and lime – sand filters for reducing nutrient runoff (Kirkkala *et al.*, 2012)
- fixing or re-fencing farm areas and realigning them with creeks to accommodate floodways
- designating buffer strips between the fields and rivers (Catchment Restoration Fund, 2014)
- erosion control in gullies and along drains and creeks by fencing and re-establishing eroded banks (Alt *et al.* 2009)
- Best management practice in irrigation water management and in the application of fertilizers, pesticides and herbicides.

Catchment restoration at the farm-level relies on individual farmers changing their practices. Restoration programmes may drive such changes via regulatory requirements, education, or encouraging adoption of voluntary industry codes of practice (see the example of the Great Barrier Reef catchments in Box 43).

CONSIDERATIONS IN APPLYING CATCHMENT MANAGEMENT

The large spatial extent of many catchments creates an inherent challenge in identifying and addressing causes of poor river health. Further, few organizations and countries globally have developed frameworks and strategies to optimize integrated delivery at the catchment scale, though there are a number of potential policy drivers to take this forward (Gilvear *et al.*, 2013).

Challenges with applying the measures and demonstrating results at both the catchment or farm scale are due to various natural and socio-economic factors, including:

- The large geographic extent of many basins creates an inherent challenge in identifying priority areas for restoration.
- In many cases, the catchments will predominately consist of private land, which is different from rivers themselves that are often under government or public control. Private land can present challenges for access and implementation. There can also be costs and legal challenges associated with restricting private land use.
- Extreme floods and droughts occur over large spatial extents and can greatly alter interaction between streams and their catchments. These events can alter habitat availability and bring significant shifts in biodiversity (Reich and Lake, 2014).
- Significant improvements in water quality can take decades, once the point-source inputs of nutrients and other pollutants from the catchment to streams, rivers, lakes and coastal waters are initially reduced (Alexander and Smith, 2006).
- At the farm scale, landowners often perceive barriers such as the cost combined with inadequate compensation and lack of confidence that the measures will achieve the desired results (Graymore and Schwarz, 2012).
- Taking restoration beyond the river corridor inevitably increases the number of government agencies involved, as well as potentially resulting in more jurisdictions. Both factors can present coordination challenges, as well as the risk that the lead agencies responsible for restoration (e.g. commonly the relevant water resources department) will not have a legal mandate.
- Managing diffuse (e.g. from overuse of fertilizer, or soil erosion) and incidental (e.g. inadvertent interception of overland flow) impacts on a river system are inherently difficult to manage.

Better understanding of catchment influences (both natural such as geology, hydrology and catchment response to rainfall events) and human impacts (e.g. land use, impounding structures such as weirs etc.) increases the prospect of successfulrestoration.

FURTHER REFERENCE MATERIAL

- Stream Corridor Restoration: Principles, Processes and Practices (FISRWG, 1998)
- A Rehabilitation Manual for Australian Streams (Rutherfurd *et al.*, 2000)
- Saving Soil: A Landholder's Guide to Preventing and Repairing Soil Erosion. Northern Rivers Catchment Management Authority (Alt *et al.* 2009)

Box 43: Case studies – Improving water quality in the Great Barrier Reef and managing invasive weeds in South Africa

Poor water quality, and in particular the impact of high nutrient and sediment loads and of pesticides, in the river systems that drain into the Great Barrier Reef is one of the most significant threats to the health of the reef. In response, a water quality protection plan, also known as the Reef Plan (Queensland Government, 2013) has been prepared with the objective of halting and reversing the decline in the quality of water entering the reef from the neighbouring catchments by 2020. The plan sets as a target that by 2018 the total nitrogen and phosphorus (nutrients) loads and the amount of pesticides at the end of the reef catchments will be reduced by 50% and 60% respectively, and that there will be a minimum 70% groundcover of dry tropical grazing land. In addition, the plan proposes that by 2018 there will be a 20% reduction in sediment load. Responsibility for implementing the plan is shared across a range of federal, state and local government bodies. Key actions include efforts to work in association with landowners to address the major sources of the pollutants and research into improved agricultural practice to reduce total pesticide and fertilizer inputs, and promoting and adopting best agricultural practice across the reef catchments. Voluntary industry codes of practice, such as those in the cotton, sugar, and beef industries, aimed at improving agricultural practice to reduce impacts on freshwater and related resources are also central to dealing with catchment degradation and associated water quality issues. The federal and state governments have committed A $375 million over five years to implementing Reef Plan. (Source: http://www.reefplan.qld.gov.au/; QAO, 2015).

Working for Water (WfW) is a South African government initiative that was launched in 1995 to address the challenge of invasive alien plant species that were posing a major threat to surface water resources. The program was also designed to create jobs for unemployed people in restoration activities. The programme aims to enhance South Africa's water security, improve ecological integrity and undertake land restoration, while providing employment opportunities for South Africa's most vulnerable communities. The programme uses mechanical methods (e.g. clearing, felling, burning), chemical methods (e.g. herbicides) and biological control (76 biological control agents have been released). Since its establishment, WfW has implemented 300 projects countrywide and has been dubbed one of the largest conservation projects in Africa. An original goal of WfW was to bring invasive species under control within twenty years, although this goal now appears unrealistic. As of 2004, approximately 2 million hectares of invaded land had been cleared by the programme. As it continues, follow-up operations rather than new clearing consume a greater and greater share of the programme's resources. (Source: Pegasys, 2012; DWAF, n.d.)

11.3. Flow modification

Flow modification is aimed at restoring a river's flow regime. This category focuses primarily on policy and regulatory measures aimed at changing flows within a river, including changes to the volume, frequency, duration or timing of flows. Other types of measures can also have an impact on the flow regime. Stormwater management can reduce the peaks of flows running off urban areas; removing or retrofitting of dams can alter or remove impacts on the flow regime as a result of instream infrastructure; and reconnecting floodplains can change the hydraulic characteristics of floods (see sections 11.4, 11.5, and 11.6).

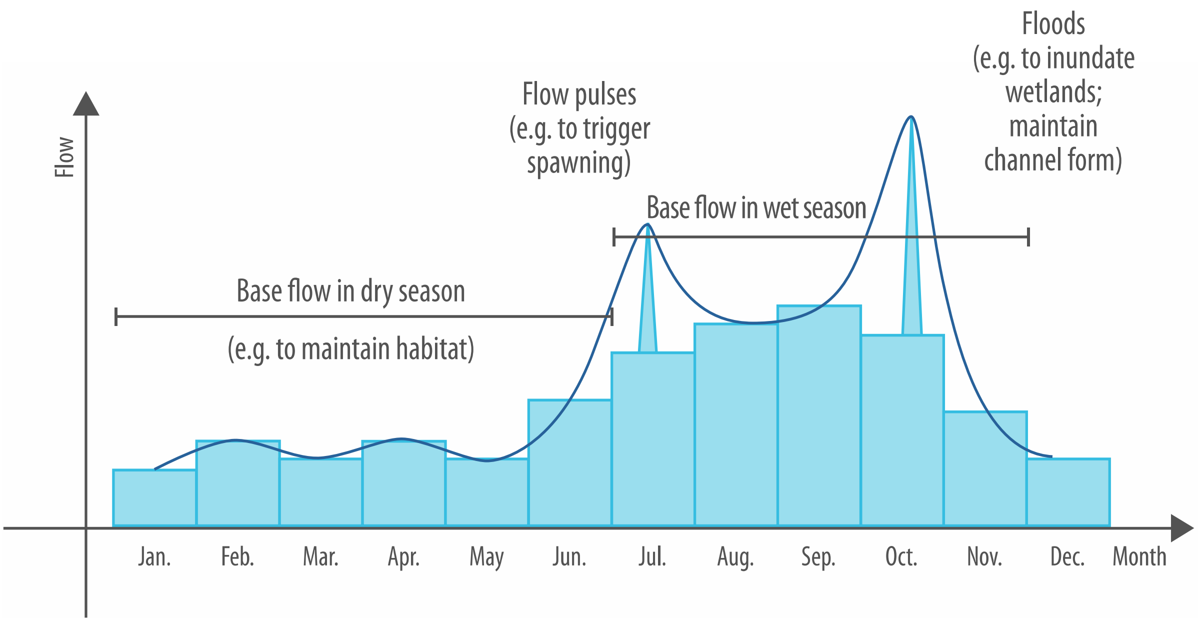
PURPOSE OF FLOW MODIFICATION

Flow regime is one of the most important drivers of river health. Flows are important for a number of reasons (Bunn and Arthington, 2002):

- Flow is a major determinant of the physical habitat in streams and rivers.
- River species have evolved lifecycles histories in response to natural flow patterns.
- Flows maintain natural patterns of longitudinal (i.e. upstream–downstream) and lateral (e.g. river-floodplain) connection.
- Changes to flow regimes facilitate the spread of unwanted pest species.

