



1 The Catchment Management Concept

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1.1 Introduction

Earth systems processes such as geological, hydrological and biogeochemical have shaped our landscapes. Global and regional climatic factors have influenced the distribution of water resources (river, lakes, groundwaters, estuaries, etc.) which has influenced the distribution of ecosystems and humans. Fluvial and erosional process have determined the form of aquatic environments, influencing the development of channel characteristics, river corridors, flood plains, deltas, along with instream characteristics and morphology such as reach structure, width, depth, and forms of meanders, bars and shoals. Pedological and geological processes influence the transfer of water between the saturated and unsaturated zone and the nature and extent of groundwater systems, and their interaction with surface waters.

The catchment, basin, watershed or similar is basic to hydrological thinking. The catchment outlet identifies the point at which all rainfall naturally drains towards or is directed to by human intervention. Natural processes result in the formation of a stable (at large scale) yet dynamic (at small scale) system bounded within physical (catchment) constraints. Undisturbed

catchments are in a quasi-equilibrium, but as landscape features are manipulated and changed by human activities such as land use and riparian management, natural processes are affected. This may result in downstream consequences such as movement of material (soil, water and bedload), generation of downstream floods, seasonal droughts, altered groundwater levels, increased contaminant transport, coastal sedimentation and many other impacts.

A pre-requisite for sustainable resource management at a catchment scale is understanding the water cycle and its fluctuations, which requires knowledge on how water moves through the environment and on the different pools and fluxes that occur across spatial and temporal scales, both within catchments and across larger geographical areas.

There are many hydrological processes that characterize catchment systems and their behaviour. Spatial patterns of precipitation both in terms of magnitude and intensity directly impact on the dynamics of stream flow generation and groundwater recharge. Soil moisture controls the distribution and nature of vegetation which in turn links losses of water back to the atmosphere through transpiration, and also infiltration. The dynamic interaction between surface and groundwaters in response to ever changing conditions at seasonal, yearly and longer term climatic variation directly influences the nature of runoff in streams, rivers, lakes and to coastal environments. Emergent properties in time and space are

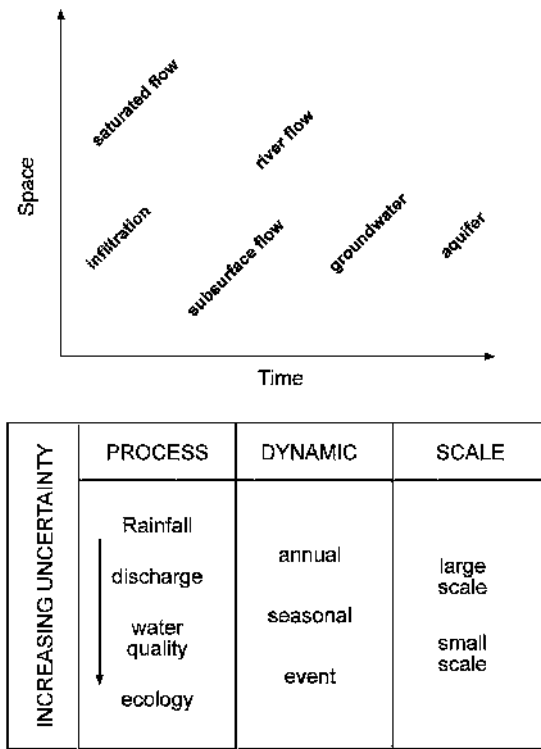


Fig. 1.1 Emergent properties and uncertainty in catchment systems.

a key characteristic of catchment systems and in defining process uncertainty (Fig. 1.1).

Additional to understanding the water cycle is knowledge of how human activities influence both quantity and quality. Recent developments in understanding the relationships between 'green' and 'blue' water have emphasized the need for catchment scale assessment and identification of wider ecosystem goods and services (United Nations 2005). Green water represents that consumed in plant production and evaporation from surfaces, and supports terrestrial ecosystems. Blue water, on the other hand, represents that which recharges aquifers and groundwaters and generates flow in rivers and lakes. It is this latter source of water that supports aquatic ecosystems and human populations. Transfers between blue and green occur when water is

abstracted for irrigation from blue resources, and is partially consumed by green flows only to return to the blue water component. Usually this transfer increases pollutant and nutrient loads into the aquatic environment (Falkenmark and Rockstrom 2006).

In summary, the key principles towards developing sustainable management of catchments are firstly to understand the natural processes occurring within a catchment. In particular, to determine the physical pathways of water movement and balances, hydraulics and dynamics. To elucidate where nutrients and pollutants are generated within the landscape and how and when they may be transported and what are their downstream physical, chemical and ecological consequences. It is also essential to understand the current and future pressures on the water in the catchment and its land use to identify competing demands for the resource given its regional or global context and the history of previous management. Additionally, it is important to consider the social, ethical and political context of options for use and management, as water resources are not necessarily concomitant with administrative, institutional or country boundaries.

1.2 Historical Perspective

The major pressures on catchment systems are through a historical timeline of land use and management, urbanization and industrialization driven by different cultures. Each of these pressures has direct and indirect consequences on water resources and there are many synergistic interactions between them at local, regional and global scales (Table 1.1).

