Edited by Laurence Smith, Keith Porter,
Kevin Hiscock, Mary Jane Porter and David Benson

Catchment and River Basin Management

Integrating Science and Governance

Earthscan Studies in
Water Resource Management

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Catchment and River Basin Management

The central focus of this volume is a critical comparative analysis of the key drivers for water resource management and the provision of clean water – governance systems and institutional and legal arrangements. The authors present a systematic analysis of case study river systems drawn from Australia, Denmark, Germany, the Netherlands, the UK and the USA to provide an integrated global assessment of the scale and key features of catchment management.

A key premise explored is that despite the diversity of jurisdictions and catchments there are commonalities to a successful approach. The authors show that environmental and public health water quality criteria must be integrated with the economic and social goals of those affected, necessitating a 'twin-track' and holistic (cross-sector and discipline) approach of stakeholder engagement and sound scientific research.

A final synthesis presents a set of principles for adaptive catchment management. These principles demonstrate how to integrate the best scientific and technical knowledge with policy, governance and legal provisions. It is shown how decision-making and implementation at the appropriate geographic and governmental scales can resolve conflicts and share best sustainable practices.

Laurence Smith is Professor of Environmental Policy and Development in the Centre for Development, Environment and Policy, SOAS, University of London, UK.

Keith Porter is Adjunct Professor at Cornell Law School and the former Director of the New York State Water Resources Institute, Cornell University, Ithaca, USA.

Kevin Hiscock is Professor of Environmental Sciences, University of East Anglia, UK.

Mary Jane Porter is recently retired from the New York State Water Resources Institute, Cornell University, Ithaca, USA.

David Benson is Lecturer in Politics at the University of Exeter, UK, based at the Environment and Sustainability Institute (ESI) in Penryn, Cornwall.

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Contributors

David Benson is a Lecturer in Politics at the University of Exeter. His research, based at the Environment and Sustainability Institute (ESI) in Penryn, encompasses multiple areas at the interface between political and environmental sciences, most notably EU environmental and energy policy, comparative environmental politics and governance, and public participation in environmental decision-making.

James Curatolo resides in the Finger Lakes Region of New York State. He is Chairman of the Wetland Trust and Wetland Team Leader for the Upper Susquehanna Coalition.

Kevin Hiscock is Professor of Environmental Sciences at the University of East Anglia, Norwich and has 30 years of experience researching the impacts of land use and climate change on surface water and groundwater quantity and quality. His ongoing research is testing measures to mitigate diffuse pollution runoff from arable agriculture.

Mark Horton is the manager of Ballinderry Rivers Trust and its environmental consultancy business River Care Ltd. Previous to this, between 2004 and 2012 he coordinated projects for the Trust, including the RIPPLE project.

Alex Inman is an independent social researcher working in the field of integrated catchment management, both in the UK and internationally. Alex worked as a researcher and consultant in the RELU-funded project on Catchment Management for the Protection of Water Resources that led to this book.

Tobias Krueger is a junior professor at the Integrated Research Institute on Transformations of Human-Environment Systems of Humboldt-Universität zu Berlin. One strand of his research is the model-based support of land-water management with emphasis on uncertainty estimation and stakeholder participation. Tobias also advances methods development in these two areas.

Mike Lovegreen worked as manager of the Bradford County Conservation District in Pennsylvania for over 30 years, and now splits his time between project coordination for the district and work as Stream Team Coordinator for the Upper Susquehanna Coalition. He is also Leadership Development Program Coordinator for Pennsylvania State Conservation Commission, setting up programmes for conservation districts in the state.

Stephen C. Maberly is Head of the Lake Ecosystems Group at the NERC Centre for Ecology and Hydrology based at Lancaster. He has a broad expertise in lake ecology and a specific interest in carbon; its fixation by phytoplankton and macrophytes and its role in global cycles.

Lisa Norton is Head of the Land Use Group at the NERC Centre for Ecology and Hydrology (CEH) based at Lancaster. She has worked with CEH for the last 14 years and specialises in agricultural impacts on the environment at landscape scales. She manages the Countryside Survey, a national integrated monitoring scheme for the UK.

Keith Porter is Adjunct Professor of Law at Cornell University Law School. He was the US Principal in the international catchment management research project that led to this book. As Director of the New York State Water Resources Institute at Cornell from 1986 to 2007 he led interdisciplinary research and outreach programmes in New York State, including the nationally significant New York City Watershed Protection Program.