Different elements of the flow regime perform different ecological functions (see Figure 11.5). Changes to river flows as a result of instream regulation (such as the construction of dams) and diversions (such as the abstraction of water for irrigation) can alter the river's ability to perform those functions. Restoration measures that involve modifying the flow regime typically aim to restore ecologically important hydrological variables.

Figure 11.5. The different components and ecological roles of a hypothetical hydrograph



Source: Speed et al., 2013

THE NATURE OF FLOW MODIFICATION

Restoring the flow regime generally involves the introduction, protection, and management of environmental flows. Environmental flows describe the quantity, quality and timing of flows required to sustain freshwater and estuarine ecosystems and the human livelihoods that depend on them. Restoring environmental flows can be via:

- Regulatory requirements for the operators of dams and other instream infrastructure to manage their operations in a way to enhance environmentally important flows. This could involve, for example:
  - minimum flows that must be released, for example to maintain base flows
  - requirements to release pulse flows at critical times of year, for example to increase the transport of sediment or to trigger fish spawning or migration
  - maximum rates of rise and fall, to reduce impacts such as bank slumping which can result from rapid changes in flow
  - requiring operators to manage other environmental properties of water releases, such as temperature, sediment and nutrients.
- Changes to the water allocation regime can limit the amount of water that can be taken by water users under abstraction licences and the times when that water can be taken. For example, reducing the total amount of water that can be taken under water licences, or imposing rules that reduce or ban water abstractions during important flow events.
- The acquisition of water licences helps retain the water that is linked to those licences in the river channel for restoration outcomes. For example, an environmental NGO, community group, or government organization could purchase water licences with the purpose of effectively retiring those

licences, decreasing the volume of water that is being abstracted from the river. Alternatively, the water may be actively used to meet particular ecological objectives (see Box 44). Such measures rely on the existence of a reasonably sophisticated water allocation regime (Speed *et al.*, 2013).

These types of measures may be introduced as part of a basin-wide planning exercise aimed at reviewing the water allocation regime. Alternatively, regulatory or other changes may be made to achieve a different flow regime as part of a dedicated river restoration effort.

CONSIDERATIONS IN APPLYING FLOW MODIFICATION

The heavily contested nature of many river basins makes the introduction of environmental flows challenging. Altering the flow regime to improve ecological outcomes typically requires changes to established rights, such as the rights of irrigators under their water licences, or hydropower operators under their concession agreements. Making such changes can be expensive (due to lost economic productivity or the need to pay compensation to rights' holders) and legally and politically difficult. The absence of a robust water entitlement regime, and absence of compliance and enforcement, can make efforts to introduce environmental flows difficult. The long lifespan of major water infrastructure, along with high establishment costs, can make it unattractive for governments to reverse previous allocation decisions to return water to the environment. Finally, there can be physical challenges with introducing a new flow regime where existing infrastructure is not be able to support the release of environmental flows.

As with many other river restoration measures, overcoming these challenges requires:

- a strong scientific case to justify the proposed approach
- a strong economic case to highlight the benefits that will be realized from a changed flow regime
- a strategic approach that maximizes the benefits of improved flows, while minimizing any impacts on existing water users
- legal and regulatory requirements for maintaining flows.

FURTHER REFERENCE MATERIAL

- Basin Water Allocation Planning (Speed *et al.*, 2013)

Box 44: Case Study – Murray–Darling Basin buy-back scheme

The 2012, Murray–Darling Basin Plan defined a sustainable level of diversions and extractions from surface and ground water resources to ensure the ongoing health and resilience of the environment. Current allocations exceed the levels defined in the plan, and the plan requires that diversions and extractions be reduced to the defined (sustainable) levels by 2019. To bridge the gap, the Australian Government has committed securing water entitlements for environmental use. The target for surface water recovery under the plan, is 2,750 gigalitres, of which over two-thirds has already been recovered through water purchases, contracted infrastructure investments, and other state and federal recoveries. The plan presents the reduction in surface water diversions in two parts: a 'local' component to provide for environmental needs within each catchment and a shared 'downstream' component to ensure the overall health of the Barwon–Darling River system in the north, and the Murray River system in the south. Water entitlements obtained by the government are held and managed by the Commonwealth Environmental Water Holder (see Box 28).

Source: Water Recovery Strategy for the Murray–Darling Basin, 2014

11.4. Dam removal or retrofitting

Dam removal or retrofitting refers to removing dams or other instream infrastructure or modifying or retrofitting existing infrastructure to reduce their negative ecological impacts. This includes measures related to removing barriers to upstream/downstream migration of fish, as well as constructing alternative pathways.

PURPOSE OF DAM REMOVAL OR RETROFITTING

Dams and other instream infrastructure can have significant impacts on river health, including impacts related to:

- Changes to the flow regime. Storage dams and hydropower peaking plants, in particular, can disrupt the flow regime, and lead to high seasonal and day-to-day fluctuations, which can vary greatly from natural flow levels.
- Trapping sediments and nutrients behind a dam. Reduction in sediment moving downstream can lead to degradation of the river channel, floodplain, and coastal delta, and result in the loss of ecologically important habitat.
- Blocking migration of aquatic organisms. Maintaining natural patterns of longitudinal and lateral connectivity is essential for the viability of populations of many riverine species, including plants, invertebrates, and fish. Dams are a major cause of habitat fragmentation, reducing the movement of species up and down the river corridor (World Commission on Dams, 2000).

Dam modification or removal can be aimed at addressing any or all of the above impacts. Dam removal may also be motivated by safety risks, particularly in the case of aging infrastructure. Dams may be removed because they are redundant, or because the costs of maintaining the dam no longer outweigh the benefits.

This may be due to change in economics of the dam, change in values, or improved understanding of the impacts.

Dam removal benefits aquatic organisms, particularly fish, by: (i) removing obstructions to upstream and downstream migration; (ii) restoring natural seasonal flow variations; (iii) eliminating siltation of spawning and feeding habitat above the dam; (iv) allowing debris, small rocks and nutrients to pass below the dam; (v) eliminating unnatural temperature variations below the dam; and (vi) removing turbines that kill fish (American Rivers and Trout Unlimited, 2002).

THE NATURE OF DAM REMOVAL OR RETROFITTING

Dam removal or retrofitting may involve:

- Removing infrastructure. A dam may be removed entirely 'in the dry' with the river being diverted or pumped around the site. Alternatively, dams may be removed in stages, being slowly lowered over a number of years, to allow for a more paced restoration of the former impoundment.
- Retrofitting existing infrastructure to improve ecological outcomes. Modifications may be designed to:
  - allow for different flow releases, e.g. off-take of water from different depths to avoid cold water pollution
  - improve capacity to better control environmental flow releases
  - introduce fish passages or other similar structures (American Rivers and Trout Unlimited, 2002).

CONSIDERATIONS FOR DAM REMOVAL OR RETROFITTING

Removing dams can be expensive, both in terms of direct costs and lost opportunities. Retrofitting can also be expensive. Because the size and location of dams vary so greatly, the cost to remove an individual dam can range from tens of thousands of dollars to hundreds of millions of dollars. It is therefore important to look for opportunities where a dam has ceased be sufficiently beneficial or is a liability. For example, where assets are becoming too expensive to maintain or are considered a safety hazard, this can present an opportunity to introduce changes.

Dam removal can result in savings over the long term. Removal eliminates expenses associated with maintenance and safety repairs, as well as direct and indirect expenses associated with fish and wildlife protection (e.g. fish ladders and mitigation for fish mortality). In addition, removal may generate income from newly available recreation opportunities such as fishing or rafting.

Sediment that collects behind a dam, sometimes over hundreds of years, may contain toxins such as PCBs, dioxins and heavy metals. Removing these toxic materials is often extremely expensive, and the threat of re-suspending these toxin-laden sediments in the process of dam removal has the potential to damage downstream water quality and threaten the health of fish and wildlife and water users. These impacts can be minimised through proper removal techniques. Dam removal can also result in fundamental changes to the local environment. The flat-water habitat created by a dam will be lost and any (created) wetlands surrounding a reservoir may be drained. (American Rivers and Trout Unlimited, 2002).

FURTHER REFERENCE MATERIAL

- Exploring Dam Removal: A decision-Making Guide (American Rivers and Trout Unlimited, 2002).
- Guidelines for Retirement of Dams and Hydroelectric Facilities (American Society of Civil Engineers 1997).
- Guidelines for Dam Decommissioning Projects (USSD, 2015).

Box 45: Case studies – Lower Penobscot (Maine, United States) and Elhwa River (Washington, United States)

The Lower Penobscot River Multi-Party Settlement Agreement forms the basis for a significant dam-removal and fish habitat restoration project. Signed in 2004 by PPL Corporation (a dam and hydropower owner/operator); a number of federal, state and tribal governments; and a collection of conservation groups, the agreement sets out a blueprint for the restoration and management of the Lower Penobscot River, the largest river basin in the US state of Maine.