Land use, in particular the use of water resources for the production of biomass (food and timber), dominated the global water flux. Irrigated land (which makes up 20% of the world's cropped land but generates 40% of the world's harvest) accounts for about 70% of water withdrawals at a global scale (Box 1.1). In many developing countries the use of water for cropping approximates

Box 1.1 Water facts and futures

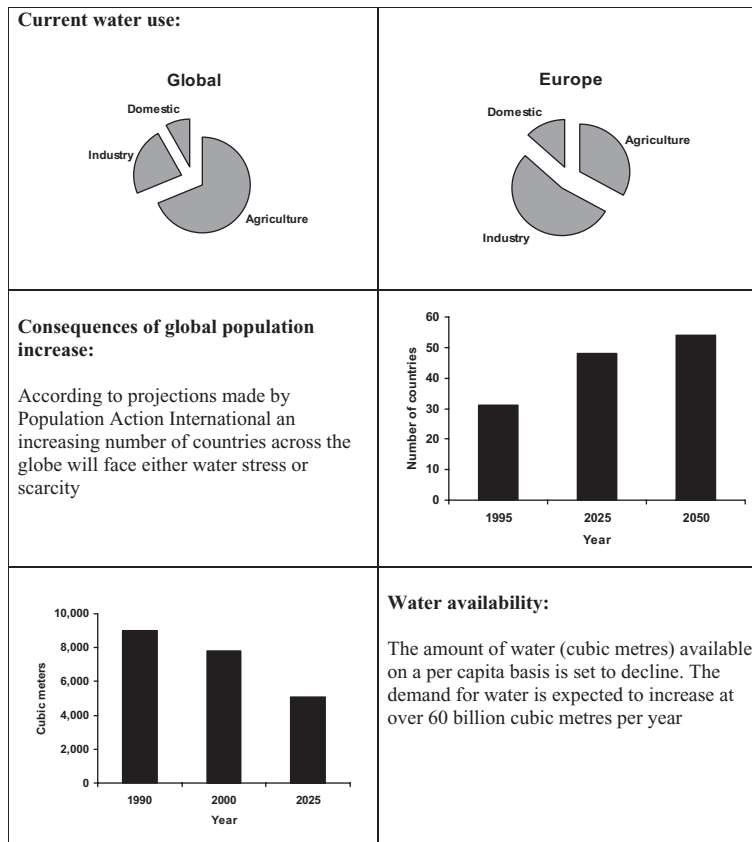


Table 1.1 Timeline of developing anthropogenic pressures on water

Timeline (years ago)	Milestone
20,000	Nomadic humans
10,000	Move towards pastoralism
5000	Emergence of Mesopotamia and Egypt as water managers – irrigation and flood control
4000	Water supply and drainage in Indus culture
4000	Evidence of water management in China
2500–2000	Roman engineers build water supply systems throughout Europe, rise in city populations
2500–2000	Groundwater transport and management emerges in Middle Eastern countries
300	Agrarian revolution increases food production, increased land drainage, reclamation and water management
200	Industrial revolution – demand for water in developed world soars
Last 50 years	World population doubled, water consumption quadrupled
Present day	Fast growing Asian economies place increasing demands on regional resources
	Over 1 billion people still do not have access to safe drinking water
	One-third of the global population currently experiencing water stress, this is set to rise
	Uncertainties about future climate place water at the centre of a global crisis

to 80% of the total water consumption. A compounding factor is that land use and ownership are inconsistent across the landscape and do not necessarily map to natural boundaries such as those delineated by watershed and catchment boundaries, therefore water use is spatially and temporally variable.

Human population growth and economic development are placing an increasing burden on global water resources. The United Nations World Water Development Report (2006) highlighted that water withdrawals (from blue water) have increased sixfold since the 1900s, twice the rate of population growth. The increasing urbanization of the world is placing a growing burden on the world's water resources through demands for production and human use. As large cities grow and available local surface and groundwater supplies are compromised, there is an increasing reliance on distant catchment sources to meet requirements (Showers 2002). Infrastructural integrity in relation to potable supply and appropriate wastewater treatment (if indeed they do exist) potentially struggle to keep pace with the rate of expansion of many cities, especially in developing countries. Urban populations are growing more rapidly than the capacity of governments to establish institutional structures. For example, if the Millennium Development Goal of halving the proportion of people without access to sustainable drinking water and sanitation is to be met by 2015, nearly 1000 million urban dwellers must gain access to improved access to basic functions (WHO/UNICEF 2004).

Regulation (where flow has been controlled or modified from its natural state) can affect the hydrology of rivers down their entire length – straightening for navigation, canalization, building of reservoirs for irrigation, storage, power generation and flood management, groundwater abstraction and inter-basin transfers all generate consequences on the dynamics of flow and for the quality of water environments. Most major rivers experience some form of regulation and large scale management on basins such as the Murray-Darling (Australia) and Colorado (USA) have been ongoing for decades.

Regulation for producing hydropower varies between countries, with Europe exploiting about three-quarters of the available resource whilst Africa only a few per cent. With concerns being raised about the environmental consequences of traditional energy generation, focus has moved to potential renewable energy sources at a range of scales including traditional embayment, dams and barriers through run-of-river schemes to small scale (<10MW), mini (<2MW) and micro (500kW) schemes.

Ecologically, freshwater biodiversity is more at risk from anthropogenic activities impacting on water quality and quantity than terrestrial systems. It is estimated that over the last thirty years or so there has been a reduction in freshwater species by approximately 50%. This figure is far higher than either land or marine ecosystems.

The consequence of all of these pressures is that the current human fingerprint on rivers and lakes is extensive. Presently less than 17% of the continental surface of the earth is free from direct human impact. Only in remote areas of North America, Siberia, Amazonia and the Congo Basin can near pristine rivers be found (Meybeck 2003), highlighting the importance of appropriate management of water resources globally.

