Land, Water and Development

Sustainable and adaptive management of rivers

Third edition

Malcolm Newson

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Water is newsworthy: there is, or will be, a world water crisis. We are approaching the limits of human exploitation of freshwater resources, notably in growing essential food, and this is aggravated by climate change. Many argue, however, that the situation is best described as 'water stress', any symptoms of crisis being entirely the fault of bad management. The complexities and uncertainties associated with improving our management of fresh water take the potential remedies out of the hands of simple, local, hard engineering and into much larger units – the basin, the ecosystem and the global context – and also require longer-term perspectives.

The Third Edition follows the same structure as its predecessors, presenting the historical and scientific backgrounds to land–water interactions and establishing the links with development processes and policies. Throughout, its two major messages are that our new philosophy should be one of 'humans in the ecosystem' and that the guidance from science, being uncertain and contested, must be operationalised in a system of governance based on participation. After a review of progress towards these elements in the developed world, the international case studies update the situation in the developing world following the Millennium Development Goals and our new emphasis on poverty and on global food supplies.

This book covers the multitude of scientific research findings, development of 'tools' and spatial/temporal scale challenges which have emerged in the last decade. It covers developments in research policy and politics including the gap between the developed and developing worlds. Tensions are highlighted in the current and future role of large dams, country studies are retained (and considerably updated) and development contexts are explored in greater depth as a dividing line in capacity to cope with land and water stress. 'Technical issues' have been expanded to cover major droughts, environmental flows and the restoration of rivers and wetlands. A separate chapter picks up these themes under terms of their relationship with uncertainty and the widespread perception that a new ethos of adaptive management is needed in the water sector.

For students of geography, environmental science, hydrology and development studies this innovative edition provides a reasoned, academic basis of evidence for sustainable, adaptive management of rivers and related large-scale ecosystems using more than 600 new sources. It will also prove invaluable for lecturers and practitioners.

Malcolm Newson is former Professor of Physical Geography at Newcastle University. He specialises in fluvial geomorphology and professional training for the Environment Agency. He worked for 16 years at the NERC's Institute of Hydrology (now CEH) on the Flood Study and then at the Plynlimon experimental catchments. He is currently Director of the Tyne Rivers Trust, a community charity promoting sustainable catchment management.

Frontispiece Flooding in the Thames Valley near Oxford. Shows the interplay of natural and human functions of the floodplain.

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Preface to the third edition

On the day this edition was begun (14 March 2007), the United Kingdom government published draft legislation under the heading of a 'Climate Change Bill'. To the author, this step underlines and configures the plethora of changes in environmental science and policy since the previous edition (Newson, 1997). We have begun a new century and can reflect on the last: during it, population increased by a factor of four, urban population by a factor of 13, water use by a factor of nine, carbon dioxide emissions by a factor of 17 . . . where does one stop the flow of statistics representing the achievements and impacts of the 'Anthropocene' era?

On re-reading the second edition of this book and having prepared word-processing files to simply and painlessly update it, I was reminded of the rustic who, on being asked directions by a tourist, gave the disconcerting answer, 'I wouldn't start from here'! Lecture materials for 'Land, Water and Development' from 2006/07 gave no solace; they had moved on almost as fast as the world of water they were presenting: 'blue water', 'green water', 'grey water', dam decommissioning. However, I was brought back to my senses by reviews and comments on the value of the first two editions which ran along the lines of 'welcome overview' and 'valiant attempt to reconcile disparate intellectual approaches' – so I did start from 'here'.

To work with the themes of land, water and development is a privilege but also a weighty responsibility for a geographer. The privilege derives from the fact that these themes, considered together, constitute a cast-iron justification for taking an interface or 'cross-over' position between and amongst bio-physical and socio-economic sciences – our traditional geographical turf. I have, for example, had a perfect excuse to put down my favoured geomorphology literature and pick up Ulrich Beck's *Risk Society*: there are not many references to gravel in that!

Any comfort attending the privilege soon disappears when one accepts that water (supply, rights, hazards, research, management) falls under a glaring international spotlight as the first major resource to approach Malthusian limits, thus becoming *inter alia* a focus of sustainability arguments and a prime dimension of the global fight on poverty. Water drags food close behind it into the spotlight by virtue of both the scandal of the wasteful use of water by irrigation and the world trade in 'virtual water' (contained in food). If this were not the source of sufficient intellectual angst, just add the zest of water's major impact *on* and *from* climate change: there remains little time for sleep!

If we accept only part of the above argument, water is clearly 'busy' and this explains why this third edition is already overdue in terms of the pace of changes, if not in the science of water, in the development of water management tools and the application of evidence-based policies all over the world. The second edition was justified by the irony that its predecessor's publication coincided with the 'Earth Summit', Agenda 21 and the Dublin Statement. Now, there is even more catching up to do. Among the translations of science into 'evidence' and 'tools' (not the same thing as 'results', as any researcher will tell you) a pivotal one has been the move towards an ecosystem/biodiversity focus for sustainable water management. Some would say that policy moved first and placed stressful demands on science: the National Water Act in South Africa and the European Union's Water Framework Directive being examples. A related, vital, global exercise was the World Commission on Dams, which used biophysical and socio-economic evidence of existing dam impacts to set standards for the 'good dam' of the future. A variety of international organisations and forums has grown up to politically promote water under headings such as sanitation/health, public participation and poverty alleviation – the latter topic receiving a boost from the Millennium Development Goals. A cynical voice has labelled these global groups 'the Water Mafia', but their existence and growth derive partly from another major new global phenomenon which has burgeoned since the second edition: the internet. 'Google' is now a verb and if you 'Google' 'water' stand back for several hundred thousand entries! Globalisation of the capitalist economic model has also allowed a commodification of water (supply – to humans), but by the same token an opening to put the case for ecological goods and services as a priority item of economic self-interest – commercial incentives work for both 'sides'.

If the banner headline message for the first edition of *Land, Water and Development* was 'look upstream', that of the second was that this catchment consciousness was really an *ecosystem* approach. Some may have considered it slightly unfair between scientific disciplines that an approach championed by hydrological and geomorphological research should receive a biological title. Aquatic ecosystems are the most damaged and most threatened on the planet. The ecosystem title also opens up the 'strong' route to sustainability in which the many values (intrinsic and to human society) of non-human biota are balanced carefully against the anthropocentric priorities which have been the dominant focus of development for two millennia. This edition records the early signs that ecologists are willing and able to join hydrologists and geomorphologists to provide a better picture of the riverine habitat. There is also a nice symmetry between the words *ecology* and *economy*, and the reconciliation of these two fields is a key element in defining sustainable development, as against 'growth', for example of gross domestic product.

Is there a banner headline for this edition, of the kind not suitable for the book's title? A front-runner, for an epoch recently titled the Anthropocene (beginning around 1800 AD: Crutzen, 2002), must be 'humans *in* the ecosystem', reflecting all the strategic and operational convergence between the biophysical and socio-economic now going on in the world of water. These words also reflect the author's belief that environmental policies must begin with the current situation of human communities and their rights. Ecosystems display resilient behaviour which can be carefully exploited to support human welfare. As an example, one can point to Nelson Mandela's approach to water supply and sanitation issues in the early days of majority rule in South Africa. He appointed a political intellectual, Kader Asmal, to supervise the provision of basic human rights to water and, simultaneously, to set up an environmental reserve to support the unique freshwater ecosystems of that country, from which it earns foreign investment. If debate is engaged over allocation of water within human society and between human and non-human biota, that allocation can, in all but the severest crises, be achieved. The word 'allocation' introduces a further headline: 'it's all hydropolitical' – but the author's background in the biophysical sciences makes such an assertion dangerous ground! One message from hydropolitics (and hydro-economics) which the author is pleased to acknowledge and engage with is that the river basin is not a rigid conceptual cage. 'Thinking outside the box' now means to the author 'thinking outside the basin', despite the confining boundaries of the ecosystem approach. If there are rival and relevant systems working across watersheds (such as trade) we need to include them and to avoid mindless 'hydrocentricity'.

By its promotion from authentic sources, including academics like the author, a particular sanctioned discourse has recently prevailed that Integrated Water Resources Management (also known as Integrated River Basin Management: IWRM/IRBM) has all the tools needed to reconcile land, water and development. Its critique is welcome. Global problems are much less simple than systems science can 'wire up' as a remedy, even if it locates social science 'sockets' into which to plug. Land, water and development now face, for example, a major interface with climate change via the necessary obsession with energy use (UK water companies consume 7,700 gwh annually – 2 per cent of industrial consumption, the biggest component cost of bringing their services to our homes) and alternative energy sources, e.g. biofuels, which compete with many of the land uses described in this book. Desalination of sea water would obviate many of the problems except that, at present, its energy use and cost-efficiency will not satisfy public accounts in most nations.

The overall challenge we face under a ‘humans in the ecosystem’ rationalisation of the Anthropocene is to share water between the needs of human society and ecosystem needs, a theme eloquently explored and clarified at the Royal Society of London by, amongst others, Falkenmark (2003b) and Wallace *et al.* (2003), under a title of Freshwater and Welfare Fragility – which ‘says it all’. The two uses should be ‘rivals’ only in the sense of the etymology of that word: it derives from ‘neighbours facing each other across a river’.

Malcolm Newson, Newbrough, Northumberland

Acknowledgements

The author wishes to acknowledge many sources of inspiration, from rivers themselves to cohorts of students who have used previous editions and who in their coursework have shown the enthusiasm and insight those books were designed to inspire. Without a semester of study leave, the job of writing at this length would not have been done and so acknowledgement for that privilege goes to Andy Gillespie and Alastair Bonnett, plus my ECAM colleagues who filled teaching gaps. Alastair's comment in his book *What Is Geography?* (Bonnett, 2008) indicates the supportive intellectual milieu at Newcastle: 'Geography, like history, is an infuriating but vital combination of the modern and pre-modern. Its ambition is absurdly vast. But we know it would be foolish and dangerous to abandon it.'

Also 'at work' my grateful thanks go to George Kania, without whose technical computing back-up the manuscript might have been on parchment scrolls. From catalogue, to purchase, to installation, to 'fool's guide', to 'idiot support': George has kept the show on the road. Beyond him, in the wider world of computing many authors would now join me in acknowledging Google (*et al.*!) for creating a new way of accessing information when writing books, helping to cure, for instance, the problem of lost or partially remembered references and quotes. I have, however, avoided the temptation to become a 'Google Scholar': undergraduate readers, please note! Also in the list of much appreciated technical advice and support must come the Taylor & Francis team – Andrew Mould, Jennifer Page and Michael Jones – as well as my friendly artwork suppliers, Ann Rooke and Chris Wannop. My dauntingly disorganised typescript was successfully righted by the keen eye of Helen Moss.

The internet has also altered my relationship with an international support network of like-minded river enthusiasts who have helped with information and encouragement for all three editions of this work: Lea Wittenberg, Iran Ghazi, Bill Rowlston, John Pitlick, Gary Brierley. I used to visit them and we would exchange large parcels of literature, but e-mails and 'pdfs' are now the currency, faster and less personal but vital. Within the UK my interests in hydrology and geomorphology are regularly informed by Mark Robinson

and David Sear, whilst the mysterious world of ecosystems is rendered a little clearer by Andy Large and by my fellow members of the Environment Agency's Freshwater Habitat Advisory Group.

'At home' I have to say (proudly!) that my family have been very little help to my writing, by which I mean that I have tried to protect Cath, Ella, Daisy and Noah from the unapproachable-Dad syndrome that was visited upon their older sisters Martha and Sara during two previous editions. Ella and Daisy's habit of starting the authorship of about three 'books' (folded, stapled blank sheets of A4) per week on the desk next to me has made me jealous; I'm looking at hand-written, beautifully illustrated, five-page 'volumes' entitled 'Hurry Santa, Hurry', 'Hobby Family, the Cat Human' . . .! When time on my own has proved vital to progress (so that Noah didn't write Chapter 7 as he threatened!), our extended family of child carers: Margaret and Alan Padmore, Carole and Ray Eke, have entertained the tribe brilliantly. Bess: you can now have the 'office' floor back to lie spreadeagled as only tired dogs know how! Cath: Happy tenth anniversary!

Malcolm Newson, Newbrough, Northumberland

Prologue

'Catchment consciousness'

In two previous editions the author felt it necessary to use a Prologue to promote, through visualisation, the holistic message inherent in 'Land, Water and Development'. Whilst the river basin or catchment area is a timeless idea, its use had been restricted to just a few disciplines, each of which took a version of it to be 'truth': hence the many cartoons displayed in the Prologue.

This phase is over. Now that this section of the book has a title – 'catchment consciousness' – we have not dispensed with the graphics; in fact the need for visualisation emerges from a much deeper cultural seam. Haikai Tané, originator of the term 'catchment consciousness', has described the power of Aboriginal art as a cultural information system capable of guiding environmental management in Australia; he further suggests that Aboriginal ecography (the pictorial representation of landscape systems) 'represents key catchment and riverine features and maps their environmental resources' (Tané, 1996).

Whilst accepting, therefore, that 'catchment consciousness' now provides quite a strong message in the environmental management of aqueous systems, it is nevertheless worthwhile to briefly emphasise its cultural significance as expressed in all forms of art. For example, Plate i shows a work of landscape-scale sculpture which lays bare the inherent complex network of flow routes in a real catchment; the sculptor had become fascinated by the way in which the pond filled by underground routes and sought to give this set of linkages between rainfall and runoff a visible manifestation.

Whilst the iconography of the basin shape and system remains a powerful influence on the way we have become 'catchment conscious' (it remains throughout the book, e.g. Figures 2.4, 3.15, 8.3), there are now equally powerful but subtle influences deriving from the many aesthetic elements entering environmental thought. As we become aware of, for example, the 'non-use' values of the natural environment, arts become a vital accompaniment to environmental debates. The watery aesthetic will remain an unseen support for 'catchment consciousness' long after the debates about IWRM and IRBM are over; images have become logos for agencies, corporations and community projects, with hot competition for original variations on a theme

Plate i 'Rain Harvester', a sculpture by Julia Barton, which seeks to expose the normally hidden connectivity between rainfall and a small pond in Northumberland.

of the water droplet which, upside down, looks like a river basin or catchment outline!

As an example of the written genre in this field, Rothenberg and Ulvaeus (2001) include in *Writing on Water* photography, poetry and prose; in an Introduction, David Rothenburg writes: 'Water does not divide; it connects. With simplicity it links all aspects of our existence. We feel its many meanings' (p. xiii). Hugh Dunkerley's poem 'River' in the same volume is also indicative of the watery aesthetic:

> The whole thing is always slipping away downstream,
> Its sliding surface a welter of accelerations and sudden breakings,
> Of whirlpooling gullets.

The cultural anthropology of water, especially rivers, gets written expression across the range of literature, from pop songs and the new genre of river 'stories' (e.g. Ackroyd, 2007; Wray, 2007) to accounts of river swims (Deakin, 1999) and to the serious academic writing of authors like Veronica Strang (2004, 2006). Strang's vivid account of the historical connection and more recent disconnection between the local people of the Stour Valley in Dorset (UK) and their river has been matched by a cultural analysis of channel restoration in the New Forest (Garner, 2006) and the political account of 'life and livelihood' in Ward's (1997) critique of water privatisation in the UK.

This book has always treated the basin in terms of the detail of the spontaneous regulation functions in the Marchand and Toornstra (1986; Figure i) model:

- regulation of water regime (terrestrial and climatic);
- regulation of erosion and sedimentation;
- water purification.

Marchand and Toornstra's description of these functions is as follows: 'The drainage basin of a river fulfils a series of functions for man that require no

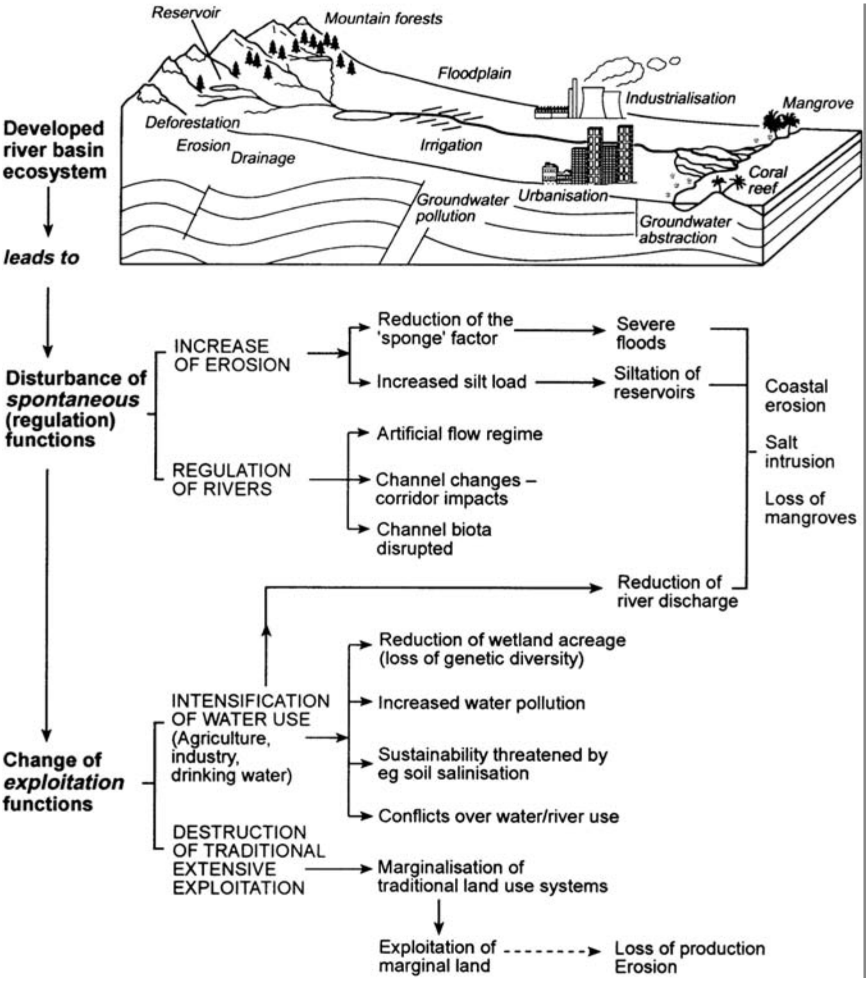


Figure i The river basin ecosystem and a 'slice' of environmental assessments (modified from Marchand and Toornstra, 1986).

human intervention, i.e. with no need of investments or regulatory systems' (p. 11).