Under the agreement, the Penobscot River Restoration Trust was entitled to purchase three existing dams from PPL Corporation. The purchase was completed in November 2010 at a cost of US $24 million. Two of the dams – Great Works Dam and Veazie Dam – have now been decommissioned. A state-of-the art fish bypass will be constructed at a third dam. Fish passage is also to be improved at four other existing dams. In return, PPL Corporation has the option of increasing power generation at six existing reservoirs. Various government approvals are still required before different parts of the agreement are implemented. However, the agreement provides a level of certainty to all parties about future plans and objectives for the basin. The objective of these works is to restore habitat for a range of sea-run fish, by restoring the connection between the river and the ocean and allowing migratory fish access to historic spawning sites that have been blocked since the construction dams. Once completed, it is expected that the project will result in an increase of fish habitat of approximately 1,600 km.

The Elwha River runs for 45 miles through Washington State, in the north-west of the US. Historically, the river was famous for its salmon run but, prompted initially by the need for power for sawmills for the local timber industry, two hydropower dams were constructed in the early 20th century – the Elwha Dam in 1914, and the Glines Canyon Dam in 1927. In 1992, largely in response to pressure from indigenous groups, such as the Elwha Kallam tribe, who were concerned about the decline in salmon fisheries, the US Congress authorized federal purchase of the two dams and ordered a study into removing them. The process of conducting research and feasibility studies culminated in 2011 when work began to dismantle the two dams (Nijhuis, 2014). The removal of the dams prompted substantial research into impacts on ecosystem functions, especially sediment regimes (see Randle *et al.*, 2015 and East *et al.*, 2015) and ecological impacts, especially fisheries (see the special session of the American Fisheries Society annual meeting, Portland Oregon at https://afs.confex.com/afs/2015/webprogram/Session3463.html). Initial monitoring data suggested that restored sediment transport and deposition processes led to the reformation of channel geomorphological features, such as sidebars, that had disappeared after the two dams had been built and that channel complexity began to increase within two years of dam removal with important ecological implications, e.g. for habitat structure, benthic fauna, salmonid fish spawning and rearing potential, and riparian vegetation (East *et al.*, 2015).

11.5. Stormwater management

Stormwater management includes the construction and management of structures (ponds, wetlands, and flow regulators) in urban areas to modify the release of storm runoff into waterways from watersheds with elevated imperviousness. It also includes measures to improve the quality of water entering watercourses from urban areas.

PURPOSE OF STORMWATER MANAGEMENT

Urban areas frequently have an altered hydrological pattern due to the increase in impervious surfaces, such as roads, roofs and stormwater drainage systems. Impervious surfaces prevent infiltration of water into the soil and dramatically increase the rate of runoff, at times resulting in flash flooding and increased erosion of streams and rivers. Stormwater also can carry high pollutant loads. Stormwater runoff from impervious surfaces is the paramount stressor to urban rivers (Walsh *et al.*, 2005, see section 10.3).

Stormwater restoration and management measures typically aim to improve a range of factors relevant to river health, including:

- flow regime: by minimizing the impacts of urbanization on the hydrological characteristics of a catchment
- water quality: by minimizing the amount of pollution entering the storm water system and removing an appropriate amount of any residual pollution
- biota: by maximizing the value of indigenous riparian, floodplain and foreshore vegetation
- habitat: by maximizing the value of physical habitats to aquatic fauna within the stormwater system (ARMCANZ and ANZECC, 2000).

Restoration methods used in stormwater management often form part of approaches such as water sensitive urban design or sustainable urban drainage systems. These methods are holistic approaches to the planning, design, construction and retrofitting of urban development to minimize its impact on river health, particularly by reducing peak flow magnitudes, extending flow duration, and reducing the pollutant loads entering waterways (see Chapter 10).

THE NATURE OF STORMWATER MANAGEMENT

Stormwater management measures include measures that involve restoring existing stormwater systems, as well as minimizing the impacts of stormwater from new developments (ARMCANZ and ANZECC, 2000:

- Structural measures: engineered and constructed systems, designed to improve quality and or control the quantity of runoff, such as sediment basins, detention ponds, constructed wetlands, swales and buffers, green roofs and roof gardens.
- Non-structural measures: institutional, educational or pollution prevention practices designed to reduce the amount of pollutants contained in the runoff (see further section 10.5 and Box 41).

CONSIDERATIONS IN APPLYING STORMWATER MANAGEMENT

Bio-retention systems (e.g. swales and basins) use vegetation to filter fine sediments and process nutrients and small particulate contaminants before they reach the stormwater drainage system. Benefits from bio-retention systems include reducing runoff quantity, changes to the timing of runoff, and improving the physico-chemical characteristics of runoff by removing suspended solids, nutrients, hydrocarbons and heavy metals (Demuzere *et al.*, 2014).

Sedimentation basins can remove coarse to medium-sized sediment and regulate flow to reduce flow velocities across an area to settle out large particles. They are often used as the first pass of stormwater treatment to prevent the sedimentation of downstream structures and can be used as an inlet pond to a constructed wetland or bio-retention basin. They are not costly to install but do require continual maintenance and dredging of material to retain their function.

Constructed wetlands filter and process fine, colloidal particulate matter and dissolved nutrients by the use of different zones with fringing, emergent, submerged and floating aquatic vegetation as biological filters. They improve stormwater quality through physical, biological and pollutant transformation mechanisms (Melbourne Water, 2010). Constructed wetlands can be expensive to construct and require sound design for effective water treatment with relevant retention times for individual zones and the capacity to contain high flow events. They require continual maintenance to remove sediment and litter from inlet traps and must be managed to prevent the breeding and spread of pest fauna and flora (e.g. mosquitoes, salvinia sp.) to neighbouring areas or waterways. However, they are a passive treatment method and they deliver other ecosystem services through their recreational and aesthetic values along with habitat for aquatic species and water birds.

Buffer strips, sand filters and swales are also used in the streetscape to filter stormwater runoff from small catchment areas. They are more cost effective on a smaller scale and have a smaller footprint, which is beneficial for retrofitting of existing urban areas.

Broader issues related to urban catchment restoration apply equally to stormwater management (see section 10.4). Because land in urban areas is expensive, urban restoration projects tend to incur greater costs than in rural areas, and it is often difficult to purchase or protect the desired extent of river floodplain habitat, which might otherwise be used to retain or delay storm flows. The restoration options are also constrained by urban infrastructure, property ownership, political pressures, and chemical contamination from leaking sewer and stormwater pipes (Bernhardt and Palmer, 2007).

FURTHER REFERENCE MATERIAL

- US Stormwater Management Best Practices (US EPA, n.d)
- Australian Guidelines for Urban Stormwater Management (ARMCANZ and ANZECC, 2000)
- Water by Design, Technical design guidelines (http://waterbydesign.com.au/techguide/)
- Singapore ABC Waters Design Guidelines (PUB, 2014)
- King County, Washington State, US, Stormwater Management Program (http://www.kingcounty.gov/depts/dnrp/wlr/sections-programs/stormwater-services-section/stormwater-program.aspx).

Box 46: Case study – Bishan-Ang Mo Kio Park, Singapore

Singapore's ABC Waters Programme aims to improve the water quality, physical appearance, recreational value, and biodiversity of Singapore's waters. While targeting waterways and reservoirs, the ABC Waters Programme also addresses the stormwater runoff generated from the urbanized catchment (for further discussion see the Singapore case study in section 2.4).

A landmark project of the programme, the Bishan-Ang Mo Kio Park is one of Singapore's biggest (62 ha) and most popular parks. Construction began in October 2009, and the park was officially opened in March 2012. It showcases the transformation of a 2.7 km concrete channel of the Kallang River into a 3 km naturalized river integrated with the surrounding green space. The park is essentially a floodplain river that allows for multiple uses – when flow is low, people can play in the river channel; when flow rises during storms, the entire park functions as a conveyance channel to pass the flow downstream to prevent flooding of the surrounding residential areas (Baur *et al.*, 2012). The naturalized channel, along with its floodplain, was designed to safely convey a 1-in-25-year storm (PUB, personal communication). Any new development in the catchment is subjected to a drainage design code that prohibits the generation of additional stormwater runoff –stormwater should be retained onsite and cannot be discharged into the river until after the storm.

Bioengineering techniques were applied to re-construct the river channel. Although the use of bioengineering is common in the developed world, it had not been used in Singapore before. The design team experimented with ten different techniques in combination with native plant species on a 60 m stretch of a side drain within the park, before applying bioengineering to the Kallang River (Baur *et al.*, 2012). Seven of theses techniques were selected in the naturalization of the channel, including fascines, riprap with cuttings, geotextile-wrapped soil-lifts, brush mattresses with fascines, reed rolls, gabions, and geotextile with plantings. A hydraulic model was developed to simulate the flow dynamics to help the design of the channel. For example, more robust plant species would be used at locations identified by the model to be subject to higher flow velocity for erosion control.