Major biogeochemical cycles have undergone serious perturbations as a result of human activity. The consequences of this have impacted on both the terrestrial and aquatic environment. Since the agrarian revolution, agricultural practices and the move towards intensification of production fuelled the usage of commercial inorganic fertilizers, and the widespread availability of nutrient solutes such as nitrate in aquatic ecosystems. Increasing concentrations of nitrogen in ground and surface waters impact on the use of these resources for human consumption (current WHO guidelines highlight a maximum safe concentration of $50\text{mgL}^{-1}\text{NO}_3$). Elevated concentrations of nitrate in coastal waters are known to drive eutrophication because phytoplankton in marine environments is nitrogen limited. The consequence of this eutrophication is widespread

hypoxia observed in the world's shallow and enclosed seas, notably the Gulf of Mexico, Baltic Ocean, Black Sea, and in locations such as Chesapeake Bay and the Delta of the Mississippi. Freshwater eutrophication is primarily though not exclusively driven by the availability of phosphorus, a nutrient elevated in surface waters through runoff from soil and sediment and strongly influenced by the input of human and animal waste. Current legislation such as the EU Urban Waste Water Treatment Directive has done much to reduce the input of phosphorus from human sources in the rivers and lakes of Europe.

Understanding the mode of transport of pollutants to aquatic environments is also of critical importance in the development of remediation strategies for future management plans. In recent times, classic point sources of pollution discharge such as that from sewage treatment works and industrial processes have been the principle focus for water pollution control in many countries. Despite tight regulations and controls on effluent discharges, pollution of water environments continues to be a problem and the focus has now turned to assessing the impact of non-point or diffuse pollution sources.

A Chartered Institution of Water and Environmental Management (CIWEM) committee discussed and agreed upon what is now a widely accepted definition of diffuse pollution published in 2000. That committee based its deliberations on published material in the standard diffuse pollution textbook of the period by Vladimir Novotny and Harvey Olem (1994). The current definition in international standard use is based on the CIWEM definition (D'Arcy *et al.* 2000), and refined by Novotny (2003):

Pollution arising from land-use activities (urban and rural) that are dispersed across a catchment or subcatchment, and do not arise as a process industrial effluent, municipal sewage effluent, deep mine or farm effluent discharge.

Diffuse pollution therefore comprises true non-point source pollution together with inputs from

a multiplicity of minor point sources. Examples of strictly non-point sources are comparatively limited, for example nitrates seeping into groundwater or in unusual circumstances, nutrients and sediment transported in sheet erosion from farmland. Most water-driven soil erosion results in contamination at a specific point via a rill or gully formed as water traverses fields to a watercourse. Similarly runoff carrying pollutants from urban surfaces typically reaches a watercourse via a point input such as a surface water sewer outfall. And the same applies to forestry plantations and most other diffuse sources of pollution. Point or non-point is really a matter of scale; a field of improved grassland in an upland rough grazing catchment is a nitrate point source for the underlying aquifer, just as each field drain is a point source for understanding inputs to a ditch or small stream. In loading terms most diffuse pollution enters watercourses via pipes, channels, gullies and rills, even atmospheric deposition, since it has to be washed from the land surfaces.

The important characteristics of diffuse pollution therefore are NOT whether anyone can find the source/s, or whether a pipe is involved. Diffuse pollution is a useful concept because it allows for estimation of important loads of pollutants in waterbodies that are not from major industrial process and municipal effluent discharges (that are typically well characterized, monitored and quantified). The concept is also useful because it explains features of pollution in receiving water bodies, for example why concentrations of some pollutants actually increase with flow rather than are diluted, why pollution peaks are variable and difficult to predict, and why impacts are often slow to develop and become evident.

Novotny (2003) characterizes diffuse pollution as follows:

- Diffuse discharges enter the receiving surface waters in a diffuse manner at intermittent intervals that are related mostly to the occurrence of meteorological events.
- Waste generation (pollution) arises over an extensive area of land and is in transit overland

before it reaches surface waters or infiltrates into shallow aquifers.

- Diffuse sources are difficult or impossible to be monitored at the point of origin.
- Unlike traditional point sources where treatment is the most effective method of pollution control, abatement of diffuse load is focused on land and runoff management practices.
- Compliance monitoring is carried out on land rather than in water.
- Water quality impacts are assessed on a catchment scale.
- Waste emissions and discharges cannot be measured in terms of effluent limitations.
- The extent of diffuse waste emissions (pollution) is related to certain uncontrollable climatic events, as well as geographical and geological conditions, and may differ greatly from place to place and from year to year.
- The most important pollutants from diffuse sources subject to management and control are suspended solids, nutrients, faecal pathogens and toxic compounds.

A useful way of thinking of diffuse pollution is that it is often the individually minor but collectively significant sources in a catchment. That is the key to the control options too; measures need to be focused on the land-based activities, rather than on the point of discharge.

The global demand for water is increasing. The world's population (currently standing at approximately 6 billion), has doubled since the 1950s and is set to increase to approximately 9 billion by 2050 (United Nations 2004). Increases in demand, combined with the current status where many water resources are degraded as a consequence of historical activities, move us closer to a potential global water crisis. The uncertainties generated by climate change further increase the requirement to develop appropriate strategies for the integrated management of water resources at a catchment scale, from mountains to seas and encompassing both land and water issues. The interconnectivity between aquatic ecosystems represents a dynamic and temporally varying environment, which includes permanent and ephemeral water bodies, coastal and estua-

rine environments, and riverine connections. Compromising this continuity, compromises the inherent ecology that has evolved to exploit it.