Mary Jane Porter recently retired after long experience as an extension and water specialist with New York State Water Resources Institute (WRI) at Cornell University. Her work included management of the WRI Competitive Grants Program and co-management with the NYS Department of Environmental Conservation of the Hudson River Estuary Program and the NY Project WET (Water Education for Teachers).

Laurence Smith is Professor of Environmental Policy and Development in the Centre for Development, Environment and Policy at SOAS, University of London. His interests span natural resources, rural development and water resources management. He was Principal Investigator for the research project on Catchment Management for the Protection of Water Resources that led to this book.

Diane Tarte is Director of Marine Ecosystem Policy Advisors in Brisbane, Australia, and specialises in providing advice on policy and programmes addressing research and management of marine, coastal and catchment areas, with particular focus on ecosystem-based management of catchments, waterways and fisheries. From 2002 to 2010 she was Project Director for SEQ Healthy Waterways Partnership, leading a regional programme delivering science, monitoring, capacity-building and communications activities.

Judith Tsouvalis is a research associate working for the Leverhulme Trust on the ‘Making Science Public’ programme, based at the Institute of Science and Society (ISS), School of Sociology and Social Policy, University of Nottingham. As a human geographer she is interested in people’s relations to nature and in the politics of nature, both of which she has empirically and theoretically explored in the contexts of forestry, farming and catchment management.

Claire Waterton is Senior Lecturer and Director of the Centre for the Study of Environmental Change (CSEC) within the Sociology Department at Lancaster University. Her research and teaching uses the theoretical approaches developed in Science and Technology Studies (STS) to explore contemporary environmental and policy problems.

Nigel Watson is a member of the Lancaster Environment Centre at Lancaster University. His research and teaching interests are in the area of water and environmental governance, and he advises governments and catchment groups on institutional arrangements and collaborative decision-making.

Ian J. Winfield is a member of the Lake Ecosystems Group at the NERC Centre for Ecology and Hydrology based at Lancaster. His research interests focus on the ecology of lake fish populations and communities and their assessment and management, with specific interests in rare fish conservation and sustainable fisheries.

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Foreword

Water is one of the most basic human needs. Protection of water supplies and the governance this entails must concern us all, whether that is at a global or local level. The complexity of this kind of challenge requires a holistic approach, drawing in not only researchers from across different disciplines but from a wide range of organisations and individuals. The Rural Economy and Land Use Programme (RELU) was underpinned by just such a philosophy. When it was launched in 2003, as an unprecedented collaboration between three research councils, it aimed to investigate the multiple challenges facing rural areas. One of these was the management of land and water use for sustainable water catchments. Other topics encompassed restoring public trust in food chains, tackling animal and plant disease, enabling sustainable farming in a globalised market, promoting robust rural economies and developing land management techniques to deal with climate change. None of this could be achieved without secure, sustainable water supplies for the benefit of people and of our environment. In this book, researchers who contributed to the RELU Programme and colleagues from across the world examine these complex issues and put forward innovative approaches that could help to address them.

Professor Philip Lowe,
Director, Rural Economy and Land Use Programme

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Among professionals, in the USA particular thanks for their generous sharing of time, knowledge and experience are owed to Dean Frazier, Patricia Bishop, Steve Pacenka, Scott Cuppett, Katy Dunlap, Simon Gruber and Fran Dunwell. The time, support and information provided by co-authors in this book Jim Curatolo and Mike Lovegreen, and by their USC colleagues, were also immense. Valuable background research contributions were made by Sorell Negro, Julia Dobtsis and Michael Bowes. From Australia, Di Tarte and Eddie Hergerl provided invaluable information and advice, aided by colleagues from the Healthy Waterways Partnership. In Denmark, Gitte Ramhøj, Per Grønvald, Lise Kristensen, Lars Mortensen and Anne Jensen kindly shared their time and experience with us. In Germany, we were similarly aided and supported by Christina Aue, Onno Seitz and their colleagues; and in the Netherlands by Nico van der Moot, Auke Kooistra and colleagues. In Ireland, Mark Horton, Claire Cockerill, Ann Marie McStocker and colleagues facilitated study of the WWF RIPPLE project and work of the Ballinderry Rivers Trust. At Loweswater in England, the assistance provided by Ken Bell stands out among the participation and many contributions by local residents. Elsewhere in England we have learnt in particular from the work of the Westcountry Rivers Trust in south-west England, aided by Dylan Bright, Laurence Couldrick, Ross Cherrington and their colleagues; also from the work of the Broads Authority and Upper Thurne Working Group in East Anglia, aided by Andrea Kelly, Simon Hooton and colleagues. Other leading contributors to the RELU-funded research who provided invaluable assistance and insights include Hadrian Cook, Alex Inman, Jon Hillman and Andrew Jordan.