The naturalized channel is the highlight of the park, with meander bends, varying channel width, rock beds, and vegetated banks that generate diverse flow patterns (Figure 10.6). As well as being aesthetically more pleasing, the heterogeneous geomorphology is also an attempt to provide a variety of wildlife habitats (Baur *et al.*, 2012). Several sustainable stormwater treatment elements are incorporated into the redesign of the park, among which is the cleansing biotope – the first in Singapore. The cleansing biotope is at an upstream location in the park and it helps to supply clean water needed for the park facilities, such as the water playground, to avoid the use of chemicals (Baur *et al.*, 2012).

Figure 11.6. The river channel in the Bishan-Ang Mo Kio Park before (top) and after (bottom) (image credit: Atelier Dreiseitl)

Source: Liao, 2013

11.6. Floodplain reconnection

Floodplain reconnection increases the inundation frequency of floodplain areas or promotes flux of organisms and material between riverine and floodplain areas.

PURPOSE OF FLOODPLAIN RECONNECTION

Floodplains are one of the most productive and economically valuable ecosystems in the world (Opperman *et al.*, 2010) and play an integral role in maintaining river health. The flooding of floodplains contributes to higher primary and secondary production and increases terrestrial fauna, a consequence of both the input of nutrients from the floodwater, as well as the release of carbon and nutrients from the floodplain. Where hydrological connectivity is maintained, flooding can allow for fauna to move between channel and the floodplain, adding biomass produced in the floodplain to the river system, as well supporting food-web dynamics (Tockner *et al.*, 2000). For example, fish species migrate to the floodplain during floods to access spawning sites, with floodplains acting as important nurseries and as well as a source of food (Stoffels *et al.*, 2013). Floodwaters support the movement of nutrients and carbon from the floodplain to the river channel (Robertson *et al.*, 1999). Floodplains also provide temporary storage for floodwaters, delaying and reducing the size of flood peaks, and can be an important source of groundwater recharge (Opperman, 2014).

This category of measure is a response to situations where the river channel has become hydrologically separated from its floodplain. This can be caused by factors including:

- channel incision, for example due to changes in the sediment regime, or dredging to improve navigation
- flow alteration, particularly the removal of peak flows as a result of dams
- physical barriers, such as levee banks constructed for flood protection, and
- floodplain aggradation.

Drivers for, and benefits from, reconnecting rivers and their floodplains include:

- reduced flood risk
- improved groundwater recharge
- improved water quality
- improved channel stability/reduced erosion, by dissipating energy during floods
- providing habitat for aquatic, riparian, and terrestrial plants, invertebrates, birds and animals
- restoration of natural processes, including erosion and deposition and (greater) nutrient flux
- improvements to aesthetic and recreational values (see generally Gumiero *et al.*, 2013).

THE NATURE OF FLOODPLAIN RECONNECTION

Approaches to restoring lateral connectivity include:

- Directly connecting the river to floodplain wetland: for example by excavating new flood channels.
- Modifying levees: Moving levees back away from the channel increases channel capacity for carrying floodwaters, provides greater room for the channel to meander, and creates floodplain habitat features, such as wetlands and forests. This can both improve flood protection and as well as benefiting wildlife (Opperman, 2014). Modifying levees has been described as providing 'room for rivers' or a 'functional mobility corridor' (Gumiero *et al.*, 2013). This approach has been applied to restoration work in the Rhine (https://www.ruimtevoorderivier.nl/meta-navigatie/english.aspx) and Danube Rivers (Ebert *et al.*, 2009).
- Removing levees or embankments: This measure increases flooding frequency and is reactivate the floodplain's natural dynamics. Removing levees or embankments can be supplemented with deep-ploughing to improve soil permeability and enhance groundwater recharge (Gumiero *et al.*, 2013).
- Geomorphological reconstruction: This approach may involve reshaping banks to gently slope to the water's edge, reducing bed depth by cutting a new channel at a higher elevation (Gumiero *et al.*, 2013), or creating artificial constriction points to reduce the size of flow event that is required for flooding to occur (see for example the Barmah Choke in the Murray–Darling Basin, MDBC, 2008). Alternatively, the floodplain may be excavated.
- Changes to the flow regime: This approach includes, for example, increasing the number, size, frequency and duration of flooding flows (see section 11.3).

CONSIDERATIONS IN FLOODPLAIN RECONNECTION

Even where physical and hydrological challenges can be overcome, development in the floodplain often prohibits the reinstatement of a natural overbank flooding regime, with social and economic pressures to avoid flooding outweighing concerns for habitat and the maintenance of natural river and floodplain dynamics (Stoffels *et al.*, 2013; Acreman *et al.*, 2007) Financial mitigation is instrumental in securing landowner support and ensuring project success.

Connected floodplains can be maintained through real-estate transactions such as acquisition, easements or government funding programs. To maintain the potential for floodplains to be inundated, it can be useful to work with willing landowners to acquire or place under easements floodplain land to maintain it in low intensity land uses (Opperman *et al.*, 2010). In addition to acquisition or easements, emerging markets for ecosystem services, including carbon and nutrient sequestration, floodwater storage, and recreation may be able to provide revenue to landowners that maintain floodplains connected to rivers (Opperman *et al.*, 2010).

Restoration of river-floodplain connectivity may benefit non-native species as well as native ones. This creates a challenge is to ensure that the restored regime benefits native fishes over non-native fishes. (Stoffels *et al.*, 2013).

FURTHER REFERENCE MATERIAL

- A Flood of Benefits: Using Green Infrastructure to Reduce Flood Risks (Opperman, 2014).

Box 47: Case study – Yangtze River Basin

In recent years, Chinese authorities and stakeholders have implemented major initiatives to restore floodplain wetlands in the Central Yangtze region. For decades, these wetlands had been drained for agriculture or urban development or cut-off from the main river by flood defence dikes. A major flood in 1998 prompted the Chinese government to re-evaluate development and water resource management strategies. From this re-evaluation, a '32-character policy' was published, which included four major approaches to flood management, including the restoration of floodplains by removing dikes and returning agricultural polders to wetlands, to enhance flood water storage. WWF then worked with decision-makers in Hubei, Hunan and Anhui provinces, along with relevant national ministries, to trial a reconnection approach that involved re-opening of sluice gates during high-flow periods, with a view to increasing floodwater storage in previously disconnected floodplain lakes, improving water quality in the lakes, and restoring biodiversity. Associated measures included working with local communities to redirect livelihoods to more sustainable, and often more profitable, work including organic agriculture and higher-premium, but less intensive, fisheries. The outcomes from these efforts have been significant. Pittock and Xu (2010) concluded that 2,900 km2 of floodplains have been restored, which has added a floodwater retention capacity of 13 billion m3, reducing flood hydrograph peaks in downstream reaches. WWF (2003) reported that the income of one community of farmers, at Xibanshanzou, had increased by 40% as a result of the programme and (Yu *et al.*, 2009) reported that wild fish catches increased by 15% within a year of the river-lake connection being re-established. Numbers of migratory water birds have also increased and a number of nature reserves have now been designated on the floodplain.

11.7. Riparian management

Riparian management includes measures related to the revegetation of the riparian zone. It also includes the control or removal of exotic species, such as weeds or cattle.

PURPOSE OF RIPARIAN MANAGEMENT

Riparian management aims to improve the capacity of the riparian zone to contribute to river health. The riparian zones act as a buffer between the river and activities in the surrounding catchment. The riparian zone can trap sediment runoff, help filter nutrients, and maintain the food-web and other important links between the terrestrial and aquatic environments. Riparian zones can also be important environments in their own right, and often harbour a high diversity of plant and animal life such as birds. Riparian vegetation provides shade, and thus influences water temperature, particularly in the case of smaller rivers and streams.

Removal of riparian buffers can have a number of negative effects on river health, including:

- increased stream sedimentation and turbidity as a result of decreased bank stability (Barling and Moore, 1994)
- reduced capacity to trap and remove contaminants (Lowrance *et al.*, 1997) and nutrients from runoff (Vought *et al.*, 1994)
- increased water temperature, light penetration, and hence increased primary production (Pusey and Arthington, 2003)
- reduced leaf litter and terrestrial invertebrate inputs, decreasing production (Pusey and Arthington, 2003)
- decreased stream width and reduced woody debris inputs (Karr and Schlosser, 1978; Sweeney *et al.*, 2004), reducing the amount of aquatic habitat.

Riparian management, including revegetation of the riparian zone, aims to restore the functions and processes inherent in riparian vegetation communities (Gregory *et al.*, 1991; Baxter *et al.*, 2005). Common objectives include erosion control, biodiversity enhancement, water quality improvement, weed control, and improved aesthetics and recreation (for example, see Water and Rivers Commission, 1999).

THE NATURE OF RIPARIAN MANAGEMENT

Riparian management can include:

- revegetation of the riparian zone, either through active (i.e. planting of vegetation) or passive (removing disturbances and allowing for natural recovery) means
- management of riparian vegetation, including land use and planning controls to limit the removal of riparian vegetation as well as active interventions to maintain the health of riparian vegetation
- management of livestock, such as excluding them from the riparian zone through fencing or establishing crossings and watering points to reduce the need for stock to access the river channel
- management of invasive weeds (see the South African case study in Box 43).