The history of river basin development (Chapter 1) illustrates the way in which humankind has consistently sought to intensify exploitation, impose artificial regulation and then regret either the investment needed or the environmental degradation caused; environmental degradation inevitably bespeaks more artificial regulation. However, this edition promotes with greater strength than its predecessors the notion of 'humans in the ecosystem'. As Carl Folke (2003) puts it, 'there are neither natural or pristine systems, nor are there social systems without nature. Instead, humanity and nature have been coevolving within the biosphere and its freshwater cycles in a dynamic fashion and will continue to do so.'

The failure of this picture is its comfortably small size: at another extreme, there are basins which traverse many international boundaries and whose rivers are too wide to see across, let alone jump across. These rivers are in great peril because they combine the scientific uncertainty of predicting the behaviour of large basins and political impasses to collaborative management. WWF marks World Water Day by releasing attention-grabbing reviews of the global predicament; in 2007 it was 'World's Top Ten Rivers at Greatest Risk'. They are: Yangtze, Mekong, Salween, Ganges, Indus (all in Asia), Danube, La Plata, Rio Grande–Rio Bravo, Nile, Murray–Darling.

How do we picture vastness?!

Chapter 1

A ‘world water crisis’?

The history and current trajectory of water management

In previous editions of *Land, Water and Development* this brief historical review had a mainly scholarly purpose: ‘to explore briefly the nature of Man’s occupation of river basins’, with the added justification that ‘the adoption of a conscious modern attempt at holistic management will almost certainly involve cultural attitudes to the problems, with their roots in history’. It is now given analytical bite by the widely cited ‘world water crisis’. Can we use historical review to discover ‘how we got into trouble’, elucidate virtues and errors along the way and identify constraints for the future in the way human society addresses its needs and the needs of ecosystems for water? Can we further identify a point at which the *Anthropocene era* began in terms of human impacts on freshwater systems or, alternatively, date the end of ‘natural’ rivers? We ask if there are historical analogues to current dilemmas, such as the Victorian rush to alleviate problems of health and poverty through domestic water supply and sanitation which led directly to degradation, through pollution, of the rivers serving to drain the excrement. Is this the direction now being taken by developing world cities (see also Chapter 5)? Because our focus is on land and development, as well as water, can history and prehistory illuminate the relative responsibilities for hydrological changes caused by catchment land use, land management, structural water management and climate? How have human institutions coped?

To gain an introductory impression of the current situation one can simply line up the descriptive terms used in titles of articles in responsible news, feature and even technical writing:

- ‘the parched planet’;
- ‘every last drop’;
- ‘looming water crisis’;
- ‘looming hydrocide’;
- ‘water – a millennial priority’;
- ‘water quality – a development bomb’;
- ‘water: one of the greatest causes of mass suffering’;
- ‘water: an imminent global crisis’.

Such articles are written partly because the global information base now exists and because an impressive array of international institutions now puts water in a prominent position. Water's links to poverty and famine are also responsible for intensive coverage, but can water justify a treatment as the first Malthusian limit, i.e. a resource exhausted by population growth alone? As with most resources, a consideration of population is useless without the parallel notions of levels of consumption and compensatory technological innovation. The widely read 'skeptical environmentalist', Bjorn Lomborg (2001), claims that water 'has been touted as a harbinger of future trouble', but he remains optimistic, stating that 'there may be regional and logistic problems with water. We will need to get better at using it. But basically we have sufficient water' (p. 149).

1.1 Hydraulic cultures and religious codes: management in advance of science

> Agriculture only makes sense if one can count on water.
>
> (Kandel, 2003, p. 193)

Irrigation began to form a strong bond between humans and river basins in the sixth millennium BC; two important river basin civilisations, Mesopotamia and then Egypt, manipulated water to sustain settled agriculture. Both irrigation and elementary flood control were practised (Kandel, 2003). The food surpluses which were generated by the success of these elementary management strategies were the basis for excess labour to be put into creating the architecture and other artefacts from which we have come to know so much about the Tigris–Euphrates and Nile valleys between 5000 and 3000 BC (Hawkes, 1976). The Sumerians built temples to the gods, whom they considered responsible for the success of agriculture, whilst the Egyptians built memorials to the kings, who were paramount in the strongly structured societies essential to primitive water management.

Toynbee (1976) describes the Sumerian achievement as the source from which Egypt and later the Indus civilisation drew their basic water technologies; he also stresses the importance of *social structures*:

> The human conquest of alluvium must have been planned by leaders who had the imagination, foresight and self-control to work for returns that would be lucrative ultimately but not immediately. The one indispensable new tool was a script. The leaders needed this instrument for organising people and water and soil in quantities and magnitudes that were too vast to be handled efficiently by the unrecorded memorising of oral arrangements and instructions.
>
> (Toynbee, 1976, pp. 45, 51)

Smith (1969) stresses the tight structures responsible for any successful hydraulic culture; summarising Wittfogel (1957) he suggests that:

> the construction and maintenance of large-scale irrigation systems require the assembly of a considerable labour force which may be most efficiently created either by the institution of forced labour or the levy of tribute and taxation or both. A centralized administration is also needed for the maintenance of canals and to control water distribution.
>
> (Smith, 1969, p. 108)

Biswas (1967) tabulates a chronology of hydrological engineering works by the Sumerians, the Egyptians and the Harappans who, by 2500 BC, had developed a very powerful (though less creative) civilisation in the Indus basin (Table 1.1). Among the most interesting artefacts remaining is the Sadd el-Kafara ('Dam of the Pagans') built *c.* 2800 BC just south of Cairo. It was apparently built without a spillway and with a capacity so small in relation to its catchment area that it failed early in its lifetime. *Distribution* of water was clearly more successful than *collection*; it requires, after all, much more organisation than understanding, and it was to be 2,000 years before the study of nature began and 4,500 years before scientific hydrology!

One must not neglect the military significance of water engineering at this time. Sennacherib the Assyrian destroyed Babylon in 689 BC by damming the Euphrates and then destroying the dam (Smith, 1972). Sennacherib became the agent of some extremely well-surveyed and constructed dams and irrigation schemes. It is suggested by some writers that the need for efficient irrigation prompted the development of geometric ground survey techniques. A tablet in the British Museum illustrates algebraic calculations for the design of dykes, dams and wells.

Water has been a central feature in the development of many, if not most,

Table 1.1 Key dates in the development of hydraulic civilisations

Date (*BC*)	*Event*
3000	King Menes dammed the Nile and diverted its course.
3000	Nilometers were used to record the rise of the Nile.
2800	Failure of the Sadd el-Kafara dam.
2750	Origin of the Indus Valley water supply and drainage systems.
2200	Various waterworks of 'The Great Yu' in China.
1850	Lake Moeris and other works of Pharaoh Amenmhet III.
1750	Water codes of King Hammurabi.
1050	Water meters used at Oasis Gadames in North Africa.
714	Destruction of quanat systems at Ulhu (Armenia) by King Saragon II. Quanat system gradually spread to Persia, Egypt and India.
690	Construction of Sennacherib's Channel.

Source: After Biswas (1967)

Table 1.2 Salient elements of attitudes taken to freshwater by major world religions

Religion	*Cultural attitudes to environment / water / rivers*
Christianity	Stewardship: humans in God's image; work ethic; water purity, healing
Judaism	People and land; reclaiming wilderness; non-specific on water
Islam	Water a gift of the Almighty; holy laws on use; ethics of scarcity; protection
Buddhism	Harmony with nature; nature a moral concept: sacred sites include rivers
Hinduism	Polytheist – gods in Nature; caste system ecological; rivers sacred

Sources: Highly compressed from Batchelor and Brown (1992); Breuilly and Palmer (1992); Gadgil and Guha (1992); Khalid and O'Brien (1992); Rose (1992); Prime (1992); Bagader *et al.* (1994)

world religions; the birth of Islam, Judaism and Christianity in semi-arid environments has helped create this linkage – the fundamental shared resource, the basis of food and livelihoods, is bound to figure prominently in religious codes (Table 1.2). However, water has an additional spirituality of its own nature, as an element, a vital force and an agent of destruction. As the poet Philip Larkin wrote, 'If I were called in to construct a religion I should make use of water' (Larkin, 1964). An interest in religious attitudes to water is no mere academic luxury: Smith and Ali (2006) demonstrate remarkable patterns in contemporary water use in UK cities related to ethnic identity, patterns which may help improve the service provided by utility companies.

Summarising the lessons for contemporary water/river management from this section of our 'rewind':

- Water had powerful cultural significance as part of a polytheistic concept of environment, one in which ecosystems were considered inclusive and were given geographical boundaries.
- Pre-settlement adaptive management was gradually exchanged for engineering solutions to assure supply and protect against hazards in established settlements.
- The politics of allocation thereafter became entwined in elaborate social structures.

1.2 Engineering and science: the rise of hydraulics and hydrology

Having tentatively concluded that water distribution can occur in advance of hydrological knowledge, how can empirical knowledge and theoretical understanding be put to work in support of engineering?

Empirical records of river levels can be traced for the Nile back to 3000 BC; the famous Roda 'nilometer' (Figure 1.1) recorded the annual flood. A system of flood warning may have been developed, using watch towers and 'extremely good rowers' (Biswas, 1967, p. 125) who propelled their boats ahead of the

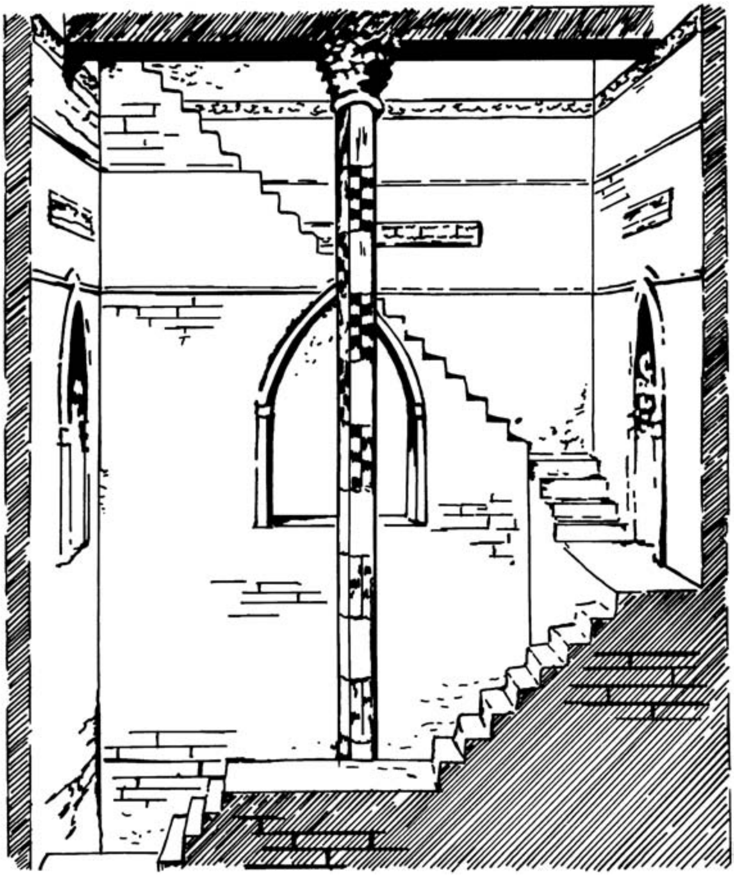


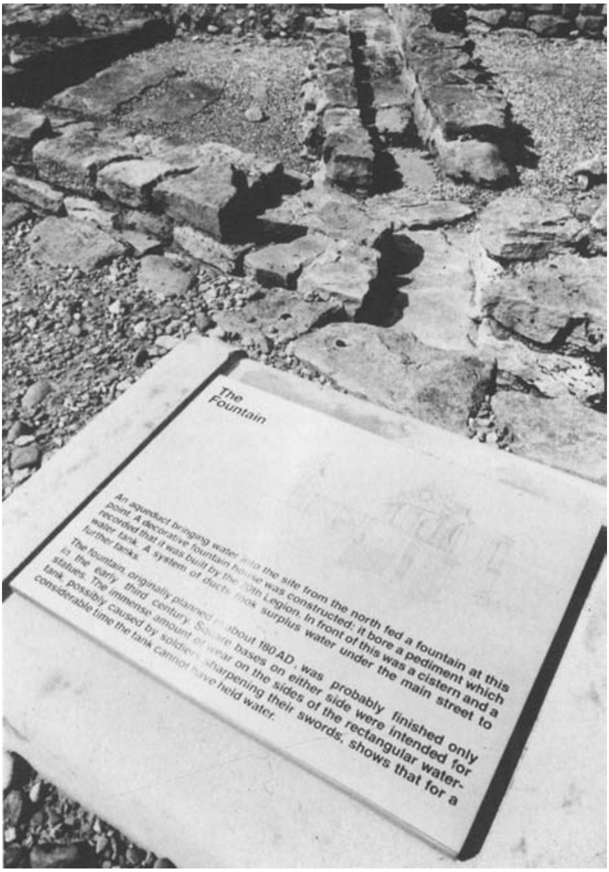
Figure 1.1 The Roda nilometer, upon which the heights of the annual Nile flood have been measured from antiquity (from Biswas, 1967).

flood wave. Biswas also records the 3,000-year history of simple water metering for irrigation supplies in North Africa. In *River God*, Wilbur Smith's imagination has the arrival of the Nile flood thus:

> we woke to find that during the night the river had swollen with the commencement of the annual flood. We had no warning of it until the joyous cries of the watchmen down at the port roused us. Both banks were already lined with the populace of the city. They greeted the waters with prayers and songs and waving palm fronds.
>
> (Smith, 1993, p. 305)

Greek philosophers were not able to advance our knowledge of hydrology, though Archimedes' observations led to the foundation of hydrostatics. The engineering skill of the Romans, however, led to great progress in urban water supply and drainage systems. Nace (1974) reminds us that, 'Despite their great hydraulic works, no evidence has been found that Roman engineers as a group had any clear idea of a hydrological cycle' (p. 44).

The Romans' largest technical problems in impressive feats, such as the Pont du Gard aqueduct (supplying Nîmes in southern France), would have been the design of capacity for flow and gradient. In an interesting review of the Pont du Gard's hydraulic design, Hauck and Novak (1987) stress the subtleties of conveying a steady flow of water down only 17 metres of fall in 50 kilometres. The Romans made a clear trade-off between the expense of a higher aqueduct (i.e. a longer span) and the need to maintain a steady gradient. In 19 BC the most precise level was a 6 metre-long bar, levelled by water



An aqueduct bringing water into the site from the north fed a fountain at this point. A decorative fountain house was constructed: it bore a pediment which recorded that it was built by the 20th Legion. In front of this was a cistern and a water tank. A system of ducts took surplus water under the main street to further tanks.

The fountain, originally planned in about 180 AD, was probably finished only in the early third century. Square bases on either side were intended for statues. The immense amount of wear on the sides of the rectangular water-tank, possibly caused by soldiers sharpening their swords, shows that for a considerable time the tank cannot have held water.

Plate 1.1 Roman water supply engineering, Corbridge, Northumberland (photo M. D. Newson).

in a groove or plumb bobs. Simple geometry and a knowledge of the flow rate would have provided the cross-sectional area of the aqueduct’s channel. The work was a masterpiece of applied hydraulics. Bratt (1995) describes more recent masterpieces of mountain water transfers – the 376 *bisses* (total length 1,740 kilometres) which traverse the steep sides of the valleys in the canton of Valais, Switzerland, in the headwaters of the River Rhône to deliver irrigation water; they were constructed as early as the eleventh century, an indication that not all such skills were lost in the Dark Ages. Nevertheless, the Renaissance in Europe was to create a ‘big picture’ of rivers which began to make fantastic feats of civil engineering for water supply and drainage look increasingly like an option, rather than ‘the answer’ (Box 1.1).

Box 1.1 Leonardo’s graphic impact on ‘catchment consciousness’

It is hard to document scientific progress during the Renaissance without reference to Leonardo da Vinci; of him Popham (1946) says, ‘water played a very important part in his life. A great deal of his energies and his intellect were absorbed in directing and canalising rivers and in inventing or perfecting hydraulic machinery’ (p. 70). He was obsessed with depicting water movement in his art, and careful observation aided his design of water wheels and pumps. However, his was not merely a brilliant combination of water engineering and art: he formalised the relationship between catchment and flow properties in his study of the Arno above Florence (see Plate 1.2). The Arno catchment map (1502–03) shows very great care with both the stream network and the contributing slopes; mountains are not shown as isolated hills in the medieval tradition but by contour shading. To record so precisely the relationship between slopes and channels and between events over the river basin and those at a site (i.e. Florence) sets up the combination of hydrology and hydraulics which was eventually to guide modern river management.

Levi (1995) considers Leonardo to be so important to the history of observational hydraulics that he devotes an entire chapter of his historical review to the man. Pughe (2001) examines Leonardo’s written ‘aqueous perspective’.

Despite the arrival of ‘the watershed’, only mystery and magic could explain what went on inside it. The next important step was the establishment of the *hydrological cycle*. Nace (1974) suggests that acceptable definitions of the hydrological cycle were published at a very early stage of recorded history, for example in the Bible (Ecclesiastes 1:7): ‘All the rivers run into the sea; yet the sea is not full; unto the place from which the rivers come, thither they

Plate 1.2 Leonardo da Vinci's map of northern Italy showing the watershed of the River Arno (Windsor Royal Library no. 12277).

return again.' Palissy (1580) is acknowledged as having had the first accurate insight into the general process of runoff (as credited by Ward, 1982). Not until John Dalton presented a paper to the Philosophical Society of Manchester in 1799 had rainfall and runoff been brought together quantitatively. It is interesting to note the title of Dalton's paper: 'Experiments and Observations to determine whether a Quantity of Rain and Dew is equal to the Quantity of Water carried off by the Rivers and raised by Evaporation; with an Enquiry into the origin of Springs.'

What lessons are revealed by this section of historical insights?

- Scientific concepts in applied fields often make progress by their very application; shortcomings or failure then exposes gaps in fundamental knowledge: there is no doubt that water engineering became fundamental to human development in this way.
- Scientific endeavour requires a sophisticated socio-political context and expenditure over and above that on its application to individual feats of 'progress', making it a real problem to incorporate formally in processes of sustainable development.