1.3 Current Solutions

International activities related to the development of policies through which to tackle the growing need for sustainable management of water resources has gathered pace over recent decades. The United Nations Conference on Water (Mar del Plata, 1977), the International Conference on Water and the Environment (1992), the First World Water Forum (Marrakech, 1997) the Second World Water Forum (The Hague, 2000), the International conference on Freshwater (Bonn, 2001) and the World Summit on Sustainable Development (United Nations Department of Economic and Social Affairs 2002), understood the need for effective and efficient management of global water resources. Principles from these international conferences evolved and strengthened the concept of 'Integrated Water Resources Management' (IWRM). The Global Water Partnership (2000) defines IWRM as 'a process which promotes the co-ordinated development and management of land, water and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems'. Importantly the development of a basin wide approach was reinforced along with strengthened governance and participation (Box 1.2).

The Dublin Principles (ICWE 1992) highlighted the importance of water as a finite resource, that development and management should be participatory, that women play a central role in global water provision especially in the poorest countries, and that water has an economic value (Box 1.2). These principles were further supported during the Second Water Forum in the Hague (WWC 2000), which reiterated that water has an economic value and that participation and empowerment are key factors in sustainable management. It further visioned that water

Box 1.2 Principles of integrated water resource management (Global Water Partnership 2000)

- **Freshwater is a finite and vulnerable resource.** Its management therefore requires a holistic approach, one that embraces the concept of the hydrological cycle and its interaction with natural processes and ecosystems and how human activity influences both quality and quantity. It identifies that natural resource yields have limits and that regional overexploitation is a constant threat. Additionally it recognizes the important spatial component of water resources and that upstream:downstream relations must be addressed to ensure equity in common pool resource management.
- **Water development and management should be based on a participatory approach.** This requires the creation of appropriate participatory mechanisms at a range of scales from national to local, and that capacity building is a central component. Participation in the decision-making process must be transparent, equitable, and that those who have an involvement or interest in water and its use and management must be included in the consultative process, and that consensus building should be the goal.
- **Women play a central part in the provision, management and safeguarding of water.** This aims to promote gender awareness and highlights the important social and cultural roles of women and men in different societies. It encourages the active role of women in decision making, and at all organizational levels.
- **Water has an economic value in all its competing uses and should be recognized as an economic good.** Clearly water has a direct economic value to users, but it also has a non-market value in relation to supporting ecosystem goods and services, and has aesthetic, cultural and religious significance. The true value of water must embrace all of these issues. It also promotes the goal of full cost recovery.

should not be monopolized to the detriment of the citizen, and of critical significance was that right of access to water for all is central to break down poverty barriers.

It was during the International Conference on Freshwater in Bonn (ICFW 2001) that basin management principles were specifically identified as a spatial context for management. It re-iterated that 'the key to long term harmony between nature and its neighbours is co-operative arrangements at the water basin level, including across waters that touch many shores'. This reinforced the key principles of effective IWRM in that all users of a common pool resource should be involved in its management irrespective of administrative, fiscal, cultural or national boundaries. Many of the world's catchment systems are transboundary. Wolf *et al.* (1999) identified 261 international transboundary rivers involving 145 different countries that covered 45% of the world's land surface, 40% of the world's

population and 60% of the world's freshwater resource.

The World Summit on Sustainable Development (WSSD) in Johannesburg (2002), consolidated UNCED Rio Summit Principles in relation to the implementation of Agenda 21 on Sustainable Development and agreed on an important step towards sustainable water management. As part of the Plan of Implementation it challenged all countries to 'develop integrated water resource management and water efficiency plans by 2005 for all major river basins of the world'.

The Millennium Development Goals (MDGs) were developed to address the world's main development challenges and are due to be achieved by 2015. They arose in the Millennium Declaration that was adopted by nearly 200 nations in September 2000. The eight MDGs break down into 18 quantifiable targets which are measured by a series of indicators (Box 1.3).

Box 1.3 Delivering the millennium development goals: the importance of water

Goal 1: Eradicate extreme poverty and hunger

- Access to water supply and sanitation, often used in broad definitions of 'poverty'
- The poor carry the greatest burden of productivity-sapping disease as a result of not having access to safe water and sanitation
- Water is essential to economic development, which can create productive livelihoods for the poor
- Poor communities are also particularly vulnerable to floods, droughts and similar water-related disasters

Goal 2: Achieve universal primary education

- Children's time is a valuable commodity in many communities especially in relation to agriculture and water provision
- Water-related disease and the poor availability of adequate sanitation affects school attendance

Goal 3: Promote gender equality and empower women

- In many areas the fetching and storing of water is done predominantly by women

Goal 4: Reduce child mortality

- Children are at risk when they are without safe water to drink
- In developing countries, water-related diseases are almost always amongst the most important causes of death of children under the age of five
- More than 1.5 million children under five die every year from diarrhoea (more than from malaria and HIV/AIDS combined)

Goal 5: Improve maternal health

- The burden of fetching water and dealing with water-related disease in the family falls disproportionately on women and puts pressure on their own health.