Part I

Overview

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1 The challenge of protecting water resources

An introduction and the purposes of this book

Laurence Smith, Keith Porter, Kevin Hiscock, David Benson and Mary Jane Porter

The necessity of integrated catchment management

Healthy ecosystems, a clean environment and safe water supplies are vital to human health, quality of life and economic well-being, and thus to the overarching goal of sustainable development. It is a simple truism that our water resources are irreplaceable. They meet our needs for drinking, food and fibre production and hygiene, and they sustain the industries and ecosystems that support our livelihoods and lifestyles (Millennium Ecosystem Assessment, 2005). Protection of the natural ecosystems of river basins and the restoration of degraded water catchments are crucial to securing the world's water supplies, maintaining their quality, regulating floods, mitigating threats to water security from climate change, conserving biodiversity and enhancing cultural benefits and social values (Vörösmarty *et al.*, 2010; UNEP, 2011).

Beyond all other natural resources it is in our use of fresh water that our dependence on a healthy environment is most evident. Society has entered an era defined by the confrontation between natural limits to our resource use and growth in human demands in which the challenges of water resource management are at the forefront. These are global challenges as the amount of fresh water on Earth is finite. Achievement of social and economic development, improved social equity and stability, and the conservation of aquatic habitats and biodiversity all depend on our management of this scarce resource. Put simply, good water management is essential for sustainable development.

Despite this need, water resources continue to be degraded and although this is catalogued by an increasing frequency and volume of international meetings and reports, remedial actions at both catchment and river basin scale often remain inadequate. The following quotes highlight some of the challenges.

Water scarcity

> More than 40% of the global population is projected to be living in areas of severe water stress through 2050.

> There is clear evidence that groundwater supplies are diminishing, with an estimated 20% of the world's aquifers being over-exploited, some critically so.
>
> (WWAP, 2014)

> There are major uncertainties about the amount of water required to meet demand for food, energy and other human uses, and to sustain ecosystems. These uncertainties are compounded by the impact of climate change on available water resources.
>
> (WWAP, 2012)

Degraded water quality

> Over 80 per cent of sewage in developing countries is discharged untreated directly into water bodies.
>
> Industry is responsible for dumping an estimated 300–400 million tonnes of heavy metals, solvents, toxic sludge and other waste into waters each year.
>
> Nutrient enrichment has become one of the most widespread water quality problems, severely degrading freshwater and coastal ecosystems.
>
> The biodiversity of freshwater ecosystems has been degraded more than any other ecosystem, including tropical rainforests.
>
> (UN Water, 2011)

Nutrient pollution

> The sustainability of our world depends fundamentally on nutrients. In order to feed 7 billion people, humans have more than doubled global land-based cycling of nitrogen (N) and phosphorus (P).
>
> The world's N and P cycles are now out of balance, causing major environmental, health and economic problems that have received far too little attention.
>
> Unless action is taken, increases in population and per capita consumption of energy and animal products will exacerbate nutrient losses, pollution levels and land degradation, further threatening the quality of our water, air and soils, affecting climate and biodiversity.
>
> (Sutton *et al.*, 2013)

Failures in the sustainable management of water resources are evident in most regions of the world. Extreme and well-known examples include the Aral Sea, diminished in volume and area by abstraction from its tributaries, and the 'Dead Zone' of the Gulf of Mexico. The latter occurs regularly and consists of a swathe of shallow coastal waters up to 22,000 square kilometres in area (equivalent to the state of New Jersey) within which there is not enough oxygen in the water to support marine life. This is caused in large part by the run-off from farms in the mid-west of the USA, from where excess nitrogen and phosphorus lost from liberal use of fertilizers on farmland is carried by the Mississippi to the Gulf. Resultant blooms of algae deprive the water of oxygen as they die and decompose.