1.3 Monks, mills and mines: coordination but abuse of rivers in England

Through the careful work of Rowland Parker (1976) it is possible to reconstruct a 2,000-year history of human settlement on the banks of a tributary of the River Rhee in Cambridgeshire (Box 1.2). Steinberg (1991) has made a parallel exploration of the development of the Charles and Merrimack rivers of New England, showing how common law and statutes evolved to cope with conflicts between the building of mills, navigation, fisheries and pollution. Guillerme (1988) reviews the period 300–1800 in France, during which the focus of 18 cities in the North passed from defence to milling to drainage, water supply and sanitation.

Box 1.2 Two millennia in the life of ‘the common stream’

Up to the period of Anglo-Saxon conquest it is clear that navigation was an important function of even the smaller elements of the river network; indeed, invasion was by that route. The settlers constructed a water mill, which must have interrupted navigation (since no mention is made of a mill leat). Later, with forest clearance on the interfluves, settlements moved from flood- and invasion-prone riversides to the terraces and low hills nearby. Those which did not were protected by the digging of moats and diversion channels.

The Domesday Book of 1086 enables us to gain insights into the distribution of mills (6,000 of them) and also of freshwater fisheries, a traditional water use by the very powerful monastic landowners of the time. After the Norman Conquest the rise of manorial estates and the use of milling tolls as part of a feudal structure ensured a rapid increase in obstructions to rivers, but also in legal protection against selfish behaviour. The chaotic picture of mills and fisheries recorded by Domesday is shown in Figure 1.2.

The next step in Parker’s record of The Brook involves legislation from manorial courts to control private use by tenants of the channel to create ponds for stock watering, human bathing, etc. Parker presents an almost continuous record of ‘river offences’ from 1318 until 1698. Gradually, pressure on the stream increases and the domination of ponding and diversion offences in the fourteenth century gives way to efficient land drainage (‘cleaning and scouring’) in the fifteenth and sixteenth and to pollution (‘noysome sinkes and puggell water’) in the sixteenth and seventeenth centuries. A selection of these offences is worthy of quotation to illustrate the ways in which English society was dealing with this two-mile stretch of minor stream.

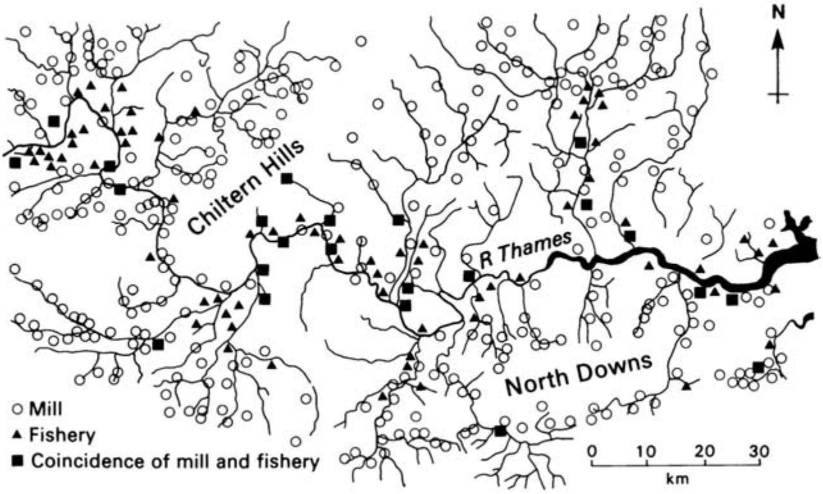


Figure 1.2 Domesday (i.e. AD 1086) mills and fisheries on the River Thames, England (compiled by Sheail, 1988).

In 1318 the following entries occur:

> All the capital pledges of Foxton fined for not putting right the brook which was stopped up by Thomas Roys.
> John Kersey fined 12 d. for diverting the brook which flows through the middle of the manor, to a width of half a foot, and causing a nuisance.
> Simon le Roo diverted the brook; fined 12 d.
> Roysia Kelle widened the stream by half a foot; fined 12 d.
> Ate Reeve did the same alongside his yard, widening the brook by letting the other bank fall in to a width of two feet; fined 3 d.

And in 1492:

> John Everard, butcher, allowed his dunghill to drain into the common stream of this village, to the serious detriment of the tenants and residents; fined 4 d.; pain of 10s.

(From Parker, 1976)

Whether manipulating streamflow for milling, stock watering, abstraction or fisheries, some form of obstruction to the natural regime was required, and we have the origins of what we now call river regulation. Sheail (1988) reviews the history of river regulation in the UK; much of the available documentary evidence refers to drainage schemes in the Fens, Lincolnshire and Romney Marsh but the conclusion is universally applied: 'Whatever the purpose of river regulation, no scheme could fulfil its potential without the cooperation of all the interests involved. A balance had to be struck between the protection of individual rights and the furtherance of the common good’ (Sheail, 1988, p. 222).

Central government became involved in drainage issues in 1427 with the establishment of a Commission of Sewers; a General Sewers Act followed in 1531. Interestingly, a complex hybrid of statute and common law was applied to water management, the presence of common law implying progress by precedents rather than a completely technocratic application of principles and hence standards (in the scientific sense).

The very extensive lowland drainage, under Dutch direction, of the seventeenth century has a literature of its own, particularly in the Fens (e.g. Darby, 1983). Less attention has been paid to the more hydrologically complex task of irrigation and drainage (of the same land) as was practised extensively in chalkland valleys from the seventeenth to the early twentieth century. The water-meadow farming system (Everard, 2005; Cook and Williamson, 2007) had much to commend it in an age of low-intensity production with plentiful labour, whilst drainage of land in the Fens was considered to be of regional and national benefit, threatening only those who took the annual harvest from the flood (duck, reeds, fish). River regulation elsewhere quickly led to conflicts of interests between upstream and downstream users of water.

In AD 528 the Roman Emperor Justinian brought together all existing Roman law in the Justinian Code (Cech, 2003). Included was the Riparian Doctrine (from the Latin *ripa*, or bank), which allowed public use of rivers whilst conveying the property rights to the riparian property owner. Effectively, this set up the conditions required for water milling – the pre-industrial power centre of communities in humid lands. Milling evoked elaboration of riparian principles and a degree of informal cooperation throughout the length of river systems to manage, for example, siltation and to retain navigation rights. The English formulation of a common law of riparian rights, datable to the *Chasemore* v. *Richards* case of 1859, gives the following rights to those who own land adjacent to rivers:

> It has been now settled that the right to the enjoyment of a natural stream of water on the surface *ex jure naturae* belongs to the proprietor of the adjoining lands as a natural incident to the right to the soil itself; and that he is entitled to the benefit of it, as he is to all the other advantages belonging to the land of which he is the owner. He has the right to have it come to him in its natural state, in flow, quantity and quality, and to go from him without obstruction, upon the same principle that he is entitled to the support of his neighbour’s soil for his own in its natural state. His right in no way depends on prescription or the presumed grant of his neighbour.
>
> (Wisdom, 1979, p. 83)

Larger obstructions also configured the law of rivers: dams were built for a variety of purposes: for hydraulic mining (called 'hushing' in the North Pennines), ore processing and separating, and to supply the canal network which expanded in the late eighteenth century. Binnie (1987) traces the origins of dams in Britain back to the Roman occupation; the occupants of fortifications along Hadrian's Wall clearly used reservoir storage on small streams. The first modern dams were the mill and fishing weirs; in 1788 cotton milling alone accounted for 122 weirs on relatively large streams. More than 150 canal reservoir dams were built, the precursors of the modern water-supply reservoirs. Finally, the growth of manufacturing and of large urban populations led to the construction of dams for domestic water supply. The conflict of interests between water storage and industrial water use led to the concept of 'compensation water', a minimum flow allowed out of reservoirs to maintain the rights of downstream users.

In this section the benefits of hindsight appear to be the following:

- In the humid temperate civilisations which came to dominate world order through commercial power, rivers became seen initially simply as a means to a commercial end, being obstructed with weirs and dams and polluted by domestic, agricultural and industrial effluent.
- Rearguard actions to conserve and protect the natural resources and services of rivers occurred mainly as the result of community-based or river-connected appreciation of sixth-century riparian doctrine.

1.4 Urbanisation and industrialisation: a steep deterioration

Whilst the Romans built sewer networks to collect waste and must therefore have understood the public health problems associated with river pollution, it is to the 'Workshop of the World', Britain during its Industrial Revolution, that we can look for an emerging approach to rivers as collection systems. Two elements of urbanisation and industrialisation prompted the need: the huge toll of life in epidemics of water-borne diseases (e.g. cholera in 1832), which forced attention to the classic source–pathway–target pollution system, and the need to establish 'gathering grounds' in the uplands to feed reservoirs of abundant pure water to be supplied under gravity to the developing lowland conurbations.

Howarth (1988) provides an illuminating history of the development of water pollution law in England and Wales (Scottish law is a separate system). Statute laws dealing with water pollution were apparently of little success in combating the public attitude to streams as dumps for all excrement and filth, not an unusual attitude in burgeoning developing-world cities of today. By the arrival of the main phase of the Industrial Revolution, England and Wales had a plethora of legislation relating to the clearance of filth from towns using water-borne systems (e.g. Town Improvement Clauses Act 1847, Public Health Act 1848) and to the mitigation of the effect of these domestic and industrial wastes on rivers. One of the principal of the latter class of enactments was a Salmon Fisheries Act (1861); because the hard-working Victorian water engineers were busy bringing clean, fresh supplies from the upland streams, concern for urban lowland streams was directed mainly at the loss of livelihood from fisheries.

The principle of riparian rights, though set out again by Lord Wensleydale in 1859, did not bring the common law into any greater efficiency than statute in dealing with the relationship between towns on the same river. Clearly the next stage was to change the geographical reference scale for administration of the water cycle, rather than to perfect new legislative principles, though the Royal Commission on Sewage Disposal provided chemical and physical principles for pollution control by 1912.

And so, in the 1930 Land Drainage Act, local drainage boards were established on a catchment basis, and the 1948 River Boards Act set up similar bodies to deal with water resources (see Chapter 7). From this point onward we see a steady move towards the addition of pollution control responsibilities to these authorities (see Chapter 7). Patterson (1987) sees in the last 100 years of river basin management in England and Wales a grave political symptom, the removal of the *democratic* element of municipal control in favour of, firstly, a *technocratic* element in the river basin authorities and, latterly, an increasing *commodification* of water. Since the 1960s the rise of environmentalism, aided by industrial stagnation and diversification, has led to a general desire to improve the purity of rivers. Water sports have become major recreations, and residential accommodation has returned to river waterfronts. Not just water pollution is involved; flood protection causes environmental damage (Purseglove, 1988) and, elsewhere in the world, irrigation does so too.

Lessons we might draw from this section of historical review include:

- Human fallibility results in unforeseen, unintended crises and policy advances through these: not an encouraging characteristic of our species in terms of sustainable development.
- In the 'unforeseen' category, the polluting impacts on rivers and groundwater through 'advances' in water and sanitation took decades to correct, an ongoing process.
- Fish and fisheries have had a vital role in protecting rivers from even more extensive damage because they are directly accountable in law and economics.
- Science has contributed to problem solving through its specialisms, not by evolving a holistic 'rivers science'.

In order to learn lessons from historical sequences about the impacts of river basin development there needs to be a concerted academic approach to the subject. In fact, new approaches to river basin management render this a practical need too, as we realise the importance of 'reference conditions' to which to restore channels and the other spontaneous regulators of the river basin (see Chapter 6). At the end of her entertaining sketchbook of river history Haslam (1991) makes the following plea:

> It is time the human ecology of rivers, a fascinating record of human ingenuity and endeavour, was rediscovered and re-appreciated. . . . man's dependence on the river has changed, so that it is *no longer immediate, but distanced*. There is a gap, a distance, between man and the use of the river, so that the river has been set aside, indeed vandalized in the name of progress.
>
> (Haslam, 1991, p. 303, emphasis added)

Few authors have yet answered Haslam's call with detailed studies of the historical sequence in a river basin. An exception is the study by Decamps *et al.* (1989) of the Garonne which relates the date of changes to the spontaneous and exploitation functions of the river to their extent. The same volume of studies contains a yet more detailed study of the history of flood protection by 'river training' in Switzerland (Vischer, 1989) which yields great insights into the epic and heroic status of those charged with removing 'swamps' and controlling channels. The HOPE project (History and future Of People on Earth: Costanza *et al.*, 2007) is currently wrestling with the nature and pace of changes in the relationships between humans and ecosystems, with an early report suggesting that the 'Great Acceleration', following the Second World War, marks the beginning of unsustainable pressures. As Steffen *et al.* (2007) put it, 'The Earth has now left its natural geological epoch, the present interglacial state called the Holocene': we are living well and truly in the Anthropocene.

1.5 Sustainability, the current 'crisis' and the challenges of the future

Quite possibly the book published in 1991 by Robin Clarke entitled *Water: The International Crisis* is the origin of the frequent use of the term 'crisis', yet the book was born in a meeting in 1989 addressing *water scarcity in semi-arid regions*. Clarke appears to end the book by claiming a crisis of global inaction in facing up to scarcity of a resource which at that time received far less political attention than food and energy. 'Crisis' appeared again in the title of Julie Stauffer's (1998) book, this time with the focus on freshwater pollution.

Politicians claim to have a problem with the term 'sustainable development' because it has a variety of definitions; it is therefore beneficial to investigate the characteristics of *un*sustainable development through historical review and deconstruction. Box 1.3 summarises the characteristics of a land, water and development project which might attract most professionals' vote as the *least sustainable* of modern times, the Aral Sea.

Many attribute both the definition and the initiation of sustainable development to the World Commission on Environment and Development (1987). However, as Clarke (1991) reveals, the International Water Resources Association berated the Commission for excluding water from its analysis. The

Box 1.3 Unsustainable development: the disastrous case of the Aral Sea

The development of the Aral Sea region was not unusual in its intention, scope or methods under the 'gigantism' model of irrigation, power and industrialisation schemes, notably in the former Soviet Union. However, there was little or no impact analysis, and the project occurred at high speed and with no mitigation of the known hydrological effects (Table 1.3). It will now require a massive corrective programme by international donors (see Postscript) to bring any social or ecological vitality back to this huge area of central Asia.

Table 1.3 Unsustainable development: the disastrous case of the Aral Sea

Location	Central Asia: formerly Soviet Union, now parts of Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan.
Former status	Fourth-largest inland sea in the world, behind Caspian, Lake Superior, Lake Victoria.
Development goals	To improve on traditional fishing, hunting and recreation as methods of economic growth via commercial irrigated agriculture, principally cotton
Mechanisms	70,000 square kilometres of cotton, irrigated via 700,000 kilometres of canals taking water from two principal rivers: Amu Darya and Syr Darya. Total diverted water: 16 cubic kilometres – equivalent to the River Colorado (USA).
Results	40 per cent of irrigation water lost to leakage of canals and evaporation; Sea shrinks by 75 per cent, converting to northern ('Little') and southern ('Big') Aral Seas. Shorelines retreat by up to 75 kilometres. Annihilation of traditional economy and ecosystem (via fertiliser and pesticide pollution); decline in life expectancy, rise in infant mortality, widespread chronic ill-health.
Mitigation	World Bank allocated $64 million to dam off the northern remnant of the Sea (its level remained 2–3 metres higher than that of the 'Big' Aral Sea to the south) and improve catchment management of the Syr Darya. Switching from cotton to more productive, less water-demanding crops (potatoes, apples) not occurring.

Sources: Glantz *et al.* (1993); Kiessling (1998); Williams (2003) reaction of the international professional community was rapid and, since this shock, water specialists have played a major role in practical incorporation of sustainability principles, for example through the Dublin Principles (Rodda and Young, 1992; Young *et al.*, 1994). Tortajada (2005) notes that, whilst the Principles received no endorsement by heads of state in their plenary statements at the United Nations Conference on Environment and Development (the 'Earth Summit') in 1992, the following ten years saw water issues rise to an international prominence widely evident at the follow-up 2002 conference in Johannesburg. The Millennium Development Goals (MDGs) (Cheru and Bradford, 2005) also put a spotlight on water supply and sanitation. There are eight Goals (but also 18 targets and 48 indicators) to be achieved by 2015:

- Eradicate extreme poverty and hunger.
- Achieve universal primary education.
- Promote gender equality and empower women.
- Reduce child mortality.
- Improve maternal health.
- Combat HIV/AIDS, malaria and other diseases.
- Ensure environmental sustainability.
- Develop a global partnership for development.

The anthropocentric focus of the MDGs contrasts with the stark interdependence of ecosystems and human well-being revealed by the Millennium Ecosystem Assessment (Alcamo *et al.*, 2003), and the links between poverty and water need to be welded rather than fractured. In the words of Falkenmark and Rockström (2004), 'Achieving the goals of the Millennium declaration will therefore be an issue of socio-ecological balancing between beneficial use of water and the fundamental goods and services that it provides . . . and protection of essential ecosystem functions'. Duda (2003) forms the view that an excessive focus on irrigated food supplies and water supply/sanitation issues in the period up to 2015 may result in a range of undesirable social and environmental outcomes.

There is no doubting the urgency of the MDGs, and this sense of anxiety and frustration over water and development has boosted claims of a 'world water crisis' amongst responsible organisations and individuals (see Box 1.4).

Many development experts have continually drawn our attention to the plentiful scope for *mis*management of resources, natural and financial, in the process of 'progress' (the historical review above confirms this). The 'skeptical environmentalist', Lomborg (2001), concludes his chapter on water with these words, 'It is an often heard cry, "Global water crisis: the major issue of the twenty-first century". But it is needlessly rhetorical and intimidating. We need better water management, pricing and import substitution' (p. 158). In his overview book *Water under Threat*, Larbi Bouguerra (2006) writes a chapter entitled 'A Water Crisis?' His subtitle, 'Scarcity or Mismanagement?', is also meaningful; under it he blames the historical rut – trapping politicians who favour subsidies for unprofitable infrastructure developments and see no commercial benefits in demand management. Biswas (2005) is also sceptical, but at a more fundamental level, seeing the 'crisis' as based on unreliable data, a focus on abstraction rather than use, and neglect of the promising roles of demand management and groundwater abstraction. Biswas has, however, other candidates as threats to the basic human reliance on water, principally 'continuous water quality deterioration' (p. 232) and 'lack of investments for both water quantity and quality' (p. 233). He blames the current fear of investors in large water projects on the ramifications of the

Box 1.4 Components of, and actors in, the 'world water crisis'

For 20 years now 'crises' over environmental issues have been presented by well-intentioned activists and organisations promoting the changes needed to bring about sustainable development. Possibly no other 'crisis' has received such widespread endorsement as the 'world water crisis', and we need to ask why and whether there is a more accurate language with which to convey a truer picture of the problem, facilitating attempts at mitigation and solution. Tables 1.4(a) and 1.4(b), and the material they reference, make a starting point for an assessment of whether this is 'stress' or 'crisis'.