Goal 6: Combat HIV/AIDS, malaria and other diseases

- Access to safe water and sanitation services can help to reduce poverty – which in turn is an important determinant in the spread of HIV/AIDS
- Effective water management can reduce malaria and other diseases endemic in poor communities

Goal 7: Ensure environmental sustainability (including the target of halving the number of people without access to water and sanitation)

- Water is key to the sustainable utilization of land, plant and animal resources
- If the water resources environment is not managed and protected, it will not be able to sustain human communities
- Provision of water supply and sanitation services is reliable and sustainable
- The reliability of domestic water supplies in dry seasons often depends on influencing the behaviour of other water users

Goal 8: Develop a global partnership for development

- Integrated water resource management is one mechanism through which such partnerships can be built, particularly where rivers and lakes are shared between more than one country

The importance of IWRM and catchment management to the deliver of the MDGs cannot be underestimated. Task force 7 of the Millennium Project recognized that without water resource development and greater attention to the management of water resources (namely, the water as it occurs naturally in lakes, rivers and groundwater), any gains in water services provision were unlikely to be sustained. The task force recommended that an integrated approach to land, water and ecosystem management be adopted in both policy and planning. Clearly water resources are an important component of addressing all of the MDGs.

In a European context waters legislation gathered pace in the 1970s and early 1980s, followed by a second wave in the early 1990s. The majority of this water policy was use-based rather than focusing on ecological integrity. In 1995, the Commission was requested by the Council of Ministers and Environment Committee to produce a coherent water policy aiming to draw together much of the existing independent and somewhat disparate Directives (Table 1.2) to provide greater synergy, reduce points of tension

between sister Directives and promote a more integrated approach. In 1997, the Commission proposal for a Water Framework Directive (WFD) was developed and in 2000, the Directive was published (EU 2000). The requirements of some old water legislation (e.g. the Freshwater Fish Directive) have been reformulated in the Water Framework Directive to meet modern ecological thinking. After a transitional period, these old Directives will be repealed. Other pieces of legislation (e.g. the Nitrates Directive and the Urban Wastewater Treatment Directive) must be coordinated in river management plans under the WFD. An additional historical factor has been the dichotomy in the approach to pollution control at European level with some controls concentrating on what is achievable at source through the application of technology, and some dealing with the receiving environment in the form of quality objectives. Each approach has limitations. Source controls alone can allow a cumulative and environmentally detrimental pollution load, where there is a concentration of pollution sources. Quality standards can underestimate the effect of a particular substance on the ecosystem, due to the limitations in scientific knowledge regarding dose-response relationships and the mechanics of transport within the environment.

The WFD addresses the need for a combined approach to pollution management. It does so as follows. On the source side, it requires that as part of the basic measures to be taken in the river basin, all existing technology-driven source-based controls must be implemented as a first step. But over and above this, it also sets out a framework for developing further such controls. The framework comprises the development of a list of priority substances for action at EU level, prioritized on the basis of risk; and then the design of the most cost-effective set of measures to achieve load reduction of those substances, taking into account both product and process sources. On the effects side, it co-ordinates all the environmental objectives in existing legislation, and provides a new overall objective of good status for all waters, and requires that where the measures taken on the source side are not

Table 1.2 Timeline of European water and associated policies

Year	Milestone
1973	First Environmental Action Programme
1975	Surface Water Directive
1976	Bathing Waters Directive
1976	Dangerous Substances Directive
1978	Freshwater Fish Directive
1979	Shellfish Waters Directive
1979	Birds Directive
1980	Groundwater Directive
1980	Drinking Water Directive
1991	Urban Water Treatment Directive
1991	Nitrates Directive
1992	Habitats Directive
1994	Drinking Water Directive (Revision)
1995	Bathing Waters Directive (Revision)
1996	Integrated Pollution Prevention and Control Directive
1997	Proposal for a Water Framework Directive
2000	Water Framework Directive

sufficient to achieve these objectives, additional ones are required (WISE 2005).

Main objectives of the WFD are to:

- protect and where necessary to improve the quality of all inland and coastal waters, ground-water and associated wetlands and to prevent their further deterioration;
- promote the sustainable use of water;
- enhance protection and improvement of the aquatic environment through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances;
- lessen the effects of flooding and drought;

To deliver this vision requires that:

- All water bodies should be protected, including rivers, lakes, wetlands, coastal waters and groundwaters.
- The basis for environmental protection to be ecological integrity (except groundwaters) and that timelined targets for achieving 'good status' be set.
- A combined approach to the management of point and diffuse sources be developed and emissions limit values determined as appropriate.
- That the fundamental unit for integrated management should be the catchment or river basin.
- Economic and non-use values of water must be factored into sustainable strategies.
- People must be intimately involved with the planning process (stakeholders who use or who have an interest in the water environment).
- Adaptive management strategies should be adopted including continuous timelined planning cycles.

The EU WFD is a complex environmental Directive, but whose principles have been developed to be simple, flexible, and familiar. This is required because the WFD is to be implemented by 25 Member States, Norway, and a number of accession countries – a complex socioeconomic assemblage of cultures, traditions, languages and histories in terms of environmental management and objective setting. The WFD is a major departure from conventional environmental protection legislation in several ways. It obliges Member

States to take a holistic, inclusive, ecological approach to water management. Additionally it requires the quality 'status' of water bodies to be measured using ecological rather than just traditional physical and chemical parameters, with more emphasis on the biological quality of a water body.

There has been much investment to date in undertaking supporting research on defining the terms of reference for the implementation of the WFD in Europe from an ecological, social and economic perspective (CIS 2000).