CONSIDERATIONS IN APPLYING RIPARIAN MANAGEMENT

While process-based approaches that address fundamental barriers to improved river health may be preferable where possible, there are still strong arguments in favour of direct intervention to address riparian degradation. These include the lack of financial, social, or political will to address root causes of system degradation (Guillozet *et al.*, 2014)

Active restoration of the riparian zone (rather than passive restoration through removal of threatening processes) can be required due to the spatial limits of seed dispersal and the temporal limits of seed viability (Broadhurst *et al.*, 2008).

Based on a review of international literature, a UK Forestry Commission report (Broadmeadow and Nisbet, 2002) found that:

- The key factors that influence riparian zone function are the width of the buffer, the structure and composition of the vegetation, and the management arrangements. However, the requirements will vary significantly for different size rivers, and in different regions. For example, the report found that buffer widths in the range of 5–30 m have been found to be at least 50% effective and often > 75% effective at protecting the various stream functions associated with undisturbed forest streams. Based on this data, the report recommended (for UK streams) minimum buffer widths for either side of the channel of 5 m for streams <1m wide; 10 m for streams 1 – 2 m wide; and 20 m for streams >2m wide. These values will not, however, have universal applicability, and different requirements will exist for different river types.
- The composition and structure of riparian buffers should be based on native riparian woodland.
- Native tree species support the greatest diversity and abundance of terrestrial invertebrates and provide a high quality of leaf litter, to the benefit of the aquatic zone.

Other considerations in managing riparian lands include:

- The width of a buffer zone should be adjusted depending on the contours of the landscape. For example, buffer width should be wider in those areas where runoff enters the watercourse (such as where there are channels that enter the watercourse (Askey-Doran *et al.*, 1996).
- Wide riparian buffers are particularly critical in urban rivers to provide physical protection against future disturbance and encroachment (FISWRG, 2001).
- As riparian buffers may extend into private land, legal and policy issues may dictating the extent of any buffer, rather than ecological factors (FISWRG, 2001).

FURTHER REFERENCE MATERIAL

- Riparian Land Management Technical Guidelines (Land and Water Australia, 2008)
- The Effect of Riparian Forest Management on the Freshwater Environment (Broadmeadow and Nisbet, 2002)
- Riparia: Ecology, Conservation and Management of Streamside Communities. (Naiman *et al.*, 2005).

Box 48: Case study – Riparian re-vegetation in the Willamette River Basin, Oregon, United States

Located in the north-west of the US, it is estimated that nearly 40,000 ha of the Willamette Basin's land area requires restoration to protect water quality. One approach adopted for riparian restoration in the basin has been the use of the 'Rapid Riparian Revegetation' or the R3 method, which aims to establish diverse and resilient riparian forests. The method is intended to increase the scope, scale and effectiveness of riparian restoration by promoting the rapid establishment of forests with high diversity and function at a low unit cost through greater efficiency in implementation. The method was developed in response to perceived weaknesses in conventional approaches used in the basin, which had relied on a 'landscaping' approach, rather than one grounded in forestry and ecology. These landscaping approaches involved trees being planted in wide spaces and the use of mowing, herbicides and irrigation until plants were established, but did not result in diverse multilayer canopies and provided ideal conditions for invasive species. The R3 method is built upon ecological principles and aims to address common limiting factors to successful riparian restoration. These factors, along with the R3 approach, are shown in the table below.

Project element	Limiting factor	R3 approach
Site dynamics	Lack of attention to disturbance regimes and ecological boundary conditions. High flows can wash away large nursery stock, plant protectors and irrigation systems.	Conduct detailed evaluation of site conditions. Select flood resistant stock sizes and avoid using plant protectors and irrigation systems.
Reference site data	Sites planted and managed out of context often revert to degraded alternate stable states.	Use reference site data as a 'guiding image' in the context of site conditions and surrounding land uses.
Ground cover establishment	Bare ground allows colonization by broadleaf weeds; tall grasses harbor voles and compete with plantings.	Seed with small-stature native grasses to establish effective cover without swamping plantings.
Species diversity	Species lists are often divorced from local plant communities.	Develop species lists informed by reference site diversity.
Site use by wildlife	Wildlife can kill or damage a large percentage of planted trees and shrubs	Account for historic, current and anticipated wildlife use in species selection and layout; inter-plant with less palatable species.
Plant mortality	Mortality among widely spaced plants creates large gaps; mortality of large planting stock can be costly.	Plant at reference densities to account for normal mortality; inter-plant to adjust composition and density.
Vegetation monitoring	Monitoring methods often evaluate progress towards goals with no ecological basis.	Evaluate revegetation trajectories against ecologically based criteria derived from reference sites.

Source: Guillozet *et al.*, 2014

11.8. Instream habitat improvement

This category includes measures aimed at directly altering the structural complexity of a river ecosystem to increase habitat availability and diversity for target organisms and the provision of breeding habitat and refugia from disturbance and predation.

This category of measures aim to directly improve or create instream habitat for aquatic species, usually in response to the loss or degradation of habitat as a result of human activities, by reintroducing or instigating complexity (of flow, form or process). While sometimes the 'structure' placed in the channel is less than 'natural' in appearance, its purpose is to mimic natural features (often deadwood and bed material features).

PURPOSE OF INSTREAM HABITAT IMPROVEMENT

In natural environments, the complex flow regimes of a river are instrumental in driving the geomorphic processes that shape the channel and instream habitat features. Anthropogenic modifications of river channels through straightening, relocation, confinement and dredging of the channel have been widespread. Such modifications commonly lead to the loss of instream habitat and disconnection of the river with the floodplain.

THE NATURE OF INSTREAM HABITAT IMPROVEMENT

Restoration may involve the use of instream structures to create a diversity of flow velocities to mimic a natural stream and induce local scour and erosion and deposition of riverbed and bank material to produce diverse instream habitats (Brooks *et al.*, 2004). Examples of restoration methods that aim to directly improve instream habitat include:

- The re-introduction of large woody debris improves physical habitat and counteracts stream incision. The re-introduction of large woody debris can be as simple as planting fast-growing tree species on the river bank that will be recruited over time with the natural process of bank erosion or as complex as engineered logjams that have several large trees anchored into the riverbed or bank (Mott, 2010).

- Bed control structures, such as rock chutes, stabilise streambeds, as well as creating a backwater pool form upstream and a stable scour pool downstream (Tasmanian Department of Primary Industries, Parks, Water and Environment, 2003).
- Groynes, retards and log sills reduce flow velocity, thus reducing erosion and promoting the deposition of sediment on the outer banks. This can result in creation of habitat (Yossef & Vriend, 2011).
- Re-introducing large boulders can reduce localised bed scouring, although can be expensive and is often not effective.

A number of more specific approaches related to improving fish habitat are shown in Table 11.1.

Table 11.1. Common structures placed in rivers to improve fish habitat

Approach	Nature of measure	Purpose
Log structures (e.g. weirs, sills, deflectors, logs, wing deflectors)	Placement of logs or log structures into active channel	Create pools and cover for fish, trap gravel, confine channel, or create spawning habitat
Log jams (multiple log structures, engineered log jams)	Multiple logs placed in active channel to form a debris dam and trap gravel	Create pools and holding and rearing areas for fish, trap sediment, prevent channel migration, restore floodplain and side channels
Cover structures (lunker structures, rock or log shelters)	Structures embedded in stream bank	Provide fish cover and prevent erosion
Boulders structures (weirs, clusters, deflectors)	Single or multiple boulders placed in wetted channel	Create pools and cover for fish, trap gravel, confine channel, or create spawning habitat
Gabions	Wire mesh baskets filled with gravel and cobble	Trap gravel and create pools or spawning habitat
Brush bundles/root wads	Placement of woody material in pools or slow water areas	Provide cover for juvenile and adult fish, refuge from high flows, substrate for macroinvertebrates
Gravel additions and spawning pads	Addition of gravels or creation of riffles	Provide spawning habitat for fishes
Rubble matts or boulder additions to create riffles	Addition of boulders and cobble to create riffles	Increase riffle diversity (velocity and depth), create shallow water habitat
Sediment traps	Excavation of a depression or pond in active channel to trap fine sediment	Improve channel conditions and morphology, and increase grain size

Source: Based on FAO (2005), after Roni (2005)

CONSIDERATIONS IN APPLYING INSTREAM HABITAT IMPROVEMENT

While the types of measures described have been shown to improve physical habitat for biota, given the variability in results for various species and structure types, the limited number of statistically rigorous studies, differential responses by different species or life stages, and the cost of instream enhancement projects, projects should be undertaken with careful consideration of scale, basin conditions and processes, and coupled with a rigorous monitoring programme.

In many instances, instream habitat improvement measures will not address underlying causes of river degradation, and efforts to directly reinstate habitat are likely to be undermined if basin-scale issues, such as those related to hydrology, water quality and catchment degradation, are not adequately addressed. Potential benefits of projects can be short lived (< 10 years).