Table 1.4(a) The components of the widely cited 'world water crisis'

Components of crisis	*Impacts*
Demand	Water demand exceeds supply or little remaining 'head room'.
Food	Major component of demand is irrigated agriculture: food.
Pollution	Water supplies finite but increasingly polluted, including groundwater.
Ecological impacts	Water storage and use compromises ecosystem health.
Health*	Widespread lack of clean supplies and sanitation, with resulting mortality and morbidity.
Global climate change	Climate change impacting on water scarcity in next two decades.

* *Figures:*
3.4 million people die each year from water-borne diseases.
1.1 billion people currently lack access to safe drinking water.
1.2 billion people directly impacted by polluted water.
1.2 billion people impacted by dryland degradation ('desertification').
2.5 billion people live in regions facing severe water scarcity by 2025.
2.6 billion people currently lack sanitation.

Table 1.4(b) Major players and statements on the 'world water crisis'

Organisation, representation	*Major statements*
World Water Council	WWC organise triennial World Water Forums (1997 onwards: the first Marrakesh Forum initiated the World Water Vision). *World Water Vision: Making Water Everybody's Business* (Cosgrove and Rijsberman, 2000). *World Water Actions: Making Water Flow for All* (Guerquin *et al.*, 2003).
World Water Commission	Formed by the World Water Council with United Nations support to carry out the review upon which is based the World Water Vision (see above).
Global Water Partnership	*Toolbox: Integrated Water Resources Management – Sharing Knowledge for Equitable, Efficient and Sustainable Water Resources Management* (GWP, 2001).
World Commission on Dams	*Dams and Development: A New Framework for Decision-Making* (WCD, 2000).
UN Human Settlements Programme	*Water and Sanitation in the World's Cities: Local Action for Global Goals* (United Nations Human Settlements Programme, 2003).
World Resources Institute/ Worldwatch Institute	*Watersheds of the World: Ecological Value and Vulnerability* (Revenga *et al.*, 1998).
IUCN	*Vision for Water and Nature: A World Strategy for Conservation and Sustainable Management of Water Resources in the 21st Century* (IUCN, 2000).
P. H. Gleick	*The World's Water* (Gleick, 1998–99 and biennially). See also *Water in Crisis* (Gleick, 1993).
R. Clarke and J. King	*The Atlas of Water: Mapping the World's Most Critical Resource* (Clarke and King, 2004).

Sardar Sarovar Project in India – 'the World Bank's "Viet Nam" in terms of its support to water projects' (p. 234). Frederiksen (2003) also suggests political origins for the world water crisis, including the Sardar Sarovar Project's impact in boosting the environmental lobby against megaprojects (see also Chapter 5).

There seems, at last, to be a majority view that the global problem is water *stress*, not crisis, though there are sporadic crises as ever with drought, conflict and mis-allocation. Winpenny (1994) defines water stress as the symptom of our rapid approach towards hydrological limits that traditional supply-led engineering can no longer 'solve'.

Instead of conducting science under the fierce and perhaps false light of 'the Crisis' the science community can do worse than address the 'global river syndromes' of Meybeck (2003). Nine major syndromes result from human interventions in freshwater systems during the Anthropocene (some date this from 1784 – the steam engine – and some from 1950 – the post-war intensification of all forms of production):

- flow regulation;
- fragmentation;
- sediment imbalance;
- neo-arheism;
- salinisation;
- chemical contamination;
- acidification;
- eutrophication;
- microbial contamination.

We discuss most of these issues in Chapter 6 but in no case expect 'solutions'; rather, there are suggestions of the *tools* available to the ecosystem approach and the uncertainty in their use (Chapter 8). Even so, these science tools must be embedded in the triangulation with the social and economic pillars of our sustainability ideals by ensuring that humans in the ecosystem derive welfare from its protection (see Chapter 9 and our Postscript).

Chapter 2

The river basin (eco)system

Biophysical dynamics, 'natural' and 'compromised'

We now use two chapters to explore the physical science basis for our confidence that a holistic concept of river basins (or 'catchment consciousness') is a fit basis for management.

In this chapter the aim is to set down those patterns and processes which lead us to the view of the drainage basin as a *systematic physical whole*, a basis for the *ecosystem approach*. It is the key concept in the wider education of politicians, planners and the public that river systems are an interconnected transport system, albeit often working invisibly (as in the transfer of dissolved salts) or over extremely long timescales (as in the evolution of floodplains): the science of geomorphology is central. In turn, this system acts as an interconnected network of *habitats* for the biota of the basin, whose diversity and resilience provide goods and services to human societies within and outside its boundaries. For newcomers to the ecosystem concept for rivers, Brian Moss provides an extremely readable example (Moss, 2002 and Box 2.1) showing how the headwaters of streams draining to the Pacific are biologically and chemically linked to that ocean in a functional web.

Box 2.1 A river ecosystem example: Pacific North-West rivers, USA

The vital message carried in this chapter, as a prelude to looking at rivers as habitat for biodiversity, is that 'natural' systems exhibit high levels of interconnectedness over long distances and periods of time. Brian Moss's example has the following components (picture, whilst reading, the image of brown bears eating 'spent' Pacific salmon often shown on wildlife programmes):

- 'Natural' vegetation of the Pacific North-West is forest, providing copious coarse woody debris and leaf litter to the regional rivers.
- Fungi and bacteria extract nutrients from tree debris, forming a nutritious film on the river-bed gravels.

- Invertebrate animals graze and shred the debris, sustained by the nutrients, giving the river a unique chemical signal which attracts returning salmon.
- Salmon swim upstream to spawn in the gravels, on riffles created by the tree debris.
- Dead, spent salmon are eaten by bears who then defecate in the forest, the trees using this nutrition.

The upshot of this suite of processes is that up to 20 per cent of the nitrate contained in the forest timber is derived from an oceanic source! As Moss observes: 'Thus the ocean, the forest and the river are connected in an intricate system of nutrients, microorganisms, invertebrates, bears and fish.'

(After Moss, 2002)

An appropriate technical term for this whole is the 'fluvial hydrosystem' (Petts and Amoros, 1996). Petts and Amoros claim that the concept 'provides a unifying approach to the study of running waters by viewing rivers as structured, four-dimensional systems – x, y, z and time' (Figure 2.1). Since the publication of the second edition of this book, there has been a vigorous swing in scientific focus towards those characteristics of biophysical dynamics that most closely correspond with the 'natural' set of conditions to which society appears to be motivated to return. The major reason for this new focus is the realisation that the interconnected transport system described here is in fact disconnected and compromised (in the words of Ellen Wohl – see Chapter 6) by many of our development activities. The motivation to understand physical damage in the fluvial hydrosystem is multidimensional and

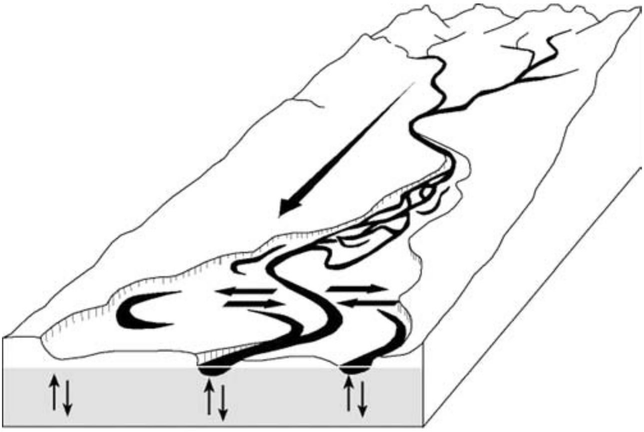


Figure 2.1 The fluvial hydrosystem in three dimensions (a fourth is time) (after Petts and Amoros, 1996).

highly complex (Newson and Large, 2006), and the resulting definitions of a 'natural' river are conspicuously broad. However, somewhere near the centre of the argument is a mantra that a diverse and functioning river environment will convey that resilience which will maintain ecosystem services to human society even through sudden changes in controls like climate (Folke, 2003 and see Chapter 6). There are other clear advantages of establishing criteria for 'natural', notably as a measure from which degrees of 'damage' (especially human impacts) can be judged and remedied.

The ecosystem model of the river basin pays particular attention to the transfer system attributes, both sediment and water. Several of the spontaneous regulation functions of the basin rely for their operation on conservation of the natural dynamics of floodplains, wetlands, 'natural' channels and the slopes contributing water and sediment to those components. Climate is a major driving variable in the gross behaviour of the transfer system, controlling basin-scale inputs of water and (through plant cover) sediments, but the archaeological record and contemporary observations prove the progressive impacts of development. By 'progressive impacts' we refer to the feedback mechanisms in the transfer system through which, for example, eroded slopes exhibit reduced infiltration capacity for rain and the resulting increase in runoff further increases slope erosion through gullying.

Hydrology has generally been in demand to provide tools for engineering throughout the twentieth century, but geomorphology is relatively new in the field of applications, drawn in principally by the ecosystem model for management, river restoration and sustainable flood control (see Kondolf and Piégay, 2003a; Downs and Gregory, 2004). An example of the pressure on the knowledge base is the requirement within the European Union's Water Framework Directive for an assessment of the 'hydromorphological' status of all Europe's rivers (see Chapter 7 et seq.). New branches of hydrology have, however, been required to advance rapidly from a hesitant collaborative start to full applications in the space of two decades. As put by Baird and Wilby (1999) in their Preface, 'ecologists have become increasingly aware of the importance of hydrological processes to ecosystem functions'. 'Hydrologists have also become more aware of the effects of plants on hydrological processes' (p. xvii). Hannah *et al.* (2004) debate whether *ecohydrology* and *hydroecology* represent a new paradigm in science; their answer is 'no' given the difficulties of supporting truly interdisciplinary research. There is a need for collaborative science at each intersection of the participating disciplines (Orr *et al.*, 2008, in press and Figure 2.2). There is an earnest need for interdisciplinary river science, especially in view of the advance of the ecosystem concept as a management pro forma, and pleas for collaboration are now being accompanied by new learned societies, journals and research agendas (Cullen *et al.*, 1999; Petts *et al.*, 2006; Thorp *et al.*, 2007; Vaughan *et al.*, 2007). Dollar *et al.* (2007) take things further by wiring in geomorphology, hydrology and ecology to establish a scale-sensitive pro forma biophysical framework

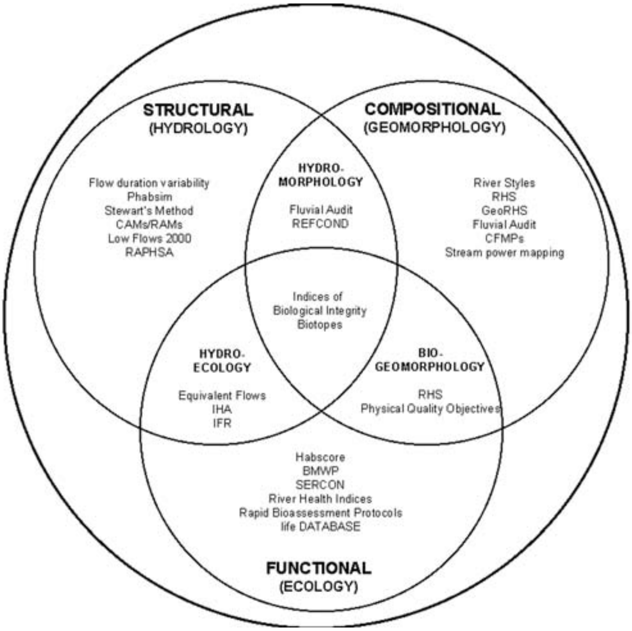


Figure 2.2 Overlap areas in the study of fluvial hydrosystems to benefit the management of freshwater ecosystems (after Orr *et al.*, 2008, in press).

for rivers as ecosystems. As a further sign of such developments, the publishers Wiley launch a new journal, *Ecohydrology*, in 2008.

2.1 Flow of water and transport of sediment

M. G. Wolman once quoted a US judge who, summing up a hearing which turned on a matter of river sediment transport, claimed that the expert witnesses seemed only to agree on one aspect of the movement of river sediments: they seldom move *upstream*!

Why should runoff prediction prove relatively easy but sediment transport more difficult? To answer this, one must attempt to unravel the complex interrelationships between the hydraulics of streamflow and the ability of flow to power transport. The most important aspect of sediment transport at the river basin scale is its *supply* from source areas, including headwater catchments, and the beds and banks of the channel network. The concept of separated supply and *transport* components of the basin sediment system has only recently been found to be analytically and practically helpful, particularly in the formulation of geographical zonations of river basins. The American geologist W. M. Davis (1899) proposed a threefold subdivision of river basins into 'youth' (headwaters), 'maturity' and 'old age' (downstream reaches) – a classification helpful for the very long timescales over which the Davisian cycle of landform development was hypothesised to occur. However, for the last 30 years geomorphologists have become orientated towards active *processes*, and the energy levels implied by terms such as 'youth' are misleading.

Schumm (1977) proposed the subdivision of *supply*, *transfer* and *deposition* zones, which is much more in tune with contemporary knowledge of processes. Schumm (1963) saw sediment size as a primary driver of river morphology within the transfer zone, though we now appreciate the breadth of controls for channel form and mobility, the essential intellectual demand being to reconcile site factors (intrinsic) with upstream, catchment and climate (extrinsic) influences acting through the discharge of water and sediments to a particular site (Figure 2.3). Sediment size remains, however, a primary diagnostic of any site within the system and thus a fundamental aid to appreciating geomorphological processes and biological responses (Table 2.1).

2.1.1 Elementary fluvial sediment transport

> Rivers exist to carry water to the sea and they develop channels able to contain their normal flow. The form of the river channel affects the flow of water in it and, through erosion and deposition, the flow modifies the form. The channel (and if it migrates, the whole valley floor) acts as a jerky conveyor belt for alluvium moving intermittently seawards.
>
> (Ferguson, 1981, p. 90)

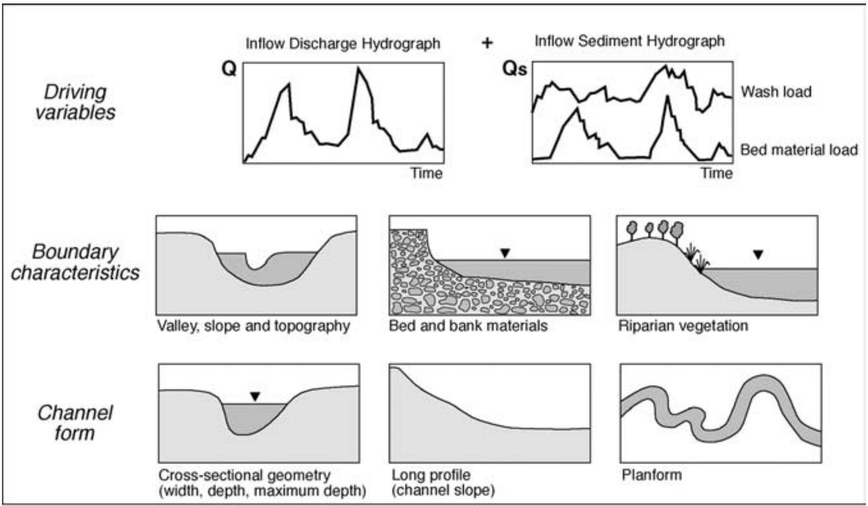


Figure 2.3 Independent and dependent controls of river channel form (after Thorne, 1997).

Table 2.1 A simplified presentation of the channel typology of Montgomery and Buffington (1997)

	Colluvial	*Bedrock*	*Cascade*	*Step-pool*	*Plane bed*	*Pool-riffle*	*Dune-ripple*
Bed material	Variable	Rock	Boulder	Cobble-boulder	Gravel-cobble	Gravel	Sand
Main roughness* elements	Grains	Bed/banks	Grains/banks	Bedforms/grains/banks	Grains/banks	Bedforms/grains/sinuosity/banks	Sinuosity/bedforms/grains/banks
Main sediment sources	Hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, bank failure	Fluvial, bank failure
Sediment storage elements	Bed	Pockets	Around obstacles	Bedforms	Overbank	Overbank, bedforms	Overbank, bedforms
Confinement**	Confined	Confined	Confined	Confined	Variable	Unconfined	Unconfined
Pool spacing	n/a	Variable	< width	1–4 × width	None	5–7 × width	5–7 × width

* Roughness refers to the hydraulic resistance to flow – the frictional resistance of the channel.

** Confinement is the degree to which the valley sides impinge on the channel itself and ‘confine’ its lateral adjustment.

It is useful to follow the path of a grain of sediment, large or small, along this 'conveyor belt' as a means of grasping the conceptual pillars of fluvial geomorphology. In the headwater, sediment-supply zone of a river basin, particularly where this is mountainous, the coupling between slopes and channels controls the amount and timing of sediment removed from the system (Figure 2.4). Largely governed by natural conditions (but often exacerbated by development), slope transport of sediments occurs by the slow, progressive production of weathered rock and its gravitational movement, progressive or sudden, towards the nearest stream channel.