Of equal if not greater significance in aggregate to such 'flagship environmental disasters' are the less extreme but globally widespread examples of overabstraction of surface and groundwater, deterioration in inland and coastal water quality, degradation of aquatic and wetland ecosystems and increased incidence of damaging floods.[1] Of particular concern in this book is the deterioration in water quality caused by diffuse sources of pollution from human activities in rural areas. However, this cannot be considered in isolation from other aspects of water and land management in our river basins and catchments.

Rain, hail and snow are the ultimate source of water but once it starts to melt, infiltrate or run off, the way water moves, is stored, is lost or degraded depends mainly on the characteristics of the land and how it is managed. The sustainable development challenge at the 'heart' of this book thus concerns how best to protect and conserve water within the landscapes in which people live, work and play. In other words, it is about managing land and water resources to achieve the multiple aims of clean and safe water supplies, profitable production of food and other agricultural commodities, viable rural livelihoods, businesses and settlements, and natural spaces for recreation, physical and psychic health, and attractive lifestyles. This requires the sustained conservation of healthy and diverse ecosystems and the goods and services they provide. However, despite the passage of a quarter-century since the Brundtland Report,[2] neither the principles of sustainable development, nor the principles of the 'ecosystem approach'[3] have yet to be comprehensively adopted in catchment and river basin management.

Inherent in these challenges are many complex complementarities and trade-offs. These prompt a comprehensive and integrated approach, and raise questions about the scale and scope of necessary action. In terms of scale, the river basin is typically the natural geographical unit to consider. A river basin encompasses the area drained by a river and its tributaries, from the source of each stream to a final destination in the sea, an estuary or inland lake. Most of Earth's land surface falls within the area of river basins. In comparison the terms 'catchment' and 'watershed' are commonly used to refer to areas of land defined by the sub-basins of tributaries within a river basin. Many such smaller catchments or watersheds can exist within a basin. More precisely a watershed refers to the divide that separates one drainage area from another, although in some countries, including the United States and Canada, the term is also applied to the river basin or catchment area itself.

There are several reasons why it is considered logical to take a river basin or catchment as the spatial unit for analysis, planning and management of land and water resources. The river and its tributaries are common to all parts of the basin and water users within the basin are interdependent insofar as the actions of one person can affect the amount and quality of water available to others. In particular, upstream water users and land managers can affect the volume, quality or seasonality of water available to those downstream. For example, draining upland peat bogs or other wetlands can remove water storage capacity and natural mechanisms that modulate the flow of a river and assimilate waste. Similarly, deforestation and change in upstream land use may affect the frequency and severity of downstream floods, while also increasing soil erosion and the sediment and other pollutants carried by the river system. Such mechanisms are also manifest as catchment to coast linkages such that changes in upstream land and water use can impact on near-shore coastal ecosystems. Pollution largely conveyed by rivers from land-based sources can account for as much as 80 per cent of all marine pollution. Overall the challenges of water scarcity, flood risk and diminished water quality each impose the need to manage water at each stage from its source to the sea. In addition, if it is true that water users and land managers within a catchment can perceive their dependence on a common resource and understand their interdependence with others, then a basis for resolution of conflicts of interest and competition over resources may exist. A catchment or basin thus appears to provide both a natural unit for strategic planning and management, and a potential 'forum' for assessment of resources, trade-offs and the incidence of impacts. This introduces the duality of technical assessment and stakeholder deliberation that is a core theme of this book.

Although these arguments for planning, analysis and management at a catchment or basin scale are clear there can be exceptions and obstacles. Exceptions may include transboundary effects arising from groundwater flows or inter-basin water transfers. In terms of obstacles it is usual to find that watersheds and thus the boundaries of catchments do not match existing administrative and political boundaries. Such institutional boundaries were usually established in eras before the relative scarcity or poor quality of water resources became a leading concern. Also, while individuals can be expected to be responsive to issues and trade-offs within their immediate locality, it is not clear that they will always be either cognizant of, or responsive to, objectives set at a larger catchment or basin scale.