The effectiveness of different measures can vary significantly between species, and with respect to different life stages. Restoration measures need to be carefully tailored to meet the needs.

Restoration projects tend to be most effective where they result in large changes in physical habitat and mimic natural processes. Many of the techniques will not be effective in high-energy channels.

Costs for the introduction of instream structures are dependant on the scale of restoration and availability of natural material, such as rocks and fallen trees, in close proximity to the restoration site (FAO, 2005 and Newbury and Gaboury, 1993). For example, artificial riffles and rock chutes are simple to design and install and have shown excellent results in the restoration of spawning grounds for salmonids.

FURTHER REFERENCE MATERIAL

- Habitat rehabilitation for inland fisheries (FAO, 2005);
- Wetlands and Waterways Works Manual (Tasmanian Department of Primary Industries, Parks, Water and Environment, 2003).

Box 49: Case study – Murray–Darling Basin, Australia

The removal of several million trees across the Murray–Darling Basin following European settlement was identified as a significant factor in the dramatic decline of native fish populations. In response, in 2003 the Murray–Darling Basin Commission started a project to restore structural woody habitats in the Murray River. The project focused on a 194-km stretch of the river where the number of structural woody habitats had been reduced by around 80% in the previous 30 years, a decline that coincided with a low abundance of native fish relative to less disturbed reaches. Between 2003 and 2009 more than 4,500 new 'snags' were reintroduced to this reach of the Murray River to provide habitat to support native fish. Early analysis suggests increasing numbers of key fish species in those areas where woody habitat has been reintroduced. Key lessons identified from the project include:

- bank stabilisation works have reduced natural tree input from eroded banks, requiring the introduction of snags to be incorporated into management plans
- delayed response times in fish populations mean that monitoring programmes need to be designed and funded over a long timeframe
- reinstating instream habitat is expensive and should only be implemented where habitat, and not other environmental factors, is the limiting factor in fish population.

Source: CSIRO, 2012

11.9. Bank stabilization

Bank stabilization includes measures that are designed to reduce or eliminate erosion or slumping of bank material into the river channel. Some degree of bank erosion can be desirable, as bank erosion is an important component of the natural disturbance regime of river systems and the long-term geomorphic evolution of fluvial systems (Florsheim *et al.*, 2008).

PURPOSE OF BANK STABILIZATION

Bank stability is important for river health because:

- biota are presumed to prefer relatively stable physical surfaces over highly unstable ones
- erosion of bed and bank material results in high turbidity, and downstream deposition of sediment, both of which can be detrimental to biota[16] (Gippel *et al.*, 2011).

Bank stabilization measures aim to address the underlying processes that result in high bank erosion rates, where the force of water is greater than the resistive forces of the bank material. Stabilization can be required where changes in river ecosystems, such as an altered flow regime, land development or the loss of riparian vegetation has resulted in accelerated erosion (FISWG, 1998). In some instances, erosion levels may be no greater than under natural conditions, but may be considered unacceptable as a result of human development in and around the river corridor and the impacts of any further erosion on infrastructure.

From a river restoration perspective (as opposed to river engineering) bank stabilization can:

- reduce sediment loads entering the watercourse and reduce turbidity
- help maintain the capacity of the stream channel, for example for flood mitigation or transportation
- improve recreational opportunities along the riverbank, for example by allowing for the establishment of new recreational areas
- prevent the loss of stream bank vegetation and improve habitat for fish and other biota (although loss of vegetation can be an important aspect of riparian renewal).

THE NATURE OF BANK STABILIZATION

There are three general approaches taken to bank stabilization (Tennessee Valley Authority, n.d.):

1. Live plantings: establishing plants, by seeding or planting container-grown plants, on the upper bank and floodplain.
2. Bioengineering: involving a combination of structural components and plant material to produce a dense stand of vegetation. The structural components, such as coconut fibre rolls, provide temporary protection while the plant growth becomes established. Bioengineering can also involve bank shaping to reduce the slope of the bank.
3. Hard armouring: a variety of techniques including rock riprap (large stones placed along the slope of a streambank or shoreline) and gabions (rock-filled wire baskets placed along a streambank or shoreline). Hard armouring for river restoration typically involves grading the bank to a gentler slope.

CONSIDERATIONS IN APPLYING BANK STABILIZATION

Infrastructure-based solutions (e.g. hard armouring) can be attractive to engineers and politicians. However, for many rivers, erosion is a natural process that delivers much need sediment to the channel and acts to re-new floodplains. Bank stabilization is generally only warranted in situations where erosion rates are well above historically natural rates.

The most suitable technique for bank stabilization will depend on the situation, including the size and location of the stream and the cause and severity of the erosion. In many cases, a combination of techniques may be optimal.

To be effective over a range of flow heights, bank stabilization in conjunction with riparian revegetation methods (see section 11.7) may be necessary. Reshaping of the bank to a more stable angle of repose is also used in conjunction with re-enforcement of the toe of the bank with more resistant material than is present in the bank itself.

16. Some biota, including certain fish (e.g. catfish) and invertebrates, are well adapted to sediment and high turbidity levels.

One challenge with both live plantings and bioengineering is protecting the bank from erosion until the vegetation becomes established, which can take several years. Earthworks and the use of more resistant material, such as large rock and root wads, can be expensive and can sometimes exacerbate the problem when large machinery has to access the riverbank.

Hard armouring can provide very good protection and will work in severe situations where bioengineering will not. There are negatives, however, including cost and loss of habitat as hardening of banks is a major cause of habitat degradation (Schmettering *et al.*, 2001). Hard armouring measures can also result in sharper rises in the flood hydrograph and generally alter flows in such a way as to result in increased erosion further downstream.

Where bank stabilization measures prevent the channel from moving (as will occur with hard armouring), they are unlikely to assist with restoring natural channel processes, and may even hinder the process.

There are also potential conflicts between stabilization measures aimed at improving habitat (such as live plantings and bioengineering) and hard armouring to protect property and infrastructure.

FURTHER REFERENCE MATERIAL

- Tennessee Valley Authority (n.d.) Using Stabilization Techniques http://www.tva.gov/river/landandshore/stabilization/stabilization.htm.
- US Environmental Protection Agency (n.d.) http://water.epa.gov/polwaste/nps/urban/upload/2003_07_03_NPS_unpavedroads_ch5.pdf
- Stream Management (Fischeninch and Allen, 2000).

Box 50: Case study – Willow spilling, United Kingdom

At least 47 km of river bank in the UK has been protected by willow spilling during the last 20 years, making it the most widely used willow-based method for erosion control in the UK. In this method, long willow canes are woven around vertically driven willow poles. Because these structures are living, resistance to erosion increases over time. Willow spilling, along with associated bank stabilization, has ecological benefits for riverine ecosystems. Three willow species are commonly used in the UK: (Crack Willow) Salix fragilis, (White Willow) Salix alba and (Common Osier) Salix vimnalis. On a turbulent section of the River Ive in Bedfordshire, a one-tiered, two-metre tall revetment was successfully installed in the mid-1990s. This site, which was 100 metres downstream of a mill weir, now has willows grown into mature trees of 20 cm in diameter and over 10 metres high. Many thicker stems and shoots have appeared along the whole length of the revetment, ensuring a locally relevant self-rejuvenating mechanism for bank stabilization (Anstead and Boar, 2010).

11.10. Channel reconfiguration

Channel reconfiguration alters channel plan forms or longitudinal profiles or converting culverts and pipes to open channels (day-lighting). It also includes stream meander restoration and in-channel structures that alter the thalweg of the stream.

PURPOSE OF CHANNEL RECONFIGURATION

Channel-based or 'hydromorphological' restoration projects are extremely common worldwide (Bernhardt and Palmer 2011). These approaches aim to restore the diversity of physical habitat where disturbances or past management practices have resulted in the simplification of the channel form, for example where rivers have been straightened or otherwise channelized, or where instream habitat has been lost, such as due to mining or dredging.

Channel reconfiguration projects are usually a response to disturbances that are so severe that the removal of existing pressures and stressors, and changes to the flow regime are unlikely to restore the channel to the desired condition within an acceptable timeframe. In these cases the channel may be artificially reconstructed, with the aim of restoring river ecosystem functions by establishing a more 'natural' physical condition.

River channel design can be based on single-species restoration or an ecosystem restoration approach (FISWRG, 2001). In the single-species restoration approach, the channel reconfiguration targets the habitat requirements of certain life cycle stages of a particular species. Alternatively, the ecosystem restoration approach focuses on the chemical, hydrologic, and geomorphic functions of the river. This approach is based on the (unfounded) assumption that once the channel can handle the prevailing flow and sediment fluxes that species assemblages, primary production, decomposition, nutrient processing, and other ecosystem processes will be restored (Palmer *et al.*, 2014).