In the polarised case of a supply-zone river valley, slope inputs are almost direct to river channels: there is not the extensive floodplain and valley floor

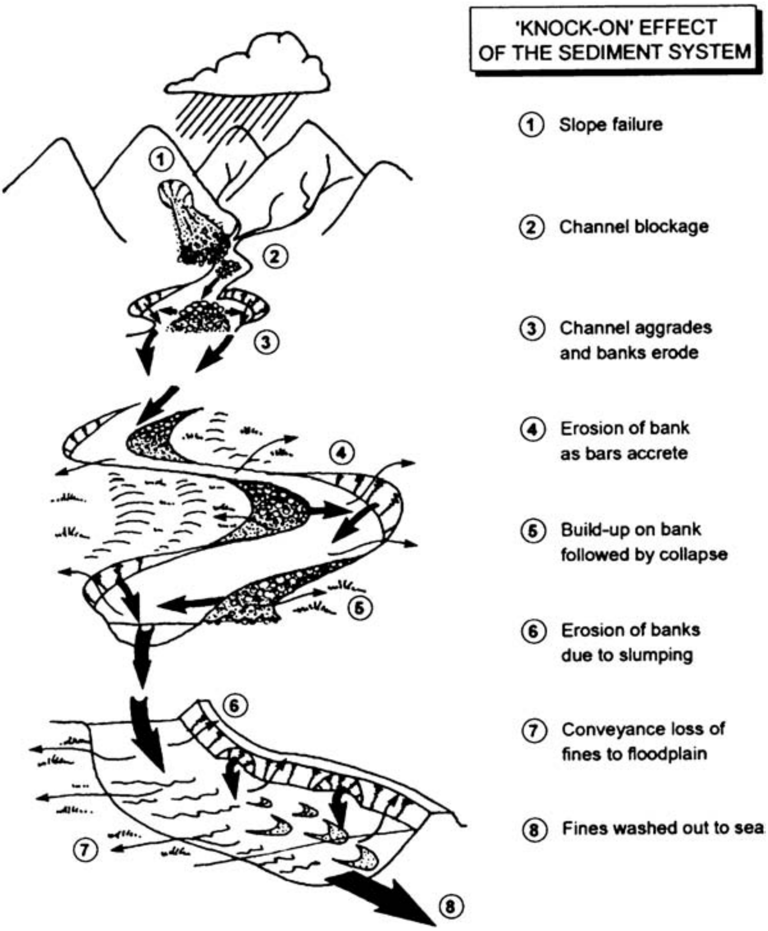


Figure 2.4 A pictorial representation of the fluvial sediment transfer system and its main process links (after Newson and Sear, 1994).

which intervenes to store sediments in the transfer zone. Clearly, therefore, there can be mismatches in time between the rate of slope-derived sediment supply and the rate of removal by the channel at its foot; the vital importance of sediment system 'coupling' is explored by Harvey (2002). Obviously, extreme events such as rare floods provide energy to both slope and channel environments but, even within the spectrum of extreme floods, there are also populations of *effectiveness*. Newson (1980) divides 'slope floods' from 'channel floods' on the basis of rainfall intensity and duration; later (Newson, 1989) he includes floods which are effective in both environments.

If we consider the stream channel transport process, we need to demarcate the different calibre or size of the grains supplied to the channel. The mix of bed sediment grain sizes determines, within broad limits, the processes of entrainment and transport within the flow. Alongside the effects of the sediment sizes available for transport by a known streamflow velocity, we have also the quandary as to the location, within the turbulent mass of water, of that energy: average velocities may be plotted during a period of measurement with a current meter, but these simple patterns demonstrate only the energy loss by friction at the channel boundaries. It has been known for over a decade that river beds in coarse sediment mixtures (gravel and coarser) form a variety of structures which feed back to a greater resistance to entrainment (the first phase of downstream transport). Such structures have been studied in experimental flumes (Brayshaw *et al.*, 1983) but their relation to natural flow regimes in large rivers requires a 'forensic' investigation of the type described by Wittenberg and Newson (2005). These authors speculate that pebble clusters, which can occur over significant portions of the bed, may operate a climate-related stability mechanism which can be destroyed during engineering activity such as dredging. The formation and destruction of pebble clusters also has much to tell us about the modes of movement of river beds, whether by random mobility, selective entrainment or equal mobility (everything moves), an escalating sequence with increasing flows.

Much of the morphological development of river channels occurs as a result of the *sinuous planform* and uneven longitudinal profile of natural channels; in this connection, therefore, it is important to research:

(a) the existence, pattern and strength of *secondary currents* or flow cells which distribute the primary, downslope, energy of the flow into effective pathways;
(b) the distribution of velocity throughout a reach, as between high and low points (*riffles* and *pools* in the alluvial reaches) and between high and low flows.

And add to the agenda an attempt to predict bed material transport rates because this form of transport can produce the channel instability which threatens erosion of structures and flooding of property. Bedload formulae (equations) have been developed and used for engineering applications for over a century. They are of four main types:

(a) those based on calculation of the shear stress produced by the flow on this stream bed;
(b) those using stream discharge as an integrating predictor;
(c) statistical/probabilistic approaches to the movement of grains;
(d) stream power calculations – a generalised energy approach.

As a review by Gomez and Church (1989) illustrates, many transport formulae are vindicated by the use of data gathered in flume experiments or from field situations of unspecified relevance to the assumptions of the method in question. Field methods for sampling bed material load are more or less unsatisfactory: tracing individual particles has led to more technical innovation than collecting the load entrained at a site using innovative samplers (e.g. Helley and Smith, 1971). Gomez and Church conclude that for general river applications, where detailed hydraulic knowledge is normally impossible to gain, the stream power approach of the formula derived by Bagnold (1977), using the analogy of an engine working at varying degrees of efficiency, is the most accurate, despite the fact that it lacks physical vigour and that actual operating efficiencies (commonly less than 10 per cent) are hard to predict.

2.1.2 Slopes, channel, storage zones

Because, in many regions of the world and under relatively frequent flood conditions, the sediment transport system can be shown to be *supply limited* (i.e. stream power to transport is not fully utilised), it becomes of critical importance to river basin management to understand the supply processes themselves. Sediment supply occurs, in the Schumm model, mainly in the headwater zone where slopes and channels impinge closely and where gravitational energy is high and weathering processes active. There are at least two sources of sediment supply which may limit (or not) the transport of sediment out of the basin:

(a) direct inputs from the slope weathering/transport system (which include man-made additional losses such as cultivation-induced soil erosion – see Chapter 6);
(b) areas (and volumes) of stored sediments resulting from past phases of erosion and deposition under different climatic conditions or from more recent flooding or channel migration; included are river bank sources in the transfer zone.

At the statistical level of analysis there is clearly good adjustment, over long timescales, between sediment transport and sediment supply. Simplistically any shortfall of supply is made up by increased erosion of bed and bank materials, leading to either incision of the transporting channel or its migration across the valley floor; the latter outcome produces the probability of undercutting an adjacent slope. The incision or migration of the channel therefore leads to conditions favouring supply. These links are often easiest to appreciate over the long term when, as Playfair wrote,

> Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of valleys, communicating with one another, and having such a nice adjustment of their declivities, that none of them join the principal valley, either on too high or too low a level; a circumstance which would be infinitely improbable, if each of these valleys were not the work of the stream that flows in it.
>
> (Playfair, 1802, p. 102)

. . . or during individual flood events when landslides, debris flows and other slope developments are shown to feed a wide range of sediment sizes into a channel system swollen by floodwaters and capable of transporting the resulting load considerable distances downstream. A major characteristic of development is that the transfer processes of the basin ecosystem are accelerated and storage volumes/times reduced. Engineering in the channel network is then required to respond to the morphological impacts of this acceleration, further encouraging 'stability' by straightening and embanking rivers, minimising lateral transfers and drastically reducing the morphological diversity which is the fundamental basis of the channel and riparian biotic system.

2.1.3 Timescales of river basin dynamics and concepts of 'stability'

Everyone has an interest in river 'stability' and, as such, it has various definitions, spread principally by the amount of flexibility and generality each has: little in the case of engineering stability, but quite a lot under natural science definitions of 'dynamic equilibrium'. Geomorphologists prefer the concept of *adjustment*: rivers change in response, perhaps delayed, to intrinsic or extrinsic drivers. If we require a picture representing the contrast between the two ways of thinking, consider Plate 2.1, which shows a 'wandering' gravel-bed river whose adjustments have been successfully interpreted for a thousand years (Passmore *et al.*, 1995) as the result of semi-natural processes; yet it looks 'unstable'! In the shorter, publicly scrutinised working scales of engineering, 'stability' is an absolutely fundamental concept, and the fact that engineering stability is a physical state far removed from dynamic equilibrium leads to important misunderstandings. Natural scientists point out the irrelevance of 'engineering stability' notions when discussing

Plate 2.1 The 'wandering' gravel-bed channel of the River South Tyne, Northumberland, UK.

the resilience to change typical of diverse and functionally intact biophysical systems: the discrepancy is a recipe for confrontation in river management.

Knighton (1984) has illustrated the time and space scales over which various features of the river basin landscape may be said to evolve (and therefore attain some sort of equilibrium or steady-state condition). Newson and Sear (1992) take this space–time scaling approach further by adding zones of conservation interest and the major natural and anthropogenic drivers (Figure 2.5). However, even a dynamic form of equilibrium yields surprises: geomorphologists are interested in *metastability*, periods of quasi-stability interrupted by episodes of rapid change which appear to managers as challenging demonstrations of 'instability'. The new approach is best summarised in the term *thresholds*. Threshold phenomena are widespread in science (Newson, 1992c), particularly in materials where failure phenomena (rapid change between two stable states) abound. The importance of threshold concepts to river geomorphology is that they permit a 'middle road' between two previously dominant philosophies of landscape development – those dominated by catastrophes and, in contrast, those of (slow) progressive processes.

In fact, the geomorphic threshold develops by slow, progressive processes of weathering on slopes or storage of sediments on valley floors, to the point where the morphology of the feature in question makes it inherently unstable even under the 'normal' range of conditions. Clearly the practical implications

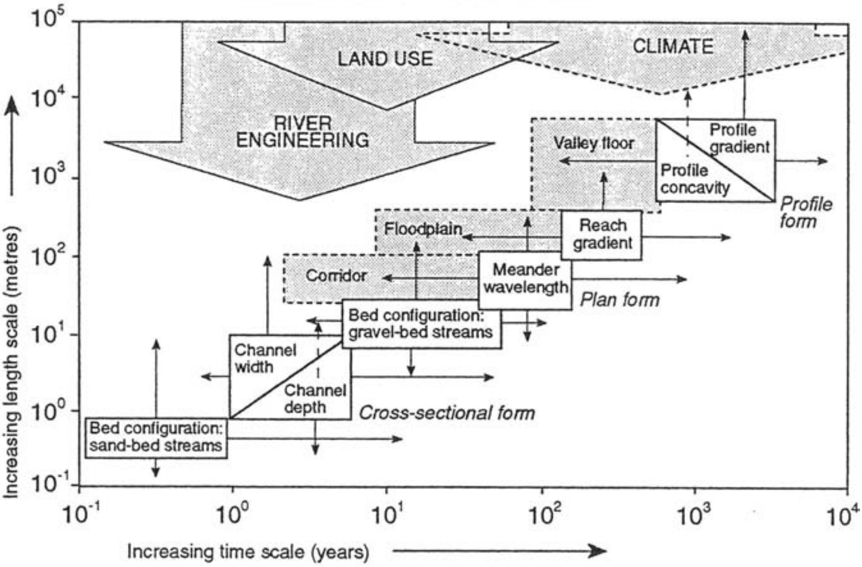


Figure 2.5 Timescales of river system sediment transport and morphological response: the characteristic length and timescales of major river forms (after Newson and Sear, 1992, following Knighton, 1984).

of geomorphic thresholds include a need to consider the flood record of a basin in relation to recent morphological change and the importance of avoiding developments such as cultivation and drainage on sediment storage zones which are in a threshold condition.

Basin development occurs against a background of a spatially and temporally varied set of stability conditions in the sediment system; these need geomorphological audit (see below) as part of environmental impact assessment. Surveys to investigate signs of symptoms of 'instability' indicative of the state of a river basin, or river reach, are relatively easy to carry out to caution the application of inappropriate regime-based designs by engineers (Lewin *et al.*, 1988). When engineers ask 'What is the alternative design procedure?', one is forced to admit that here the unpalatable choice may be between doing very little (using low-cost, 'soft' engineering) and very indirect forms of river engineering, e.g. erosion control on sensitive slopes and valley floors. Geomorphologists and ecologists increasingly gang up to say 'Do nothing', implying a conservation philosophy – a retreat from the river; for many rivers, the law is on their side.

The workings of the 'conveyor belt' are perhaps best demonstrated by where and when it stops; we need to know where sediments are stored in the system and their average residence time in those stores before 'moving on' by rejoining the channel system. Madej (1984) has compiled the spatial and temporal picture of fluvial sediments stored in the Redwood Creek basin of Northern California. Figure 2.6 here shows her classification of the storages as active, semi-active, inactive and stable, together with their distribution in planform, valley cross-section and with drainage area. Such

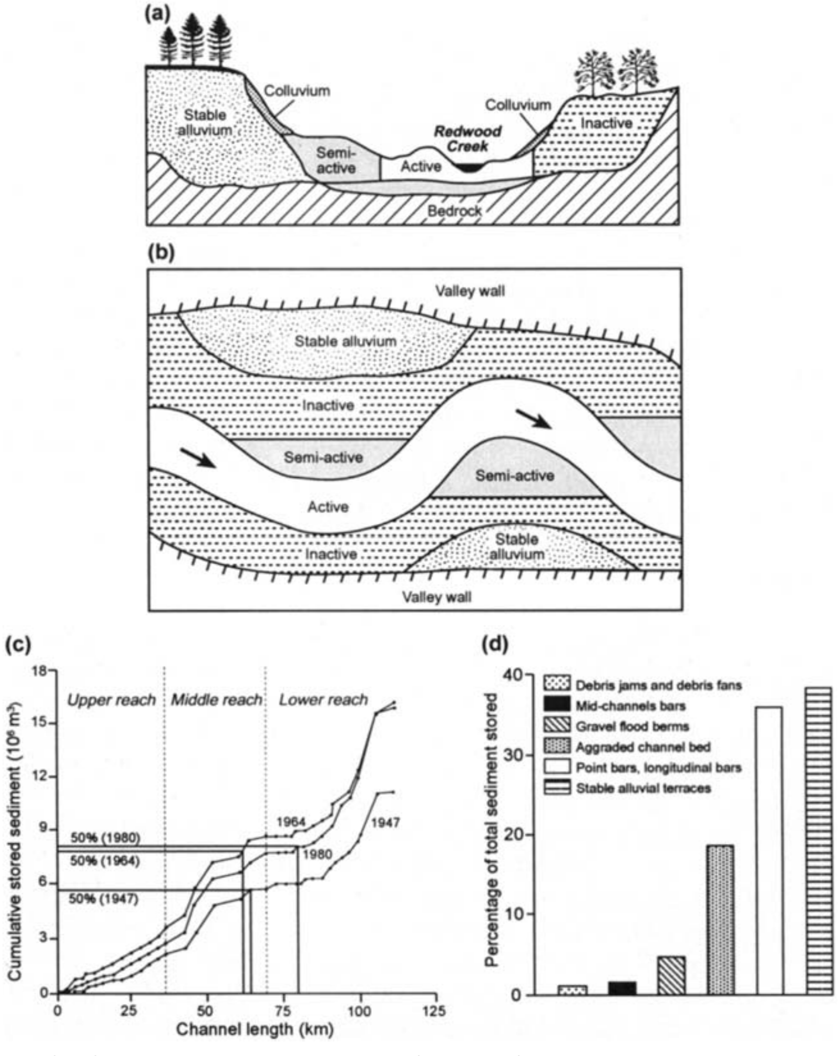


Figure 2.6 Sediment storage – a regulatory function of catchment ecosystems: Redwood Creek, California (after Madej, 1984).

(a) Schematic guide to the four main stores in cross-section
(b) Schematic guide to the four main stores in planform
(c) Cumulative volumes of stored sediments at three dates (centre of curve indicated by 50% line)
(d) Volume of sediment in various compartments

an inventory is of exceptional value in assessing the likely impact of 'opening' or 'closing' storages, e.g. by cultivation/drainage of hitherto stable zones or flood proofing the channel from semi-active areas. Inventories of stored sediments also help refine the dubious concept of 'delivery ratio' (see also Chapter 6) in which a point-source rate of sediment release diminishes in a linear fashion downstream as parts of the load enter storage. 'Delivery ratio' has both computational and conceptual objections (Parsons *et al.*, 2006). The overview point is, nevertheless, that sediment storage is a spontaneous regulatory function of the intact ecosystem and should be conserved.

2.2 Channel morphology: indicating process and state?

Channel morphology is an output from the sediment transfer system – it can be diagnostic of system states, and geomorphologists have designed channel classifications and typologies in an effort to formalise their knowledge of this diagnostic value (Table 2.1 and Box 2.2). More recently, the wider meaning of geomorphological states, e.g. for physical habitat status, has led to the urgent development of rapid assessment typologies; for discussion, see Newson (2002).

Box 2.2 'Natural' rivers and channel typologies

If we seek to benefit from river ecosystems in good condition we must understand what this condition is and how it varies between different types of channel: 'one size' does not 'fit all'. The European Committee for Standardization (CEN, 2004) lists the 'reference conditions' (a term equivalent to almost 'natural') for hydromorphological quality in rivers as:

- reflecting totally, or nearly totally, undisturbed conditions;
- lacking any artificial instream and bank structures that disrupt natural hydromorphological processes, and/or unaffected by any such structures outside the site;
- bed and banks composed of natural materials;
- planform and river profile: not modified by human activities;
- lateral connectivity and freedom of lateral movement: lacking any structural modification that hinders the flow of water between the channel and the floodplain, or prevents the migration of a channel across the floodplain;
- lacking any instream structural works that affect the natural movement of sediment, water and biota;
- having adjacent natural vegetation appropriate to the type and geographical location of the river.

A new generation of channel typologies is now emerging, using basic drivers of flow discharge and sediment supply/transport, such as the sevenfold division by Montgomery and Buffington (1997 – see Table 2.1). A hierarchical component is the additional virtue of a system of River Styles designed in Australia by Brierley and Fryirs (2000, 2005). In the latter scheme, the geomorphic units of the Montgomery and Buffington approach remain but the landscape unit, valley setting and floodplain characteristics are added at higher levels and bed materials at lower levels. The River Styles approach has recently been tested as a predictor for the occurrence of diatoms, macrophytes, macroinvertebrates and fish in the Bega River basin, New South Wales, Australia (Chessman *et al.*, 2006). Biodiversity certainly reflects the degree to which the geomorphic condition deviates from 'natural'.