Despite the importance of catchments and river basins it can thus be difficult to determine the best scale at which to manage land and water resources, or at which to implement programmes and policies for their improvement. This will depend on a range of factors and a complexity which can be compounded by the timescale over which problems may materialize and the cumulative nature of impacts that can occur. As we will explore further in this book local management of land and water at a catchment or sub-catchment scale is the natural default situation and has many advantages, but the logic of water resource management at a whole catchment or basin scale will also require interventions at this higher scale. In turn this will require appropriate and effective multi-agency and multi-level governance arrangements.

The logic of catchment management also reveals that any single management intervention in a catchment or basin can be expected to have foreseen consequences and side effects, both of which will be subject to uncertainty. Given such complexities and interdependencies the logic of assessment and management at a catchment scale extends to the need to be holistic and comprehensive in scope. The concept of integrated catchment management thus includes integration of the management of landscapes, waterways, lakes, estuaries and coastal ecosystems within a river basin. It encompasses the management of both water quantity and quality, and diverse uses of water by the public, industry, agriculture and other land uses, and the energy sector. It requires data and scientific understanding that is integrated both across disciplines and with the location-specific knowledge of local residents and resource users. As noted above integrated catchment management must be coordinated across the tiers and divisions of administration and civil society that exist. In terms of objectives, integrated catchment management requires that economic and social goals are aligned with ecological and environmental outcomes. In implementation it requires that voluntary efforts coincide in objectives and are coordinated in implementation with the programmes and projects of the private and public sectors.

Catchment management exhibiting some or all of these features of scale and scope has become a global phenomenon, but with different forms emerging in different contexts (Benson *et al.*, 2013) – for example, 'watershed management' in the USA prompted by the provisions of the federal Clean Water and Safe Drinking Water Acts; 'integrated catchment management' in Australia under the Landcare programme and latterly the National Heritage Trust and Caring for our Country initiative; 'river basin management' as required by the Water Framework Directive in the European Union; and the Integrated Water Resources Management (IWRM) paradigm adopted by the United Nations and other international bodies. Each of these can be contrasted to prior governance regimes for water that can typically be characterized as technocratic and engineering led, primarily public sector, and focused on single-sector objectives of water abstraction and supply, hydropower, navigation or flood control (Molle, 2009).

This global and 'paradigmatic' change in management philosophy and practices potentially provides multiple and diverse cases on which to draw for learning and lesson transfer between locations and jurisdictions. A selection of leading cases provides the basis for this book and its attempt to draw lessons for catchment management, and specifically the control of diffuse pollution in rural areas.

The objectives, focus and scope of this book

In this book 'catchment management' is used as a generic term to refer to the management of water and to the relevant management of land uses and built infrastructure at a catchment and sub-catchment scale. As such use of the term overlaps with a range of related concepts including river basin management planning, watershed planning, integrated catchment management and relevant aspects of IWRM.

The subject of this book is how best to protect, conserve and manage water resources at their source and at the scale of a catchment or watershed. Issues of scale are very important and raise challenges for the transferability of recommendations and best practice. This book focuses on small- to medium-scale catchments for surface and groundwater. Challenges at a whole river basin scale for major rivers, including international transboundary issues, are not directly addressed although some of the lessons drawn here are potentially transferable to such cases. The issues and approaches that are considered at a smaller scale are certainly relevant as 'building blocks' and potential delivery mechanisms for the challenges of large basins.

This book seeks to provide an innovative perspective by adopting an inter-disciplinary approach to critical comparative analysis of drivers and modalities for catchment-based water resource management that include governance systems and institutional and legal arrangements. Catchment management crucially depends on these drivers and modalities. Case studies in the book allow a comparison of catchment scientific approaches, governance systems and institutional arrangements for the management of water resources, drawn from case examples in the USA, Australia and north-west Europe. This collective experience and understanding is supported by lessons culled from the wider international literature to attempt an integrated and globally applicable synthesis of the scope and commonalities of catchment management.

Focusing on water as a natural resource, the primary purposes for catchment management are the efficient allocation and use of a catchment's water resources and cost-effective application of measures to protect catchment ecosystems and the quantity and quality of the water that these produce. A further breakdown of water management objectives according to water use by sectors of the economy could include: water supplies for people and animals; water for agricultural (including aquaculture) and industrial production; water for nature conservation and capture fisheries; navigation; recreation; power production; flood control; fire protection; and waste disposal.