Common reasons for channel reconfiguration include:

- improved water conveyance in flood-prone areas, typically by slowing the flow of floodwater and thus reducing flood peaks
- mitigation of unstable river bed and banks
- increased sediment transport
- enhancement of riparian habitat, and
- improved recreational opportunities (USGS, n.d.; Roni and Beechie, 2013).

THE NATURE OF CHANNEL RECONFIGURATION

Channel reconfiguration includes direct interventions to physically reconstruct the river channel. This involves determining the dimensions of the channel – such as its width, depth, slope, and cross-sectional shape – as well as the size of bed sediments (FISRWG, 1998), and then engineering works to alter the existing channel to meet the design requirements.

There is a wide range of literature on the different methods for and risks associated with designing channel reconfiguration (see Further reference material below).

CONSIDERATIONS IN APPLYING CHANNEL RECONFIGURATION

Channel reconfiguration is underpinned by the largely untested assumption that if required habitat conditions are recreated, then biological restoration will follow; this is the so called 'Field of Dreams' theory, that 'if you build it, they will come' (Palmer *et al.*, 1997). For this, and related reasons, channel reconfiguration projects can fail to address issues required for true restoration, like water allocation or increasing infiltration capacity of watershed (Palmer, 2014).

In designing channel reconfiguration projects, it is important to recognize and work with the natural geomorphological processes of the target river. This is in contrast to approaches that simply use reconfiguration via hard structures (rock, concrete) as a means of redirecting the river along an alternate path.

In some instances, the most cost-effective method for achieving channel modification may be partial intervention for assisted recovery, where a river is attempting to recover, but is doing so slowly or uncertainly and where restoration activities may facilitate the process. Using the rivers natural ability to form diverse instream habitats and a more stable planform over time will achieve the best outcome if restoration methods are used to assist in this process and realistic goals and timelines are set for the project.

Where a river's hydrology and sediment load has been altered as a result of land use changes or other factors, channel reconfiguration should not target the historic channel condition. Rather, the new channel design should be developed with regard to the prevailing conditions (FISRWG, 2001).

Channel modification methods can be popular with the public because they produce more immediate results, but can be very expensive (Gordon *et al.*, 2013).

The planning process for reconfiguration projects can be long and involve a number of interested stakeholder groups that may be impacted by a change in the river path through the landscape and can require the buyback of land adjacent to the river.

Channel reconfiguration can have negative short-term impacts (such as the loss of instream and riparian habitats; increased erosion), as a result of the re-engineering works.

FURTHER REFERENCE MATERIAL

- Stream Corridor Restoration: Principles, Processes, and Practices. (FISRWG, 2001)
- Reconfigured Channel Monitoring and Assessment Program. (USGS, n.d.(b))

Box 51: Case study – Isar River, Germany

The Isar River, a tributary of the Danube River, runs through the centre of Munich, Germany. Restoration of the Isar River was primarily driven by the fact that flood defences did not meet existing technical standards, as well as a growing demand by for more recreational space. River health was also considered poor, both in terms of water quality and the loss of biota. These calls for a more natural and recreational river together with flood control were combined to form one project (see Box 13).

The new flood protection measures were designed to withstand a one in a hundred year event. To do this, the river channel was widened by 30%, the bank and flood corridor lowered to allow for greater discharge and existing dykes had to be improved. Retaining walls were sunk into the dykes to give them greater strength and they were made wider to increase stability. There were multiple benefits from these improvements. Widening the riverbed improved the deposits for gravel so gravel banks returned and the re-modelling of the river channel and floodplain, which was kept as meadow, opened access to the public for recreation. A number of weirs were also replaced with natural rock ramps to improve fish passage.

As well as a significant reduction in flood risk, the restoration works have resulted in other benefits, including:

- Ecological improvements: The relocation of dykes improved structural variability within the habitat; the removal of weirs reconnected the river, enabling transportation of sediment and providing vital habitats for spawning fish and invertebrates; and flowering meadows and gravel banks created new habitats for butterflies and other biota.
- Recreational opportunities: The measures improved the access and use of the river and floodplain to the general public, providing better recreational facilities for more than 1 million inhabitants in the city and tourists. The draw for people to use the river in Munich as an outdoor recreational area, allows for greater protection of other sections along the Isar to protect threatened species and habitats.
- Water quality: Among other things, the city of Munich built has implemented measures to reduce the storm water flow into the Isar. Water quality in the river during normal flow is now very good.

Source: Tickner, 2013

11.11. Water quality management

This section deals with measures that protect existing water quality or change the chemical composition or suspended particulate load so as to improve river or stream water quality.

PURPOSE OF WATER QUALITY MANAGEMENT

Declines in water quality are one of the most significant threats to river health (see section 1.3) and improving water quality has been a primary goal of river restoration projects and strategies since some of the first restoration initiatives (see section 2.4).

Management measures may be targeted at improving any or all of the many parameters that are commonly used to assess water quality, including temperature, turbidity, conductivity, pH, nutrient levels, and the presence of heavy metals. Measures commonly target water quality outcomes in accordance with standards related to the designated use of the particular water body, for example standards related to drinking water or recreational use (see Box 36).

A number of the other categories of measures included in this chapter also address water quality issues, including measures related to catchment management (section 11.2), flow modification (section 11.3), stormwater management (section 11.5), and riparian management (section 11.7). These different measures can each have different consequences for water quality parameters (see Table 11.2).

Table 11.2. Potential water quality impacts of different restoration measures

	Fine sediments	Water temp	Salinity	pH	Dissolved Oxygen	Nutrients	Toxics
Reduction of land disturbing activities	↓	↓	↓	↑↓	↑	↓	↓
Limit impervious surface area in the basin	↓	↓		↑	↑	↓	↓
Restore riparian vegetation	↓	↓	↓	↓	↑	↓	↓
Restore wetlands	↓	↑↓	↑↓	↑↓	↓	↑	↑
Stabilise channel and banks	↓	↓	↓	↓	↑	↓	
Re-establish riffle substrate				↑↓	↑		

↑ indicates an increase in the water quality parameter as a result of the measure, ↓ indicates a decrease and ↑↓ indicates that the parameter may increase or decrease. No arrow indicates negligible effect.
Source: FISRWG, 2001

This section focuses primarily on measures aimed at (i) removing or mitigating the effects of pollutants already present in a river system and (ii) reducing the pollutant load from point source pollution.

THE NATURE OF WATER QUALITY MANAGEMENT

Reducing point source pollution loads may involve:

- reducing the amount and type of pollutants produced, for example through improved operational procedures (e.g. different manufacturing processes or practices)
- improving filtration or processing of pollutant waste, to reduce the amount and nature of waste that enters the river ecosystem.

Wastewater impacts may be reduced through more stringent discharge standards for wastewater treatment plants, tertiary treatment and filtration capability, use of bio-retention basins to further treat effluent, recycling of treated effluent to reduce outputs, and minimisation or re-use of pollutant residuals and biosolids from wastewater treatment plants.

In the mining sector, water treatment methods that reduce the potential for water contamination and minimize the amount of water requiring treatment include, interception and diversion of surface water, recycling water used for processing ore, capturing drainage water and storage in tailing dams, evaporation ponds and installation of liners and covers for waste rock and ore piles (Lottermoser, 2012). Active treatment include the use of settling ponds and flocculants to remove contaminants from the water column as well as ion exchangers, membrane filters and reverse osmosis. Treated water can be recycled for use in the mining process to reduce the amount of water used overall and decrease the amount of treated effluent discharged into rivers. Passive treatment methods include the use of bacteria-controlled metal precipitation, uptake of contaminants by plants (bioremediation) and filtration through soil and constructed wetlands (Wolkersdorfer, 2008).

In addressing industrial pollutant loads the use of inline filtration systems, similar to wastewater treatment plants are common but biological filtration using bio-retention basins and constructed wetlands are often a cost effective approach to the treatment of effluents. Often these are more feasible for industrial operations that are smaller in size, deal with non-hazardous waste and have effluent treatment capacity that is not strongly influenced by wet weather flows. Re-use of treated effluent and conversion of biosolids into renewable energy are also progressive approaches to managing pollutant loads from these industries (Pescod, 1992).

There are various policy and regulatory measures that can be put in place to encourage or require the changes necessary to reduce point source pollution. These can include:

- minimum standards for water treatment plants, industries, mines, and other polluting businesses, in terms of both processes that result in the production of waste as well as the treatment of that waste
- use of discharge permits to limit the pollutant load entering a river ecosystem, coupled with planning mechanisms to identify the total pollutant load that can be released without compromising water quality objectives
- responsibilities for risk management related to potential pollution events
- water stewardship approaches, which encourage voluntary action on the part of relevant businesses (see for example www.allianceforwaterstewardship.org/ and http://wwf.panda.org/what_we_do/how_we_work/conservation/freshwater/water_management/).