The WFD functional unit is based on river catchments or collections of river catchments (River Basin Districts), rather than traditional political divisions such as counties or regions. River basins or catchments in this context are made up of lakes, rivers, streams, groundwater and estuaries – and all the land that surrounds them, and drains into them. The WFD thus promotes a more integrated, holistic approach to water management, and one that transcends national borders. Involvement of the public is a key requirement. The WFD puts consultation, public involvement, stakeholder engagement and access to information at the heart of its development and specifically states that 'the active involvement of all interested parties' must be encouraged by every Member State. It is anticipated that this will enhance community, industry and stakeholder input to the management of water resources in Europe, which has previously been weak in many situations.

In order to achieve the overall aims the WFD promotes an objective based approach for adaptive management based on a planning cycle composed of four main elements (Fig. 1.2), against a formalized timetable:

- Characterization: including an assessment of water bodies at risk of not achieving WFD objectives as a result of man-made pressures.
- Environmental Monitoring informed by the characterization.
- Setting of Environmental Objectives.
- Design and implementation of a Programme of Measures to achieve these environmental objectives.

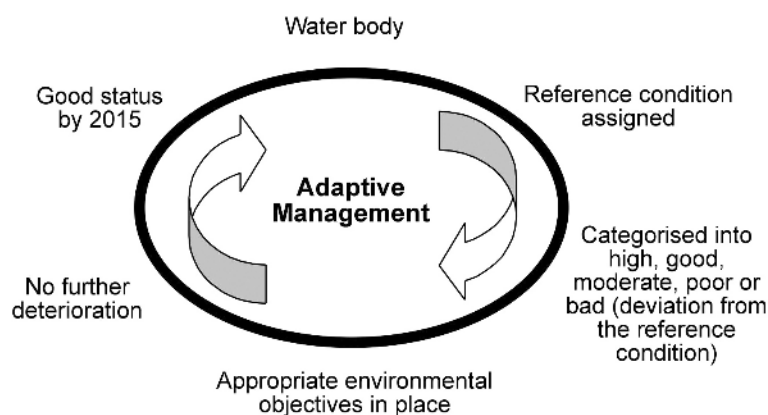


Fig. 1.2 The WFD adaptive cycle.

- No further deterioration in the ecological quality of aquatic environments.

- Achieving 'good status' for all waters by 2015. A key concept underlying the WFD is that of integration which is seen as the major focus of management of water protection with the regional planning process, and a consideration of economic aspects of water use (CIRCA 2003; WATECO 2003). These represent a mountain to seas continuum and management must embrace the complete hydrological cycle. This involves:

- Integration of environmental objectives, combining quality, ecological and quantity objectives for protecting highly valuable aquatic ecosystems and ensuring a general good status of other waters.

- Integration of all water resources, combining fresh surface water and groundwater bodies, wetlands, coastal water resources at the river basin scale.

- Integration of all water uses, functions and values into a common policy framework, i.e. investigating water for the environment, water for health and human consumption, water for economic sectors, transport, leisure, water as a social good.

- Integration of disciplines, analyses and expertise, combining hydrology, hydraulics, ecology, chemistry, soil sciences, technology, engineering and economics to assess current pressures and impacts on water resources and identify mea-

asures for achieving the environmental objectives of the Directive in the most cost-effective manner.

- Integration of water legislation into a common and coherent framework. Integration of all significant management and ecological aspects relevant to sustainable river basin planning including those which are beyond the scope of the WFD such as flood protection and prevention.

- Integration of a wide range of measures, including pricing and economic and financial instruments, in a common management approach for achieving the environmental objectives of the Directive. Programmes of measures are defined in River Basin Management Plans developed for each river basin district – a collection of individual catchments and water bodies specified by each Member state.

- Integration of stakeholders and the civil society in decision making, by promoting transparency and information to the public, and by offering a unique opportunity for involving stakeholders in the development of river basin management plans.

- Integration of different decision-making levels that influence water resources and water status, be it local, regional or national, for an effective management of all waters.

- Integration of water management from different Member States, for river basins shared by

several countries, existing and/or future Member States of the European Union.

In America, the Environmental Protection Agency (US Environmental Protection Agency 1993) supported the development of a 'watershed protection approach' formulated around catchment management. This approach was to be an integrated, holistic, problem-solving strategy used to restore and maintain the physical, chemical and biological integrity of aquatic ecosystems, protect human health and promote economic growth. USEPA's watershed approach has three major cornerstones. First is problem identification, which identifies the primary threats to human and ecosystem health within the watershed. Second is stakeholder involvement, which involves the people most likely to be concerned or most able to take action. And third is the integration of actions, that is, corrective efforts taken in a comprehensive, integrated manner once solutions are determined. The approach evaluates success and refines actions as necessary (US Environmental Protection Agency 1993).

USEPA views this approach as placing a heavy emphasis on the many elements that affect water quality, including chemical composition (toxics and conventional pollutants), physical water quality (temperature, flow and circulation), habitat quality (channel morphology, composition and health of biologic communities) and biodiversity (species number and range). The approach encompasses all waters – surface and ground, inland and coastal – and is seen as a framework for integrating existing programmes (CGER 1999).

The watershed approach was also endorsed by US federal agencies through the Unified Approach to Federal Land and Resources Management (US Department of Agriculture 2000), embracing many of the concepts of IWRM. They define the term as a 'framework to guide watershed management that; uses watershed assessments to determine existing and reference conditions, incorporates assessment results into resource management planning and, fosters collaboration with all landowners in the watershed'. The

framework considers both ground and surface water flow within a hydrologically defined geographical area (US Army Corps of Engineers 2000).