Overabstraction, flood risk and water quality are almost universal concerns. Water pollution comprises point and diffuse (or non-point) sources of contamination including discharges from wastewater treatment and industry, surface run-off from fields, seepage of nutrients and other contaminants from soil into groundwater, stream bank erosion and discharges from dispersed and numerous minor point sources such as field, farmyard and urban drains. Diffuse or non-point source water contamination is the most difficult to overcome and its control is a primary concern of this book. A point source can be defined as a discrete and discernible conveyance of wastewater such as pipes, ditches, channels and other means of conveying water. Point source water pollution is potentially amenable to solutions based on the pre-discharge treatment of wastewater, and implementation of such solutions requires a combination of regulation, technology and investment. This is feasible where an economy is sufficiently developed, but challenges may remain in terms of securing the necessary political will, prioritization and financing.

In contrast diffuse or non-point source water pollution is the release of pollutants from dispersed activities and sources across the landscape. It comprises true non-point source contamination and that which arises from many individual and relatively minor point sources. Examples of true non-point sources are seepage of nutrients from soil into groundwater and sheet run-off from the surface of fields or via numerous sub-surface field drains. Examples of multiple minor point sources are field ditches and farmyard drains or surface water drains from houses, other buildings and hard standings. The distinction made here illustrates that the classification of a pollution source as point or non-point (diffuse) may often not be a clear one. For practical purposes, particularly in rural areas, it may be better to recognize a spectrum of pollution sources from the truly diffuse to the large-scale and concentrated discharges of industrial units, wastewater treatment plants or intensive livestock farming operations. Although more diffuse sources may individually have negligible effect on the water environment, at the scale of a catchment or water body they may have a significant impact in aggregate.

Before industrialization began in the early nineteenth century the main causes of water pollution were untreated human waste and organic and inorganic pollution from artisanal industry. Since then rapid technological development, economic development and population growth, and industrial and urban expansion have intensified and broadened pollution problems from agricultural and other rural sources, road and urban stormwater run-off, sewage and industrial effluents. The challenges also continue to evolve, and for example, new chemicals such as pharmaceuticals which may not be amenable to standard treatments of wastewater discharge are increasingly recognized as a problem that is increasing in its severity.

A dominating sub-set of diffuse water pollution issues are those associated with eutrophication; a term used 'to describe the complex sequence of changes in aquatic ecosystems caused by an increased rate of supply of plant nutrients to water' (Schindler and Vallentyne, 2008). 'Cultural eutrophication' (Schindler and Vallentyne, 2008) can be rapid and is the enrichment of water with nutrients, principally compounds of phosphorus and nitrogen, from human activities. This contrasts with the very slow process of natural eutrophication of lakes and other water bodies as they accumulate sediment from their catchments. The main human sources of nutrients are inadequately treated sewage, arable and livestock farming, conversion of forested land to other uses, and other sources including garden fertilizers and pets (Schindler and Vallentyne, 2008).

Collectively such pollution causes environmental damage and carries health risks and other economic costs. Nutrient loads to water bodies from untreated human sewage and livestock manure are usually accompanied by significantly raised concentrations of coliform bacteria or protozoans such as *Cryptosporidium* or *Giardia*, carrying the risks and costs of waterborne disease. The nutrients themselves promote the growth of many species of alga, the populations of which can be used to define the trophic status of a lake or other water body. In the worst cases eutrophic lakes and slow-moving rivers can become dominated by Cyanobacteria, commonly known as blue-green algae. Such species are poor food for higher aquatic animals and can proliferate to form blooms or scums on the water surface. These are generally unsightly and unpleasant, while some species can release toxins harmful to animals and people (Schindler and Vallentyne, 2008). Such algal blooms can give an 'off-taste' and turbidity to drinking water, require cleaning from water intake filters and pipelines, and render bathing and recreational areas unpleasant or unusable. Problems caused by excessive nutrients are likely to be worsened during periods of lower water flow and higher temperatures in summer months. As noted above, oxygen depletion of both inland and coastal water can also result from algal blooms induced by nutrient pollution. Though photosynthesis by the algae may raise dissolved oxygen during the day, at night a dense algal bloom will reduce dissolved oxygen through respiration, and further oxygen depletion in the water column occurs when algal cells die, sink towards the bottom and are decomposed by bacteria. Ultimately a 'dead zone' arises when oxygen depletion progresses to hypoxia and death for all fish and invertebrates.