In some instances, existing pollutants in a river ecosystem may be of a type or level such that reducing further pollutant inputs and improving flows will not be sufficient to achieve the required river health outcomes within an acceptable timeframe. In such cases, more direct interventions may be required. This may involve:

- Physical methods: for example dredging to remove contaminated sediments; isolation and coverage, whereby layers of fine sand or mud are used to cover a contaminated riverbed to isolate the pollution section; aeration to artificially increases oxygen levels, particularly to support the degradation of organic pollutants; improved flows to dilute pollutants (see section 11.3, flow regime).
- Chemical methods: for example, the use of algaecides in response to algal blooms.
- Biological methods: for example, the introduction of microbes or the use of plants to absorb and remove contaminants from the environment (see Zhong, 2007; Tang *et al.*, 2012; Xu *et al.*, 2004).

CONSIDERATIONS IN APPLYING WATER QUALITY MANAGEMENT

Improving water quality is a key element of river health and many other restoration objectives may be unsuccessful where water quality is poor. Efforts to improve water quality need to consider any changes in the basin that will affect the inputs and processes that drive water chemistry and water quality outcomes. In identifying different types of measures, it is important to consider what aspects of the river ecosystem will be affected and in what way.

Active treatment methods are costly in terms of power requirements and maintenance of treatment plant equipment (e.g. filtration units, membranes). However, upgrades to treatment plants to achieve more stringent discharge standards have resulted in significant improvements to water quality and aquatic ecosystem health over relatively short time periods (see the Mersey River case study in Box 52). Domestic wastewater treatment plants are applicable in all urbanized areas and urban local bodies are usually involved in their implementation. Meanwhile, policy and regulatory mechanisms are necessary to drive investment by industries in effluent treatment. The type and scale of treatment required by an industry depends on its nature; more hazardous/toxic wastewater usually requires greater treatment to meet regulatory standards.

Where new (improved) waste treatment and discharge standards are implemented, these will often involve new costs, both capital and operational. Consideration needs to be given to who should pay for these (e.g. the polluter or the beneficiary).

FURTHER REFERENCE MATERIAL

- Stream Corridor Restoration: Principles, Processes, and Practices. (FISRWG, 2001)
- Wastewater treatment and use in agriculture (Pescod, 1992).

Box 52: Case study – Mersey River, United Kingdom

In an effort to rid the Mersey Estuary of its unenviable title of the most polluted estuary in Europe, North West Water (the then public water utility in the Mersey region) in 1981 embarked on a clean-up scheme designed to counteract the years of misuse and neglect. From an analysis of the river's main problems, it was seen that levels of oxygen within the main river systems and Mersey Estuary, driven by the high levels of sewage discharged into the waterways, was a major stumbling block to improved water quality. One of the first steps was to tackle direct discharges of crude sewage into the region's waterways. For example, new primary sewage works at Sandon Dock replaced 28 crude sewage discharges directly into the Mersey Estuary through the Mersey Estuary Pollution Alleviation Scheme, diverting wastewater to a new treatment works. This was just one programme initiated as a direct result of massive investment by North West Water (and its private- sector successor utility company, United Utilities) in sewage treatment.

Further improvements to the treatment of wastewater now include tertiary treatment for the removal of ammonia from wastewater. Exposure to short periods of ammonia may kill salmonid fish species. For example, at Davyhulme wastewater treatment works in Greater Manchester, a natural purification process using a biological aerated flooded filter process removes ammonia, reducing discharges into the Manchester Ship Canal. Water quality improvements now mean the Mersey supports a wide range of fish species, including migratory fish such as salmon apart from other species like trout, lamprey and dace. The increase in the numbers of fish in the river has encouraged a number of other animals to return to the Estuary. These include porpoises, grey seals and even octopus (Mersey Basin Campaign, n.d.)

11.12. Instream species management

This category includes measures that directly alter aquatic native species distribution and abundance through the regulation, addition (stocking) or translocation of animal and plant species and/or removal of exotics.

PURPOSE OF INSTREAM SPECIES MANAGEMENT

Instream species management directly manages aquatic species to achieve desired river health outcomes. This may involve protecting, enhancing, or restoring populations of target aquatic species that are of importance: for example species with high biodiversity value or commercial value (e.g. for fishing), or species that provide other priority ecosystem services. Alternatively, it may involve the removal of pest species that pose a threat to river health.

THE NATURE OF INSTREAM SPECIES MANAGEMENT

This measure can involve:

- regulation of the take of aquatic species, e.g. prohibitions or limits on the type and number of aquatic species (e.g. fish, shellfish) that can be taken
- restocking, e.g. the release of fish or other species into an ecosystem in which a population of that species already exists
- species translocations aimed at reversing historical declines in the status of species of conservation significance. Conservation translocations involve of reinforcement and reintroduction within a species' indigenous range. Conservation introductions, involve assisted colonisation and ecological replacement outside indigenous range.

Measures may also involve the removal of invasive animals or plants, where they pose a threat to other (usually native) species (e.g. through predation or competition), or where they impact on the provision of ecosystem services (such as invasive plants that clog waterways, reducing flows and hindering navigation).

CONSIDERATIONS IN APPLYING INSTREAM SPECIES MANAGEMENT

There can be significant risks with the translocation of species, based on their potential affect on both the focal species as well as other species, their associated communities, and ecosystem functions, in both the source and destination areas. Any proposed translocation should have a comprehensive risk assessment with a level of effort appropriate to the situation.

Translocations of organisms outside of their indigenous range are considered to be especially high risk given the potential for adverse impacts.

Social, economic and political factors must be integral to translocation feasibility and design. These factors will also influence implementation and often require an effective, multi-disciplinary team, with technical and social expertise representing all interests (IUCN/SSC, 2008).

FURTHER REFERENCE MATERIAL

- Guidelines for Reintroductions and Other Conservation Translocations (IUCN/SSC, 2013)
- FAO Technical Guidelines for Responsible Fisheries (FAO, 2012c).

Box 53: Case study – Reintroduction of beavers (Scotland) and anadromous fish (New York City)

The European beaver (Castor fiber) became extinct in the UK about 400 years ago. In May 2008, the Scottish Government licensed a trial reintroduction of beavers to Knapdale Forest, near the west coast of the country. This trial was stimulated in part by the EU Habitats Directive, which requires EU Member States to assess the potential to reintroduce certain species, including the beaver. The licence was granted to a partnership of NGOs and research institutions led by the Scottish Wildlife Trust and the Royal Zoological Society of Scotland (RZSS). The first reintroduced beavers were caught in Norway in 2008, quarantined for six months and released in spring 2009. The trial period ended in May 2014. A condition of the licence stipulated that Scottish Natural Heritage should coordinate independent scientific monitoring of the trial. This monitoring included assessment of socio-economic outcomes, including public health, and the impacts of beavers on other aquatic species, habitats and ecosystem functions woodland. A synthesis report drawing on this monitoring effort, along with other literature and beaver reintroduction case studies, was produced by Scottish Natural Heritage for the Scottish Government in June 2015 (Scottish Natural Heritage, 2015) ahead of a final decision being made about continuing the reintroduction process. The report concluded that, although some species of conservation concern might be adversely affected by the presence of beavers in the ecosystem, overall the effect of reintroductions on biodiversity was very positive. Impacts on ecosystem services could be mixed and depended on location. Four scenarios for future beaver management in Scotland were suggested ranging from complete removal of beavers from the country to widespread expansion of the reintroduction programme. The trial process stimulated wide public debate and strong opinions for and against reintroduction. At the time of writing this book, the Scottish Government was still to make a final decision about whether or not to continue the reintroduction programme.

The connection between the marine and riverine systems of the Bronx River in New York has been severed since the 1600s when the first dam was erected. Alewife reintroduction is part of an effort to increase habitat availability regionally and support and increase biodiversity locally. Alewife and blueback herring populations are declining throughout the northeast due to a number of factors including pollution, poor fisheries management and barriers to migration. Stocking alewife in the Bronx River will provide the species as a whole with additional habitat. Alewife recolonization can also result in a net import of nutrients to the riverine system, which potentially can increase decomposition rates within the river (New York City Department of Parks & Recreation, n.d.). Through the stocking efforts, alewife and other anadromous fish once again are able to pass from river to ocean.

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Note that for the Chinese case studies referenced in this book, much of the material relies on contributions made by members of the GIWP team, based on documents that are not publicly available. In these instances, the source of the material is referenced as 'GIWP'.

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RIVER RESTORATION
A strategic approach to planning and management

River restoration is now a common response to declining river health and its importance to water resources management can only be expected to grow. However, many traditional approaches to river restoration are unsuitable for addressing the complexity associated with basin-scale restoration in heavily developed and contested river basins.

Drawing on experiences from around the world, this book presents a framework for a more strategic approach to planning and implementing river restoration measures. The framework is designed to balance the multiple roles performed by river systems and to support river restoration that better aligns with the broader social, economic, and ecological objectives for a basin. In addition to describing the history and evolution of approaches to restoration, the book considers issues including: setting restoration goals and objectives; assessing the costs and benefits of restoration measures; prioritising restoration measures; and restoring urban rivers.

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