During the WSSD in 2002, the EU announced the launching of the global EU Water Initiative. It highlighted the important role of a river-basin-scale approach to sustainable management, particularly for transboundary catchments. Although there are a number of high profile areas of regional tension water has also been an issue for developing co-operation, removing conflict and building joint capacity. Indeed as part of regional development negotiations water may serve as a key criteria in conflict prevention (Wolfe *et al.* 2005).

The Danube has the greatest number of countries sharing its length in the world. A total of 18, over twice that of the Rhine (eight), over four times that of the Elbe (four) and six times that of the Rhone (three) (Wolf *et al.* 1999; ICPDR 2007). Of these, six are EU member states, three are accession countries and seven are not members of the EU. The Danube is 2800 km long, drains an area of 8000,000 km and is home to over 80 million people.

The Convention on Co-operation for the Protection and Sustainable Use of the River Danube (Danube River Protection Convention, DRPC) forms the overall legal instrument for co-operation on transboundary water management in the Danube River Basin. The Convention came into force in 1998, and aims to ensure that surface waters and groundwater within the Danube River Basin are managed and used sustainably and equitably. The signatories to the DRPC have agreed to co-operate on fundamental water management issues by taking 'all appropriate legal, administrative and technical measures to at least maintain and where possible improve the current water quality and environmental conditions of the Danube river and of the waters in its catchment area, and to prevent and reduce as far as possible adverse impacts and changes occurring or likely to be caused'.

To implement the DRCP, the Danubian countries agreed when it became operational to estab-

lish the International Commission for the Protection of the Danube River (ICPDR) to enhance regional co-operation and the implementation of the DRCP. Following the implementation of the WFD, the ICPDR provided a platform for the development and establishment of a River Basin Management Plan for the Danube River in line with the WFD. Although not legally obligated to fulfil WFD requirements non-member states have embraced the concept and are working under the auspices of ICPDR under bilateral and multilateral agreements to ensure sustainable management of Europe's second largest river.

In southern Africa more than 70% of surface water resources are shared by two or more states and water is unevenly distributed in the region (Green Cross International 2000). In 1995 the member states signed a Protocol on Shared Watercourse Systems, and as part of that established River Basin Commissions and River Authorities representing the component parts of each major river basin. This recognition of catchment as a central spatial component to resource management provided a platform for co-operation between states. This Protocol is currently under review, with a view to improving political issues surrounding water management.

Australia's variability in rainfall and runoff is similar to that of southern Africa, and although it has a high per capita discharge (20× that of the Middle East) the resource is unevenly distributed both spatially and temporally. Over half the potential resource is located in the north and east of the country (approximately 20% of the land area) where only 15% of the total population reside. The greatest use of water is for irrigation agriculture, some 70% (Smith 2009). Nearly 40% of food production occurs within the Murray-Darling Basin (see Chapter 13).

In 2004, an International Agreement on National Water Initiative was initiated by the Australian Governments and ratified in 2006. The overall objective of the National Water Initiative is to achieve a nationally competitive market, regulatory and planning based system of

managing surface and groundwater resources for rural and urban use that optimizes economic, social and environmental outcomes.

Other international initiatives such as the Nile Basin Initiative (1999), La Plata River Basin Treaty (1969), the Sustainable Development of the Mekong River Basin and the establishment of the Mekong River Commission (Jacobs 2002), the Ganges Treaty (1966) and the Okavango River Basin Commission (1994) all highlight the importance of considering water resource management issues at a catchment or basin scale. The Network of Asian River Basin Organizations (NARBO), established in 2004, was specifically established to respond to the challenges of catchment management in the monsoon areas of Asia. The emerging global consensus on the necessity for an integrated approach to water resources has further embedded IWRM concepts in catchment planning.

In all of these country and regional examples the general evolution from technical innovation to social engagement to moral attitudes highlights the development of thinking on water resource management from past to present to future, respectively.

1.4 Synthesizing Knowledge for the Future

There are different visions on what catchment management actually represents based on sectoral perspectives even of an identical resource (Fig. 1.3). A key for the future is to look to identify synergies in those perspectives and the development of common targets and/or goals.

To move this thinking forward a key issue is to identify what we can learn from the past. Global water resource management is not starting from time zero, but must work with the legacy or inheritance of historical sectoral management, legislative frameworks and scientific understanding. Primarily, production goals have strongly influenced the pattern of water resources management which we have today, which varies globally dependent upon the distribution of natural resources, climate, economics and social