The classification by Rosgen (1996) has been exported far from its 'home' in the USA. However, this raises problems: for example, channels in the heavily developed lowlands of the UK fall into only a couple of Rosgen classes. To stretch the characteristics of British river channels further appears to be most valid using statistical analysis for sorting out the 'swarm' of data characteristics (Jeffers, 1998). Driven by the need to understand and protect world-class freshwater ecosystems from very considerable anthropogenic threat, South Africa has seen promising progress towards integration of flow, channel form, substrate and channel/floodplain biota. In Kruger National Park, the River Sabie has been the subject of intensive classificatory effort, partly using mesoscale combinations of the bedrock and sand morphology but increasingly by means of integrated, scaled holistic concepts (Dollar *et al.*, 2007).

At every site on a river system which is transporting water and sediment, the channel's morphology is adjusted, or is in the process of adjusting, to these downstream fluxes. Characteristic *planform* channel morphologies typify transport systems for different calibres of sediment (see Figure 2.7); relationships between planforms and flow regimes are known to exist but are poorly quantified because of the influence of sediments and of other factors to which we may pay only brief attention. Adjustment of form to flow cannot occur if the bounding materials (bed and banks) are too resistant. Therefore bedrock or glacial deposits may confine the channel in a non-equilibrium pattern. The content of silt and clay in channel boundary materials is also effective in determining the width/depth allocation in an individual cross-section: cohesive banks create narrower channels. Of perhaps greater importance to modern forms of management orientated towards conservation is the

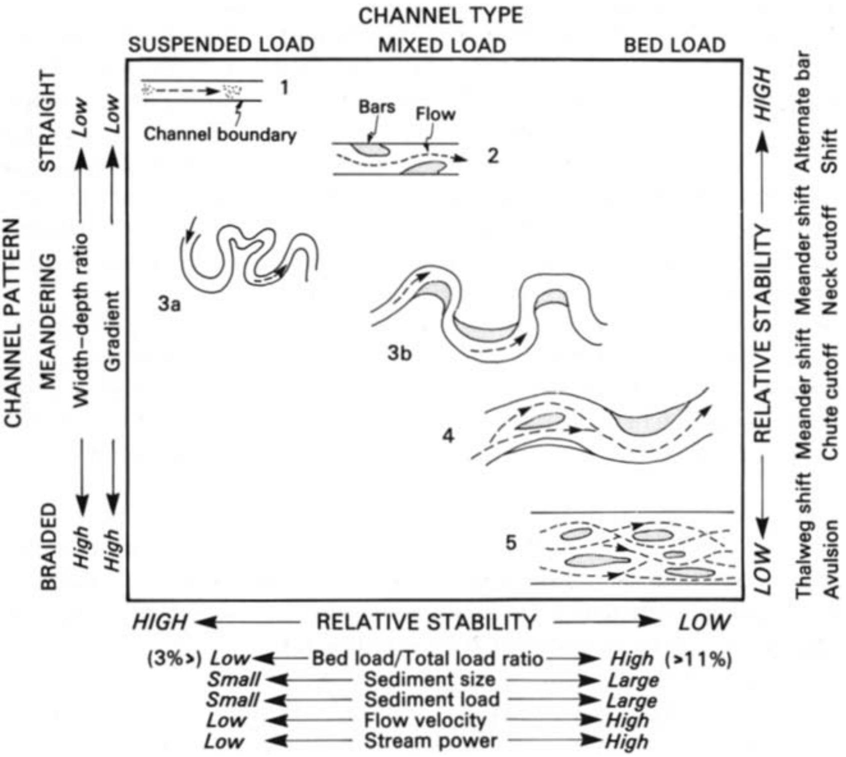


Figure 2.7 A classification of river channel planforms based upon sediment load, cross-section and stability (Schumm, 1985).

importance of bank vegetation (in-channel vegetation also influences flow capacity).

There is a somewhat schizoid attitude to the value of vegetation in UK rivers. On the one hand, its role in preventing scour and protecting bed and banks is recognised, both through the binding action of roots and through the streamlining of flexible leaves and stems. The UK Hydraulics Research Station (Charlton *et al.*, 1978) established, for example, that unvegetated and short grass channels are, on average, 30 per cent wider than their tree-lined counterparts, implying a medium-term stabilising impact (in engineering terms) for trees on river banks. On the other hand, there are, in lowland rivers, known flood risks resulting from additional hydraulic resistance or roughness of profuse 'weed' growth, the reduction of channel capacity by the bulk of plants, the possibility of increased turbulence around trees in floods, the risk of sudden bank failure if a tree falls, and the possibility of log-jams or weed-jams at narrower bridging points damming the flow. The evidence is growing that, in the UK lowlands, the 'natural' state of river morphology owed much to the longer-term ‘instability’ of floodplain and riparian trees: their death or destruction by floods leads to ‘coarse woody debris’ (CWD) which hugely diversifies in-channel energy conditions (hence sediment dynamics and morphology) and in-channel and riparian habitat. Gurnell (2007) introduces a collection of papers on the significance of ‘wood in world rivers’, and the significance of riparian tree growth has now spread far beyond its role in promoting ‘stable’ river banks to a point where floodplain forests become part of river restoration (Millington and Sear, 2007) and are protected by water laws in some countries (Piégay and Landon, 1997).

2.2.1 ‘Stable’/‘unstable’ channels and ‘natural’ channel change

The sinuosity of river planforms has always excited the interest of a number of sciences, but key factors in our present knowledge based on channel patterns have been the ability to make measurements of bank erosion relatively simply and our access to relatively long periods of data from old plans, maps and aerial photography (see compilations by Gregory, 1977 and Hooke and Kain, 1982; also Figure 2.8). As a result of this concentration in fact we have tended to underestimate the contemporary importance, at least locally, of *vertical* morphological adjustment (Schumm *et al.*, 1984; Lewin *et al.*, 1988).

The tendency of rivers to follow curved rather than straight courses is another systematic problem of river engineering. The Davis (1899) classification, by linking meanders to the ‘mature’ or ‘old age’ river, has tended to give the impression that a river wanders aimlessly *without energy* for erosion. This is a fallacy, since meanders develop in floods, when the river has maximum available energy. Energy not used to overcome bed and bank friction is far from equally distributed across a river. Instead, turbulence breaks up into a number of cells, producing currents which act laterally with as much force as the main thread of downstream flow. These secondary flows are generated in any stream and with a regularity which relates to the stream’s width, i.e. to the space available for the cells to develop. Upwelling flows close to a vertical river bank are a corollary of the ‘piling up’ of water flowing round a bend; such flows are erosive, particularly at depth.

In streams where banks are compact but where a coarse sediment load is carried, secondary flows create midstream shoals, or riffles, and pools at fairly regular intervals; where the banks are erodible, riffles and pools still occur, but the secondary cells produce a sinuous river planform by lateral erosion and deposition. Cut-banks occur opposite shoals, and together they create the familiar pattern of the meandering river. In terms of theoretical foundations for meander ‘instability’, Hooke (2003) favours a model of the changes of planform sinuosity over time – bends tighten followed by cut-offs – and this, more than ascribing cut-offs to flood-rich eras, can help strategic

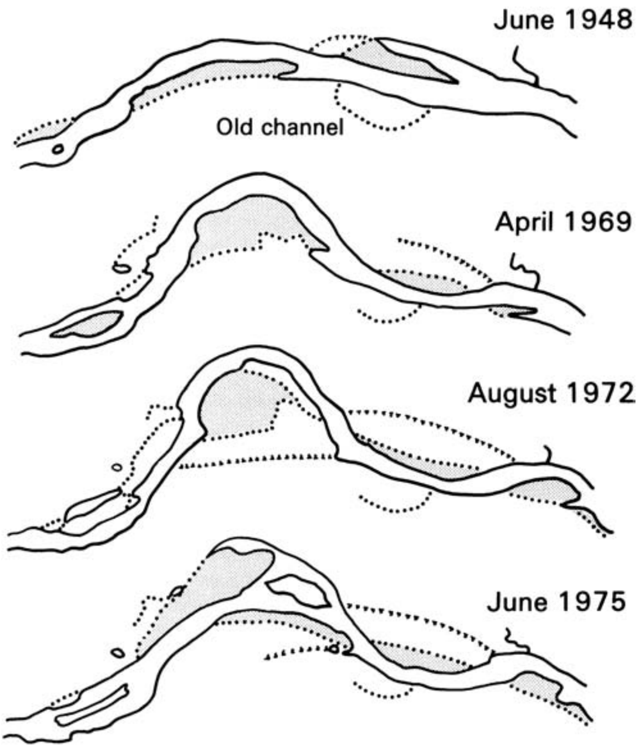


Figure 2.8 Channel planform change identified from historic maps and aerial photographs: River Severn, Maesmawr, mid-Wales (Thorne and Lewin, 1982).

plans for floodplain development or conservation. Thus, the River Bollin (Cheshire, UK) gradually increased its sinuosity (channel length divided by valley length) from 1.5 to nearly 3.0 between 1850 and 1970 before a cluster of cut-offs reduced the sinuosity to 1.5 again by 2001.

River managers continue to need new guidance as to the 'natural' adjustment of alluvial channels and tools to predict it (Sear *et al.*, 2003). There are form guides to river 'instability' (Lewin *et al.*, 1988), but there are also good grounds for assuming that man-made changes to flow and sediment systems evoke morphological change which may occur over relatively short timescales. We also need to consider that metastable equilibrium conditions are quite common in the fluvial system, and field indications of the state of the catchment (such as those provided by Sear *et al.*, 1995, in Table 2.2(a)) should be used in conjunction with Schumm's brainstorming model (in Table 2.2(b)) to establish the most likely drivers of a range of forms at a particular field location.

Table 2.2(a) Identifying sediment sources: indicators of stability and instability

Categories	*Upland zone*	*Transfer zone*	*Lowland zone*
Potential sediment sources	Slope debris Peat slides Alluvial fans Boulder berms Channel bars Bank erosion Forest ditches Forest roads Moorland 'grips' Mining	River cliffs Terraces Bank erosion Channel bars Field drains Field runoff Urban runoff Tributaries/upstream Mining	Upstream Bank erosion Bed movement Field drains Field runoff Wind blown material Tributaries Urban runoff Tidal sediments Mining
Evidence of erosion	Perched boulder berms Terraces Old channels Old slope failures Undermined structures Exposed tree roots Narrow/deep channel Bank failures both banks Armoured/compacted bed Gravel exposed in banks	Terraces Old channels Narrow/deep channels Undermined structures Exposed tree roots Bank failures Armoured/compacted bed Deep gravel exposed	Old channels Undermined structures Exposed tree roots Narrow/deep channel Bank failures Deep gravel exposure
Evidence of aggradation	Buried structures Buried soils Large uncompacted bars Eroding banks at shallows Contracting bridge space Deep fine sediment in bank Many unvegetated bars	Buried structures Buried soils Large uncompacted bars Eroding banks at shallows Contracting bridge space Deep fine sediment in bank Many unvegetated bars	Buried structures Buried soils Large silt/clay banks Eroding banks at shallows Contracting bridge space Deep fine sediment in bank Many unvegetated bars
Evidence of stability	Vegetated bars and banks Compacted weed-covered bed Bank erosion rare Old structures in position	Vegetated bars and banks Compacted weed-covered bed Bank erosion rare Old structures in position	Vegetated bars and banks Weed-covered bed Bank erosion rare Old structures in position

Source: Newson and Sear (1994)

Table 2.2(b) Qualitative models of channel metamorphosis, illustrating the direction of morphological response to particular combinations of changing discharge and sediment yield (after Schumm, 1969)

(a) Increase in discharge alone $Q^{+}\quad w^{+}d^{+}F^{+}L^{+}s^{-}$	Decrease in discharge alone $Q^{-}\quad w^{-}d^{-}F^{-}L^{-}s^{+}$
(b) Increase in bed material discharge $G_b\quad w^{+}d^{-}F^{+}L^{+}s^{+}P^{-}$	Decrease in bed material discharge $G_b\quad w^{-}d^{+}F^{+}L^{+}s^{-}P^{+}$

(c) Discharge and bed material load increase together; e.g. during urban construction, or early stages of afforestation

$Q^{+}G_b\quad w^{+}d^{=}F^{+}L^{+}s^{=}P^{-}$

(d) Discharge and bed material load decrease together; e.g. downstream from a reservoir

$Q^{-}G_b\quad w^{-}d^{=}F^{-}L^{-}s^{=}P^{+}$

(e) Discharge increases as bed material load decreases; e.g. increasing humidity in an initially sub-humid zone

$Q^{+}G_b\quad w^{=}d^{+}F^{-}L^{=}s^{-}P^{+}$

(f) Discharge decreases as bed material load increases; e.g. increased water use combined with land-use pressure

$Q^{-}G_b\quad w^{=}d^{-}F^{+}L^{=}s^{+}P^{-}$

2.2.2 *Catchment sediment flux, channel change and development impacts*

Flow changes can be expected following changes in land use, land management (e.g. drainage) and the manipulation of river flows by the water industry (e.g. abstraction for water supply). Schumm's matrix (Table 2.2(b)) therefore considers changes for different combinations of the flux of water and that of sediment at the catchment scale. Woodward and Foster (1997) bring together an international review of the impacts; Table 2.3(a) is their summary of recorded impacts on suspended sediment transfer – bedload is much more difficult to measure (see Newson and Sear, 1994 for UK studies). The difficulties associated with measuring and modelling the movement of bed material, a major control on channel form and changes to it (and hence the impacts of catchment development on these), have meant that very few studies have directly implied a causal change between land use/management and channel response. However, at the small scale, there have been attempts to link commercial plantation forestry, land drainage, flood protection and urbanisation to channel change ('instability' in the engineering sense, 'adjustment' in the geomorphological sense) (Newson and Leeks, 1987; Roberts, 1989).

Fewer than 10 per cent of the world's rivers have any form of sediment record, whilst more than 72 per cent of the landmass has river flow data. However, access to major new data sources like remote sensing permits new attempts to model 'natural' and anthropogenic sediment yields. The most ambitious effort to date, reported by Syvitski *et al.* (2005), calibrates a

Table 2.3(a) Changes in catchment sediment flux derived from land-use and land-management changes upstream

Location	*Land use change*	*Increase in sediment flux*
Monitored catchments:		
Westland, New Zealand	Clearfelling of forest	×8
Wales, UK	Clearfelling of forest	×8
Northern England, UK	Afforestation – plough/drain	×100
Texas, USA	Clearfelling/cultivation	×310
Lake and reservoir surveys:		
Lake Sacnao, Mexico	Deforestation/urbanisation	×35
Lake Ipea, Papua New Guinea	Agricultural intensification	×10
Seeswood Pool, UK	Agricultural intensification	×4.5
Old Mill Reservoir, UK	Increased grazing	×4.5
Dayat er Roumi, Morocco	Land drainage	×45
Llyn Geirionydd, UK	Mining	×4
Kargeholmssjon, Sweden	Agricultural intensification	×4.4

Data from Woodward and Foster (1997)

Table 2.3(b) Sediment loads for rivers before and during the Anthropocene era

Climate zone	*Pre-human load*	*Modern load*	*Load retained in reservoirs*
Tropical	1,690±480	2,220±360	16%
Warm temperate	9,070±2,600	8,030±1,250	15%
Cold temperate	1,940±250	1,460±160	47%
Polar	1,330±170	900±120	6%

After Syvitski *et al.* (2005)

catchment *model* of sediment yield from the tiny minority of large rivers monitored close to the coast. The predictions are therefore for 'terrestrial sediment flux to the global coastal ocean'. In deriving the actual records they determined, for the longest records, that 48 per cent of rivers showed little change in their historical loads, 47 per cent showed decreasing loads caused by dams and reservoirs (see Chapter 6), and only 5 per cent showed an increase caused by disturbance. The latter figure is surprising because of the large number of catchment studies showing increases from disturbance (Table 2.3(a)) – but these are much smaller *headwater* areas. Table 2.3(b) lists the modelled 'natural' and anthropogenic loads *to the coast* for major parts of the planet.

2.2.3 Hydraulic geometry, regime and channel design

Whilst the trajectory of much current geomorphological research favours a generally metastable interpretation of channel form developments, it is essential to review briefly the equilibrium (steady-state) approaches which have played a major part in management of the world's river channels during the

Anthropocene. *Hydraulic geometry* and *regime* approaches represent, respectively, the geomorphological and engineering conceptual frameworks for the adaptation of channel width, depth and velocity of flow to water discharge. The former is empirical, involving field data collection from representative cross-sections; the latter is theoretical and therefore more flexible and capable of extension to include channel slope, roughness, and sediment load. Both assume that in the longer term (timescales are not specified) there is an adjustment of channel dimensions to flow which is predictable. Thus regime theory is ideal for the construction of new conveyance channels (needed for flood relief or irrigation) and was largely 'proved' in practice with low-gradient canals lined by cohesive materials.

After its widespread popularisation in the formative text of Leopold *et al.* (1964), hydraulic geometry dominated field studies, either of changes with flow at-a-station or downstream as flow builds up. Park (1977) compiled the first international review of the results. This indicated little consistency in the exponents (rate of change) reported for width, depth and velocity with discharge at-a-station or downstream.

Regime channel design begins with a clear problem – of producing an active channel which may well scour or fill temporarily but which, during its design lifetime, will transfer its charge of water and sediment *without* profound morphological change. The regime approach selects a stable width and depth and, therefore, a velocity (together making up water discharge); the hydraulic resistance, slope and sediment transport properties are also chosen from deterministic equations. Slope is rarely adjustable in channel design, since bridges, sewer outfalls and other structures cannot (except in new irrigation schemes) be adjusted *a posteriori* to channel slope. There is abundant evidence that straight channel planforms, designed and built in good faith to provide flood protection, are liable to adjust to a meandering or even to a braided pattern without considerable structural protection; the paradox is that 'rational' engineering can *increase* damage and cause collateral impacts on the ecosystem in the longer term. 'Natural' channel morphology is part of the spontaneous regulation function of the transfer system; it can only be sacrificed at a cost. Part of that cost can be assessed by the enormous expenditure now incurred in many developed countries in river *restoration* (see Chapter 6). As part of the rapid learning curve facilitated by river channel restoration (see Chapter 6), it has become much more common to use analogue undamaged channel forms as 'design', rather than using numerical design procedures based on equilibrium principles. Numerical design is, however, retained for assuring the conveyance performance of the restored channel.