In recent years a combination of legislation, investment in wastewater treatment plants and de-industrialization has improved the quality of surface waters in some countries by controlling or eliminating discharges from point sources. This process is generally more advanced in developed economies, whereas developing countries are experiencing different stages and combinations of the problems identified above. In rapidly developing countries such as China, India, Mexico and Brazil, agricultural intensification and unprecedented rates of urbanization and industrialization have caused water pollution problems on a huge scale (Shiklomanov, 1997).

This book draws on experience from the north-eastern United States of America, south-eastern Queensland in Australia and north-west Europe. In each of these regions at least some reduction in pollution from point sources has been achieved through regulation, investment and technological improvements in the treatment of wastewaters (and as a result of de-industrialization in some locations), but water quality problems remain because of diffuse pollution derived from current and past land use (agricultural and urban) plus atmospheric deposition. These are global problems wherever farming is sufficiently intensive and relatively dense human populations are served by inadequate sewage treatment facilities. Data shows that in OECD countries the pollution of rivers with nitrogen generally increases with the usage of nitrogenous fertilizers per hectare of arable land, although there is considerable geographical dispersion around this trend (United Nations, 2010).

Diffuse water pollution poses particular challenges for public policy, the implementation of control strategies, best management practices, and scientific research and analysis. Innovative management approaches are required as solutions ultimately require behavioural change by many actors and thus a broad societal response. They must also be flexible and adaptive to stochastic catchment conditions and to long-term trends. They must be integrated with the management of abstraction and flows, and of flood risk. Internationally new models of governance for difficult land and water resource management problems of this nature are emerging that recognize and seek to incorporate such factors. This nexus of challenges and the means for their solution provides the focus for this book.

The challenges and uncertainties of controlling diffuse water pollution

Given natural limits to resource use and growing human demands, solely technological and reductionist approaches to the management of water and other natural resources are being questioned in the face of environmental degradation, and even collapse of ecosystems (Allan *et al.*, 2008). Many natural systems are inherently dynamic and complex, and knowledge of how they work and what determines outcomes is incomplete. At the same time decisions on how people use and conserve natural resources are subject to diverse legitimate but often competing values, resulting in a wide range of objectives and interests needing to be met. These are the characteristics of a 'wicked problem' and diffuse water pollution provides a clear example of such a challenge (Smith and Porter, 2010). This is explained further below.

Consider first the scientific uncertainty that may exist for land and water users, and for environmental scientists and managers. The absorptive capacity of surface and groundwater for diffuse pollution is a 'common pool' resource and stopping the use of that resource for disposal of pollutants (whether deliberate or a consequence of lack of awareness and control measures), through measures such as imposing a zero-discharge policy for the non-point sources, is prohibitively costly if not impossible. Polluters make multiple and interdependent uses of land and water resources and are numerous, dispersed and often remote. Typically they are not fully aware of the environmental consequences of their actions, and they will vary in their perception of both water quality status and its value. For scientists and managers there is uncertainty about pollution sources, pathways and impacts, about the occurrence of spatially and temporally stochastic pollution events, and about the consequences of any given pollutant loading for ecosystem, economic and public health outcomes. Individual discharges are for most practical purposes unobservable and unverifiable and thus cannot serve as the basis of regulation. Even if a source is observable, the transmission path from source to receptor involves many unknown variables such as rainfall, soil type, microbial activity and level of groundwater table, preventing the ability to relate the effluent to both its source and impact. This, together with a time lag between emission of a diffuse pollutant and its appearance in a receptor stream, lake or aquifer exacerbates the difficulty of establishing a link between the source and the ambient level of pollution (O'Shea, 2002).

The efficacy of control measures and the most cost-effective approaches for monitoring are also uncertain. As noted, solutions to diffuse water pollution ultimately require behavioural changes on the part of land users, residents and other actors in rural and urban areas which are inherently difficult to achieve and sustain. Catchments are also heterogeneous and the data available to diagnose problems and to design and target prevention or control strategies are rarely adequate. These uncertainties are not all equal relative to the management purposes at issue. Determining the priority of uncertainties and the relative weight they merit is a key aspect of the development of solutions (Smith and Porter, 2010).