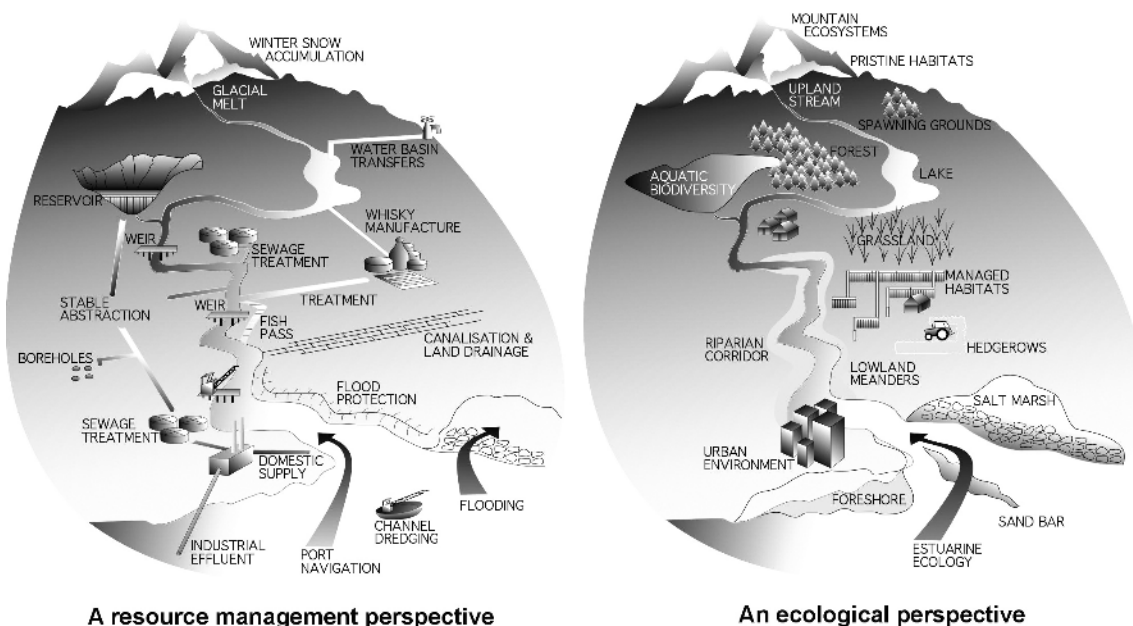


Fig. 1.3 Perspectives of catchment management.

structures. Additionally there is not a 'one size fit all' philosophy that can deliver in all locations; rather there is a desire to build generic approaches for sustainable management.

Over time, scientific understanding has begun to unravel the complexities of systems functioning and the importance of a mountain to seas holistic approach to understanding the interdependencies of physical, chemical and ecological process. There is potentially large spatio-temporal variability in the numerous physical processes and interactions within the hydrological cycle alone, before consideration of these changes on biogeochemical processes governing nutrient, carbon, sediment and, potentially, contaminant fluxes within catchments. Similarly, connectivity between stores in both space and time for surface and groundwater is of critical importance and is poorly understood in many situations. In addition, the consequence of some historical actions (such as the long term chemical contamination, or overabstraction of groundwaters) is only now being realized, in some cases

decades to centuries later. Simple questions such as do how changes in land cover and its management influence soil water distribution, or what role does that soil water play in ecological processes, carbon storage or seasonal recharge still represent unknowns from an environmental science perspective, before factoring in the consequences of current and potential climatic change.

Globally the quality of information on our natural environment has grown almost exponentially over recent decades, as has the computing power available to process, interpret and model such data. This, however, has not been consistent across the globe. For example, by their very nature monsoon-fed river systems contain large inherent annual and decadal variability and identifying the consequences of specific anthropogenic influences is difficult to capture. Also understanding the current state of aquatic resources and the identification of reference conditions in many developing countries is being outstripped by the rate of change in the quality

of these resources due to rapid economic growth and associated environmental degradation. This is particularly so in Asia. The relative importance of engaging in active catchment management in these contexts is of critical importance if appropriate sustainable development is to be achieved.

Many emergent issues have only recently achieved enough scientific understanding to warrant debate and addressing. For example, future restoration of degraded/damaged habits has highlighted the importance of hydromorphology in ecosystem dynamics. Most major river systems have been historically engineered, resulting in a legacy of dams, impoundments, canalization, levee development and riparian management, channel manipulation, land drainage and loss of floodplain. This removes the ecological integrity and natural links between land and water, affecting overall biodiversity and potential for species migration. It has been estimated, for example, that in the Mississippi and its associated delta only 10% of the original flood plain remains in a natural or semi-natural state (Gore and Shields 1995).

Hydroecology is now a central component in the EU Water Framework Directive and other developing national legislation. The WFD requires the development of reference condition for each water body type, which equate to the ecological conditions appropriate if the waterbody was in a pristine state, undisturbed by human intervention. These include hydromorphological and physio-chemical condition, such as flow regime (quantity and dynamics of flow), river continuity to allow for migration of species, etc., lake levels and residence times, morphological characteristics, along with appropriate chemical parameters.

Although many issues in catchment management have been focused on individual sectoral challenges there is an emerging ethos to move from single issue management to that of multiple issues and to identify potential win:win options. There is also a realization that successful management requires a balance between environmental protection and enhancement, the potential for economic growth, and an awareness of social per-

spectives, attitudes and beliefs. The catchment as a spatial unit for integration provides a focus for systems understanding, linking air, land and water. The quality and quantity of water available to both people and ecology is a barometer of the current state of the environment.

What are the drivers for a catchment approach and what is the binding force which makes them operational? As highlighted earlier the catchment concept has been the cornerstone to the development of much environmental legislation especially in developed countries, but this is not necessarily the unifying force in all occasions. Collaborative catchment or watershed institutions represent a new approach to environmental governance. Sabatier *et al.* (2005) highlight that such collaborative institutions focused on mutually acceptable goals require participation and representation from appropriate stakeholders, a community ethos, legitimacy and wider acceptance, and a survival strategy to ensure perpetuity. Success is measured not by outputs but by outcomes which have tangible benefit and acceptability within the stakeholder community. Local action and engagement, the adoption of voluntary measures, the establishment of community based water 'champions' are all examples of mechanisms whereby the catchment concept is being adopted as a common currency in environmental protection, whether laid down in statute books or not. The challenge for the future is to ensure that robust scientific understanding on the efficacy of single and multiple actions in catchments is available to underpin the decision-making process. In a changing world with increasing population pressures and demands on both blue and green water, and an uncertain future driven by potential climatic changes, this has never been so pressing.

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