2.3 Towards the 'fluvial hydrosystem': floodplains

In the currently fertile research field linking fluvial geomorphology and freshwater ecology it is frequently stressed that we must 'get out of the channel': the river itself is barely half the ecosystem story. The floodplain is not a universal neighbour to the channel but one over which the interests of humans and non-human biota are once again *rival*. The floodplain is of critical importance to a range of human river-use systems and to the conservation of nature: natural floodplains are amongst the most biologically productive and diverse ecosystems on earth (Tockner and Stanford, 2002). They represent a further component of the spontaneous regulation function in the sediment transfer system. Therefore, it is essential to know how floodplains form, their natural regulatory functions and how our use of them incurs *costs* as well as yielding *benefits* like fertile soils, flat rail routes and level building sites. Globally, riverine floodplains cover more than 2 million square kilometres but are under threat from development, flow regulation, flood control, alien species and pollution. Tockner and Stanford (2002) provide a useful bibliography of the many comprehensive books published on floodplains during the last 20 years, together with a thorough global inventory of the larger floodplain areas.

A cross-section through a river valley in the transfer zone indicates several important features (Figure 2.9). The *valley floor is* the broadest definition, encompassing all the landforms dominated by processes of deposition, including legacies such as those of glacial deposits. At the narrowest level is the *river corridor*, recently defined officially for survey and conservation purposes in the UK. In many countries the concept of protective, buffering *riparian zones* is becoming part of river management culture, again emphasising the interdependence of the channel and its surrounding features.

The floodplain represents that area across which the river escapes during floods and therefore may be subdivided by the frequency of the flood

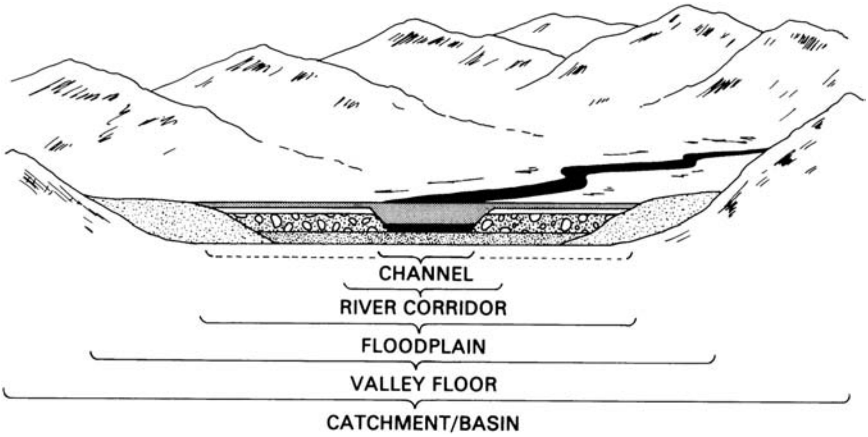


Figure 2.9 Zones of the valley floor within the basin – these can also be used as a geopolitical guide to progressively improving catchment management to benefit the channel (see Chapter 9).

concerned. Since the discharge which fills the channel (*bankfull discharge* of hydraulic geometry; *dominant discharge* of regime theory) occurs between once a year and every other year, floodplains appear captivatingly suitable for human settlement, agriculture and communications. There is considerable surprise and anxiety when, subsequently, damaging, more frequent or deeper, costly and fatal inundations occur.

2.3.1 Floodplain formation and functions: floods, aquifers

Much of the damage caused by out-of-bank flooding occurs by relatively concentrated flows down infilled river channels; these so-called *palaeochannels* also provide the best indication of floodplain formation processes. As sinuous patterns evolve and migrate, valley sides become eroded; the active channel therefore creates a wider valley in which both floodwaters and sediments can be stored. The storage of sediments is, as we observed in Section 2.1, a salient property of the transfer system, and in confined river reaches there is clearly a throughput of both flow and load until spreading can occur. In formerly glaciated regions, valleys tend to have adjusted to the flow of ice or to substantial meltwater streams. The present channel is therefore often a 'misfit' in a wide valley.

Sediments enter floodplain storage in two principal ways: by deposition in the channel (e.g. as bars and shoals) followed by abandonment, through migration, of that channel, or by deposition from out-of-bank flows. Clearly the former mechanism favours coarse clasts of sediment and the latter fine clasts; the result is that floodplains are frequently composite, with coarse material below, topped by fines. Channel planform exercises considerable control on the patterns of overbank sedimentation (Bathurst *et al.*, 2002). Work on rates of floodplain siltation by floods in the UK (Walling *et al.*, 1999) suggests, however, that the optimum deposition site is frequently close to the channel, permitting the build-up of natural levees. This study also revealed that up to 40 per cent of the annual supply of fine sediment is stored on the floodplain, justifying our consideration of intact floodplains as spontaneous regulators by balancing the channel/estuary as a site of siltation and hence also removing attached pollutants from the river. Annual rates of floodplain accretion reveal large variability, brought about by the degree to which floods can access the floodplain (in the face of its elevation relative to the channel and of artificial barriers like flood banks) and the sediment load/calibre of the floods which gain this access.

The finer deposits on floodplain surfaces, often carrying organic and chemical nutrients (Thoms, 2003), make a fertile parent material for soil development – one of the original reasons for the 'hydraulic civilisations', notably that of the Nile, whose floodplain is seasonally inundated and 'fertilised' with silt. However, during the Anthropocene we have also come to realise the capacity of fine sediments to bind nutrient chemicals and industrial toxins. In the Tyne basin in Northern England, therefore, floodplain soils are occasionally polluted to dangerous levels for crops by heavy metal pollution derived from mining activity upstream as far back as the Roman occupation.

It is becoming clear that floodplains will be the next focus for restoration efforts (Pahl-Wostl, 2006) but that rational restoration design will require considerable site-specific detail on the hydrology and sedimentation dynamics of the channel–floodplain interaction. Whilst new general survey techniques to provide detail of the interaction zone have been initiated (Sear *et al.*, in press), we will continue for some time to rely on numerical modelling (Nicholas and Walling, 1998) or sediment budgeting (Visser *et al.*, 2007) to preface the subtle interactions required.

There are two dimensions in which floodplain sediments act as aquifer deposits. First, the down-river flow of water is seldom restricted to the channel itself; large volumes can move ‘invisibly’ close to the open channel but as shallow groundwater, having leaked into the coarser deposits of the floodplain, often following the palaeochannels described above. There are two notable demonstrations of this phenomenon: the successful abstraction of relatively large amounts of quite pure water for supply from floodplain deposits (including those of former river courses in the semi-arid zone) and the ‘loss’ through temporary leakage of volumes of water released from regulating reservoirs (Chapter 6).

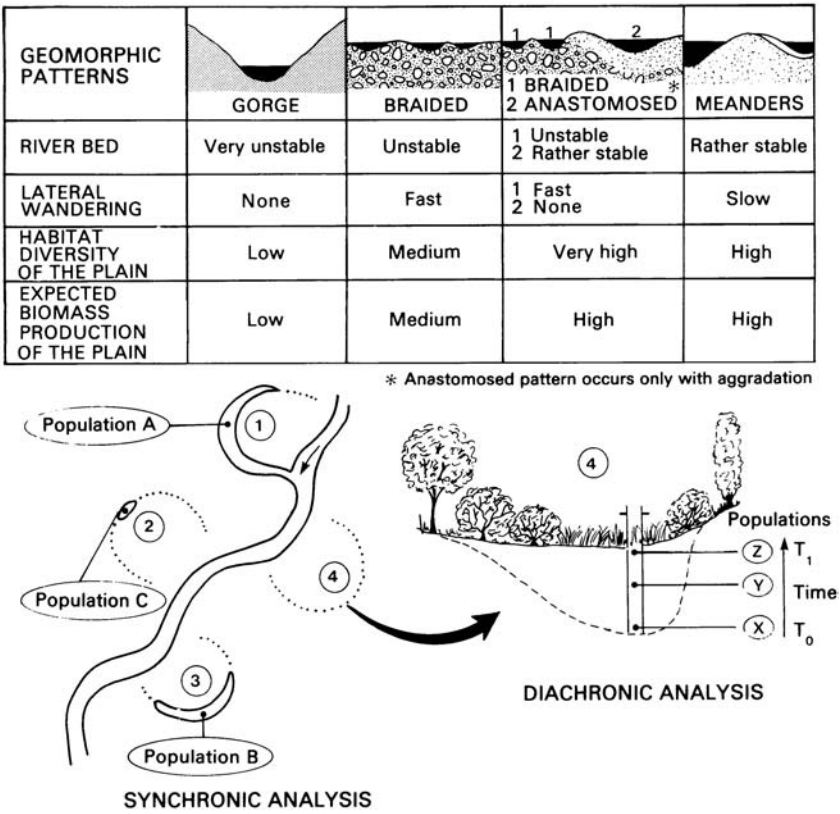
In the other dimension, at right angles to the down-valley flow, all the runoff contributed from valley-side slopes enters the channel via the floodplain deposits. Therefore considerable modification of flow patterns occurs across the floodplain, and we now know that this is accompanied by beneficial chemical changes such as nutrient stripping (Pinay and Decamps, 1988).

2.3.2 Floodplain modifications in the Anthropocene

The typical river valley of the developed world is now a wide corridor of intensive land use and water use. In a polarised case the following developments may have occurred:

(a) channel straightened and erosion-proofed;
(b) extensive flood protection structures;
(c) extensive irrigation and/or drainage;
(d) removal of natural vegetation and wetlands;
(e) encroachment of buildings and structures towards the channel;
(f) use of floodplain and channels/palaeochannels for waste disposal;
(g) river flow regime regulated by upstream dams and abstractions.

Floodplain restoration may well form the next objective of the ‘humans in the ecosystem’ movement, and the recovery of such important regulation functions has tangible economic benefits to offer. Figure 2.10 illustrates that dynamic adjustment of the channel increases the ecosystem services



GEOMORPHIC PATTERNS	GORGE	BRAIDED	1 BRAIDED 2 ANASTOMOSED	MEANDERS
RIVER BED	Very unstable	Unstable	1 Unstable 2 Rather stable	Rather stable
LATERAL WANDERING	None	Fast	1 Fast 2 None	Slow
HABITAT DIVERSITY OF THE PLAIN	Low	Medium	Very high	High
EXPECTED BIOMASS PRODUCTION OF THE PLAIN	Low	Medium	High	High

⁎ Anastomosed pattern occurs only with aggradation

Figure 2.10 The importance of 'wild' river channel migration and floodplain formation for the creation of a variety of habitats in space and through time (Amoros *et al.*, 1987).

rendered both to the local environment and to downstream channel–floodplain couplings.

In Figure 2.10 the biological populations A, B and C are sequentially incorporated in the stream ecosystem, as are those at depths X, Y and Z, providing natural stream migration rates are permitted. Many life stages of, for example, invertebrate animals have high survival rates in fluvial storage zones. Tockner and Stanford (2002) state that more species of plants and animals *by far* occur on floodplains than in any other landscape unit in most regions of the world. The economic valuation methods of Costanza *et al.* (1997) put the global value of their services to human society as nearly 20,000US$.ha^{-1}.yr^{-1}. Sadly, little or no use is made of this valuation approach in honestly assessing the costs of flood protection for human interests. In the UK, new research points to the desirability of considerable floodplain 'retirement' to allow nutrient stripping from the effluent of productive agriculture on valley sides and interfluves. There is also a considerable interest in the natural use of floodplains to store floodwaters, a use to which farmers have apparently become adjusted, as in the case of Lincoln (see Chapter 7).

2.4 Sediment 'delivery' at the basin scale: sources, pathways and targets

Outside the realm of catchment research (generally small-scale basins – see Chapter 7) it is virtually impossible to calculate either average or extreme sediment transport rates or *yield* (i.e. the rate of output per unit area). On-the-spot measurements of the sediment load moving in suspension or along the bed (much more difficult) are often restricted to those cases where a specific and costly problem of erosion or sedimentation is present, or at proposed reservoir sites as a guide to siltation rates after damming. The available techniques are far from satisfactory, particularly because none of the routine ones produces a continuous record of either suspended or bedload yields, especially during flow extremes. The need for simultaneous measurements of river *flow* also conspires to make sediment yield and transport rate measurements difficult. Progress is, however, under way towards, for example, the use of turbidity sensors to measure suspended sediment loads (Walling, 1977) and the installation of pressure-sensing or weighing traps for bedload (Reid and Frostick, 1986). The use of tracers is also fraught with difficulty unless, as in the case of soils, radioactivity from atmospheric pollution can be detected far downstream.

There is an increasing need as part of river ecosystem management to regulate sediment yields because of the deleterious impacts of excessive deposition – to the point where sediments, particularly fines, are seen as a physical pollutant, whether or not they have adsorbed toxic or nutrient chemicals. 'Siltation' is now seen as a major case of diffuse pollution in the UK, notably from agricultural sources; however, we remain in considerable ignorance of the sources, pathways and targets of 'silt' (too broad a term) in the river ecosystem. We are thus currently unable to establish regulatory protocols on, for example, agricultural practice at source, river flows in the pathway and rehabilitation where target species such as fish are threatened. Wood and Armitage (1997) have listed the important factors in the forthcoming debate about sediment controls in the UK under the European Union's Water Framework Directive (Table 2.4 and Chapter 7).

The most severe practical problem confronting the measurements of sediment budgets for management (e.g. to determine the rate at which a new reservoir will fill with sediments) is that temporal and spatial discrepancies in throughput of sediments leads to mismatch of, for example, soil erosion rates and sediment yields further down the basin (see also Chapters 5 and 6). For small basins it is now common to see the sediment budget compartmentalised into all the relevant sources and sinks (see Foster *et al.*, 1988 and

Table 2.4 Factors influencing diffuse river pollution by fine sediment ('silt')

Factor	*Importance*	*Comment*
Topography	Variable	High on steep slopes, low on gentle slopes.
Soil type	Variable	Soils vary in erodibility by rain and surface runoff.
Ground cover	Variable	Impact of rainfall less with dense ground cover but may be irrelevant to channelled runoff.
Sediment delivery	High Moderate Low	No buffer zone or disturbance to riparian zone. Some form of buffer zone or source remote. Source remote or extensive control measures, focusing on surface water management.
Agriculture	High Moderate Low	>50% arable or poorly managed land. <25% arable or pasture/other cover. Fallow, woodland or effective control of runoff.
Forestry	High Moderate Low	Clear-cut or bare soil within riparian zone. Conservation approaches to mechanised harvesting or buffer zone restrictions. Well-managed harvesting and use of non-forest or riparian natural woodland strips.
Urban	Variable	Road sediments, sewage sediments: type of urban surface and construction/drainage activities.
Disturbance	Variable	Highly variable depending on location, timing and management of disturbance (some natural, like fire).

Adapted from Wood and Armitage (1997)

Figure 2.11). Sediment 'fingerprinting' is now an established geomorphological tool and in the UK has revealed the high degree of storage for eroded fine sediments within small headwater catchments; delivery ratios can be as low as 14 per cent to 27 per cent (Walling *et al.*, 2002). Such sediment sourcing is an ideal corollary to mapping of long-term storage zones – spontaneous regulators – as a preface to determining their sensitivity to basin development (Section 2.1). The problem of delivery processes becomes much more severe when, in certain glaciated or eroded regions, a considerable legacy of stored sediments becomes re-mobilised after hundreds or even thousands of years. On the eastern seaboard of the USA, the era of European settlement led to massive soil erosion; much of the resulting sediment was, however, stored as *colluvium* (a basal slope deposit).

The most integrative concept with which to leave an impression of the basic physical stability of the river basin is perhaps that of sediment residence times. Figure 2.12 shows a section through a typical humid, cool river basin and indicates the location of the key sediment storages and an estimate of the average duration of that storage.

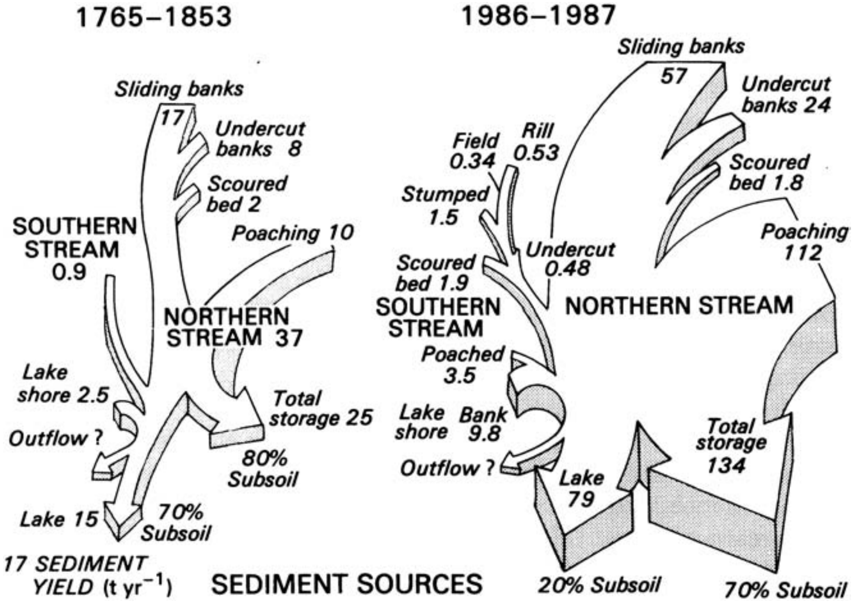


Figure 2.11 Source components of the sediment inflow to two Midland lakes (Foster *et al.*, 1988).

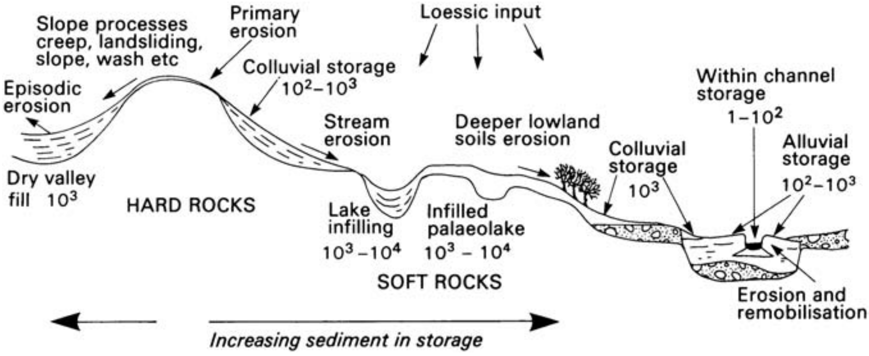


Figure 2.12 Duration and location of long-term sediment storage in the fluvial landscape (Brown, 1987).