Design and implementation of pollution prevention and mitigation measures may require both generic and location specific bio-physical research, together with socio-economic assessments of their potential impacts. Examples include investment in community wastewater treatment systems, improvements to the sewage systems of remote rural homes, management practices on farms to contain animal manures and optimize plant and animal nutrient regimes, and changes to land use and landscape. The outcomes of all such technical solutions will depend on stochastic catchment and climatic conditions and longer-term trends in influences such as market opportunities for farm enterprises and other economic activity, or climate change.

Complexity and uncertainty also arise because pollution prevention and mitigation measures will usually themselves have other indirect benefits or costs. This emphasizes the need for a holistic, comprehensive and adaptively integrated approach to catchment management. Changes in land use and management practice, for example, may also provide improvements in habitat for non-aquatic biodiversity, contribute to downstream flood alleviation or alter the existing balance of greenhouse gas absorption or emission.

Another source of technical complexity for managers is manifest in the form of institutional issues. Spatial patterns of human and ecological water use and waste disposal, and the bio-physical boundaries of catchments and ecosystems, rarely coincide with administrative and other legal jurisdictions. A political and administrative fragmentation typically exists that can be a hindrance to coordinated and catchment-scale water management and protection measures. Legal authorities for water supply and protection may span multiple agencies and levels of government, prompting questions of whether and how the existing governmental and institutional framework can adjust to accommodate catchment-level disparities of geography and jurisdictions – for example, whether transboundary collaboration, and even new institutional structures, may be needed at scales ranging from local government to international river basin authorities. The technical problems of catchment management are also cross-sectoral, spanning the responsibilities of agencies for agriculture, forestry, fisheries, highways, planning, waste disposal, building regulation, flood control and the environment. This reinforces a need for inter-agency communication and coordination (Smith and Porter, 2010), and for the capability for cross-sectoral and multi-disciplinary assessment and planning.

Next consider uncertainty about society's values and objectives. Most people can be expected to express a desire for higher water quality and the other benefits that may stem from integrated and effective catchment management, but there are inherent trade-offs that may moderate this preference in varying degree for different groups. As a consequence the willingness of different groups to change behaviour or to bear some or all of the costs of pollution mitigation will vary. Diffuse pollution is an externality of land uses that produce goods, homes, livelihoods and landscape attributes that sustain rural communities, are generally desired by society, and in some incidences can be recognized as 'public goods'. It is thus valid to ask whether reducing water pollution will compromise the viability of the rural economy, and key questions that follow are: who should pay the costs of water protection, and who benefits most from pollution reduction and enhanced water quality? For example, should the burden of preventing water pollution fall on rural land users upstream for the benefit of a downstream urban area? Or should farmers in a water supply catchment area be required to achieve a higher standard of care in their management practices than that required of farmers in other catchments? Such questions raise issues of equity and social justice as well as economics. The answers are not immediately self-evident and will be contested. Assessment and planning to control diffuse water pollution must therefore extend beyond farms and wastewater treatment plants to consider possible trade-offs relating to all aspects of land and water use, landscape heritage and the rural economy, including the viability of settlements, transport networks, habitats and recreational activities (Cook and Smith, 2005).

From a policy perspective diffuse water pollution can also be understood as a case of 'market failure'. The absence of market incentives to reduce pollution motivates intervention by governmental and non-governmental entities to modify the incentives signalled by markets that determine behaviour. As explained above, unlike point source pollution, the temporal and spatial nature of diffuse pollution renders its complete monitoring and regulation impractical. Even if the sources of diffuse pollution can be definitively identified, the monitoring and enforcement costs of an approach based on regulation alone are likely to be prohibitive. As a consequence policymakers should be prepared to utilize a combination of measures that includes: regulation; economic incentives and voluntary agreements with land users; self-regulation based on enhanced knowledge and cultural changes; advisory and education campaigns; and direct land management strategies that may require land acquisition and change or restriction on use. This policy instrument 'mix' further adds to the complexity identified above, and the central challenge can be recognized as one of how to determine and implement the best combination of measures for a specific catchment, given local conditions and preferences, and wider national or transnational priorities and policy constraints (Cook and Smith, 2005). The most appropriate method of pollution control will depend upon, among other things: the information available; the type of resource to be regulated; the degree of uncertainty that exists; the costs of damage; the number of polluters