2.5 Incorporating the basin-scale sediment system in ecosystem management

It is now important to stand back from the 'connected' fluvial system created by 'natural' hydromorphological processes and brainstorm the significance of its components for freshwater ecosystems. Clearly, the morphology of river channels is 'home' to river biota, but the fluxes, currents, loads and budgets of sediments and solutes also have a profound influence on biodiversity.

This chapter began by stressing the ecological significance of the 'fluvial hydrosystem'; *physical habitat*, we learned, was as much composed of channel margins, floodplains and wetlands as of river channels themselves. Current interest in the relationship between fluvial forms/processes and biodiversity (as a surrogate for ecosystem 'health' or 'integrity') arises partly because, in the developed world, severe river pollution from urban and industrial sources has now been controlled, leaving biophysical controls 'on top'. There is also the growing realisation that humans must not appropriate all, or even most, of a river's flow if they are to benefit from ecosystem goods and services in a sustainable way. Figure 2.13 illustrates not only the five major influences on ecosystem integrity or health, all of which have been impacted in some way during the Anthropocene, but also the components of 'channel character' and 'flow conditions', the only aspects for which we have space in this book.

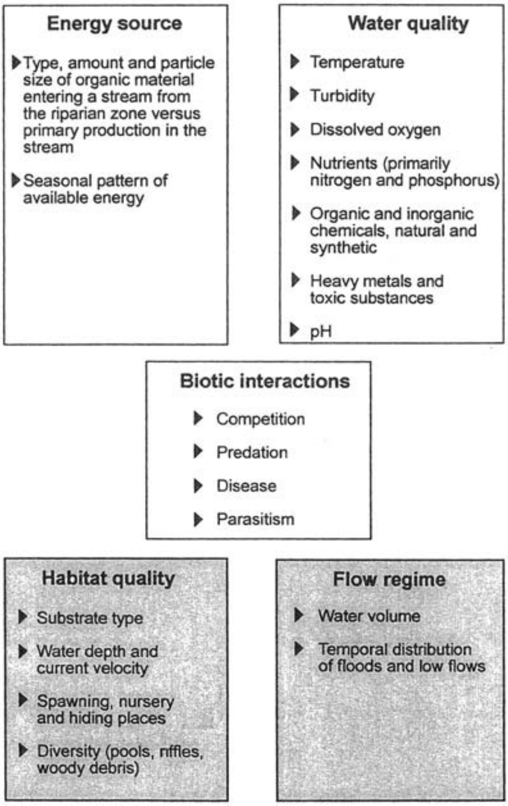


Figure 2.13 Five principal factors influencing freshwater ecosystem integrity or health (after Karr *et al.*, 1986).

The confidence of the geomorphologist in seeking a role in river basin management springs from the fact that, when the sediment transport system of any basin becomes destabilised, that basin 'falls apart' in more than one sense (see White, 1982). A considerable problem exists in convincing responsible agencies and institutions that fluvial geomorphology is relevant to river basin management (see Brookes, 1995a). Nevertheless, fluvial specialists are now making a considerable contribution to river management, and it is often the simpler classificatory and observational materials which are of most help to river managers (Sear *et al.*, 2003): channel dimensions, features and sediments are all vital to habitat condition and any restoration to an ideal state (Brierley and Fryirs, 2005). Thus the fluvial hydrosystem concept and the concept of 'hydromorphology' (as a basic conditioner for freshwater habitat) have prompted a much wider application of geomorphological ideas and data (Kondolf and Piégay, 2003a; Downs and Gregory, 2004).

The components of the geomorphological contribution to biodiversity (habitat) management are:

- a scaling of river basin components to reflect the interaction of morphological features and landscape ecology – the processes by which biota utilise river physical habitat;
- typologies of morphological features and their co-occurrence at the reach scale such that the characteristic assemblage can be used as a template;
- assessments of the condition of channels within each type – inferring what is 'natural' by making assessments in a range of contexts from, for example, heavily urbanised channels to pristine wilderness;
- contributing to interdisciplinary studies (variously labelled hydraulic stream ecology, habitat hydraulics, ecohydraulics – see Chapter 3) which explain the processes of flow and sediment size/movement controlling the use of 'biotopes' by organisms (Vaughan *et al.*, 2007).

2.5.1 Fitting together the jigsaw of water, sediments and biota for rivers

The most popular hierarchical model of a river catchment, much used and modified during 20 years, is that of Frissell *et al.* (1986); it allows both a working subdivision of the basin or catchment so as to create working units for scientific appraisal and the assignment of driving variables to various levels of the hierarchy. It is vital, for example when working at a microhabitat scale on, for example, preferences of invertebrate animals for different locations in a pebble cluster, to appreciate that the flow regime and sediment yield for that site are in fact controlled at the catchment or segment (bounded by tributaries, geology) scales. However, infilling practical detail of each or selected levels in the hierarchy has only slowly materialised. A general review of progress during the 1990s is provided by Newson and Newson (2000), who advocate use of meso-scale patches of uniform physical conditions (*physical biotopes*) as a convenient one for meaningful field surveys. Biotopes change with flow and can therefore be re-mapped under different river discharges to reflect the core meaning of 'hydromorphology' (as recently defined by the European Union – see Chapter 7), and knowledge of the biotopes characteristic of established river types can be used to scale up for catchment management or down for the detail of, for example, different life stages of the organism in question. More recently, Clifford *et al.* (2006) have cast doubt on the significance of hydraulic differences between biotopes and whether biotopes can ever be seen as typical of morphological units.

Despite the continuing academic debate about the appropriateness of different research scales and techniques, the demand by managers to set 'environmental flows' (Chapter 6) or to restore channels to their 'natural' state is insatiable for practicable tools. This demand occurs at three principal levels:

- demand for typologies so that the definition of 'natural' is appropriate to the suite of environmental variables controlling the river in any location (e.g. riffles are not appropriate to an estuary); this topic is developed further in Box 2.2;
- demand for information on anthropogenic impacts, past, present and future, on any particular suite of features used as habitat so that off-site conservation measures can be applied;
- demand for the design of channels which best suit the needs of a community ('rivers of dreams' – see Chapter 6), an aesthetic, specific animals or plants or biodiversity.

At the time of writing, in the UK, geomorphological assessment of rivers is now carried out principally to support habitat assessments, replacing its earlier prime deployment for flood risk management (design of channels, banks and maintenance schedules/techniques). Government conservation agencies are under regulatory pressure to protect nominated rivers (Sites of Special Scientific Interest, habitats of species covered by 'Biodiversity Action Plans', our best-known game fish under 'Salmon Action Plans') and to have programmes of measures in hand to protect the good ecological status of all rivers not heavily modified by anthropogenic activity to date. The books by Kondolf and Piégay (2003), Downs and Gregory (2004), Brierley and Fryirs (2005) and Sear *et al.* (2003 and in press) are testimony to the growing influence of geomorphology, nurtured by the rapid increase in public perception of physical (hydromorphological) damage to rivers, their disconnectedness and the compromised processes now driving their functionality.

Having treated at length the disconnections in the fluvial hydrosystem's major 'arteries' – river channels – we move outwards to those compromising the 'natural' routes for runoff through vegetation and the soil.

Chapter 3

Land–water interactions

The evidence base for catchment planning and management

Calder (2005a) has re-badged IWRM as ILWRM, the 'L' standing for *land*. Links between land and water are often multidimensional. One of the preoccupations of water resource managers in the UK between 1930 and 1970 was that human recreational pressure on reservoir catchments might damage water quality and lead to the spread of disease, e.g. cholera and typhoid fever, through the supply system. However, during the 1970s recreational facilities were slowly developed on both reservoirs and rivers, with the extra purification costs borne by water suppliers. By 1990 recreational water users were being warned that reservoir and river water threatened their health as the result of algal blooms resulting from farming practices! By 2005, the Environment Agency in England and Wales had identified diffuse pollution from catchment land uses as a major risk to the successful implementation of the EU Water Framework Directive (WFD) to defend and restore water bodies. In this way, 'catchment consciousness' has become scientifically justifiable. In the words of a leading protagonist (Calder, 2005b), 'more and more we regard every part of the land surface of the globe now as part of a catchment that can either supply water or receive our watery discharges'. Falkenmark *et al.* (1999) entitle an influential report *Water: A Reflection of Land Use*. The need for information and data on the influence of land use and management on surface and subsurface runoff is urgent. Both information and data are available but uncertain (see Chapter 8). For the moment we proceed according to a 'precautionary principle', reacting as though hydrology were a more exact science, at least in terms of evidence to support regulation and management.

The situation is complicated by three further factors:

- widespread occurrence of land-use 'myths' (Calder, 2005b);
- grossly unequal distribution of hydrological measurement networks across global environments, including a serious shortfall in the most rapidly developing environments resulting from the investment (capital, maintenance) required to operate them;
- inextricably political nature of the interface between land and water rights, through property, economic or legal instruments (Hodgson, 2004).

So widespread and unhelpful is the mythology of land-use impacts on hydrology, particularly deforestation, that the UN’s Food and Agriculture Organization (FAO) has emphasised the need for less tendentious headlines than, for example, ‘Deforestation in the Himalayas blamed for killer flood’; its view is that, ‘Given that impacts of land use on water resources are the result of complex interactions between diverse site-specific factors and offsite conditions, standardized types of responses will seldom be adequate’ (FAO, 2002, p. 1). Perhaps a more revealing and legitimate headline was that which appeared in April 2001, ‘Hillside homes add to Malaysian flood woes’: we need to consider the full picture of development before inferring hydrological impacts. Incidentally, the FAO has set up a division of its global operation entitled ‘Land and Water Development’.

During the last decade, hydrological science has become more confident about taking the whole-catchment ecosystem approach, with a significant ‘land-use hydrology’ caucus growing within its professional bodies. The increasing collection of land *cover* data by remote sensing (not the same as land-*use* or land-*management* data – see below) and the availability of these data have helped to facilitate this change. However, relatively few hydrologists are willing to create compilations of concepts or empirical studies to help inform the river management community (with some exceptions, e.g. Falkenmark and Chapman, 1989). A division of the hydrological cycle into ‘blue’ and ‘green’ water is a particularly useful prelude to the whole ‘land-use hydrology’ topic (Box 3.1).

Box 3.1 ‘Blue’ water and ‘green’ water, a hinge to the hydrological cycle with educational value for sustainable water use

Evaporation, as we have learned, is not easily predictable yet is the critical process sustaining the hydrological cycle and the partitioning of ‘green’ water at the Earth’s surface, redirecting precipitation, plant and soil water back to the atmosphere (Figure 3.1). Land-use hydrology has at its core the solution of the water balance equation for a particular unit of land, normally a river basin but often at much smaller ‘plot’ scales where measurements can be more accurate and control more secure:

P	$-$	Et	$\pm$	S	$=$	Q
Precipitation		Evapotranspiration		Changes in storage		Discharge in stream

The real dilemma in evaporation studies is that of how to separate two controlling processes in the loss of ‘green’ water from soils and vegetated surfaces:

(a) *Interception* is the detention of precipitation on plant surfaces and its re-evaporation from that location.
(b) *Transpiration* is the 'use' of water by the plant physiological system linking roots and leaf stomata (variable openings).

Once we have grasped the basic separation of components shown by Figure 3.1(a), we can advance to the four relevant perspectives on global water shown by Figure 3.1(b) in which the resource viewpoint can be separated into an 'ecological' total but with 'economical' runoff and 'social' withdrawals for human use.

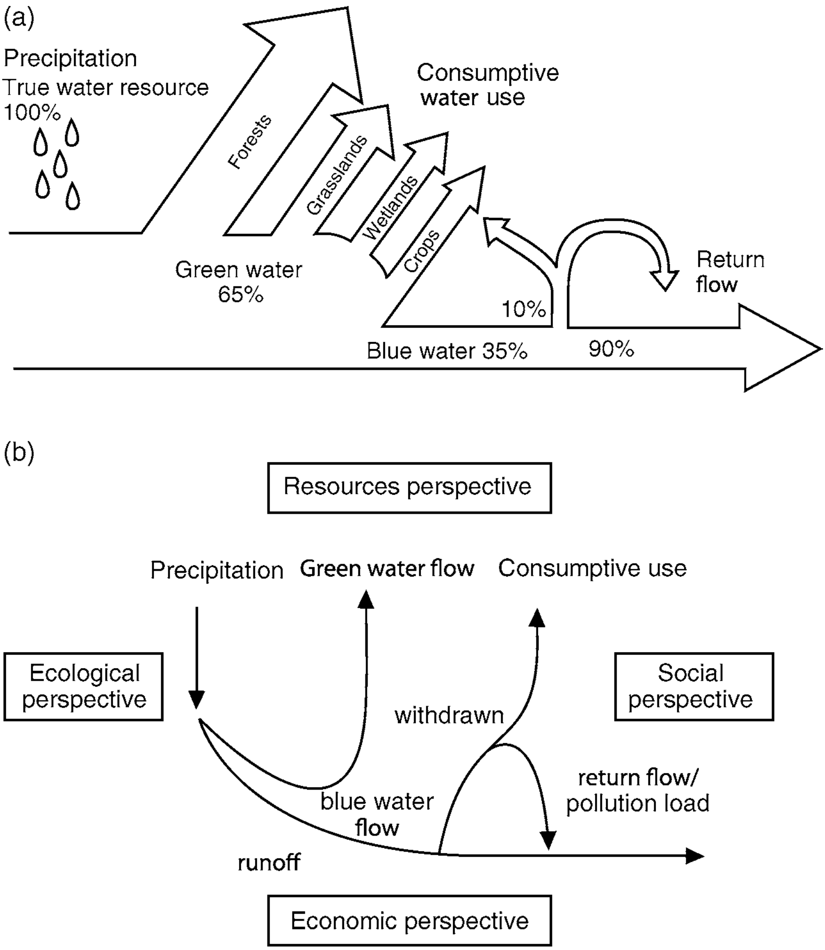


Figure 3.1 'Blue' and 'green' water partitioned in the land phase of the hydrological cycle (a) as a global balance and (b) as management domains.

Plate 3.1 The ‘water delivery’: children learning hydrology – collecting their minimum daily needs for ‘blue’ and ‘green’ water from the doorstep as if it were dairy milk.

Plate 3.1 shows two children in the UK, accustomed to a couple of bottles of dairy *milk* being delivered to the front door each morning, being confronted by their daily *water* requirements in two colours of bottle: blue (background) and the many more green bottles (foreground). The impact is that the respective volumes constitute their basic human needs for water of the two ‘colours’.

3.1 Vegetation, soils and hydrology: a humid climate perspective

Although recent publications have redressed the position of dominance (by investment) held by hydrological research in humid (mainly temperate)

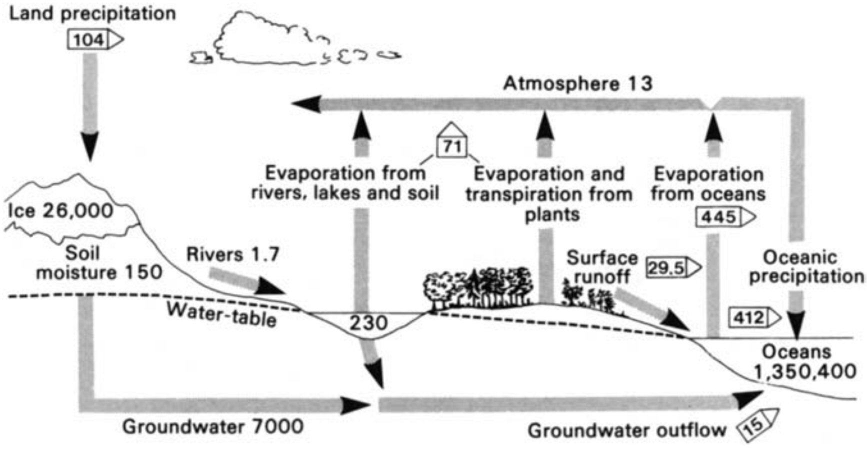


Figure 3.2 The global hydrological cycle (all volumes in thousands of cubic kilometres).

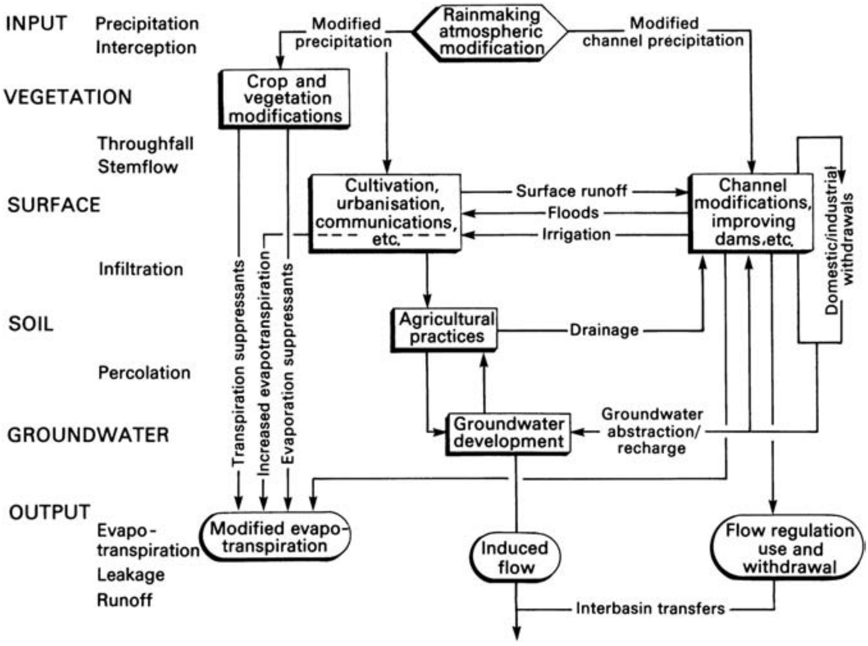


Figure 3.3 Factors influencing hydrological processes in the river basin (from Ward, 1967).

climates (e.g. Bull and Kirkby, 2002; Bonell and Bruijnzeel, 2005), we introduce the role of the land's surface in translating precipitation into groundwater and streamflow from the author's own environment. The UK is a humid, temperate land surface with a dense network of surface stream channels. However, even in mountainous parts of the UK, less than 2 per cent of the surface area of a river basin is occupied by stream channels: the huge majority of rainfall is translated to river flows via a canopy of vegetation and a mantle of soils, weathered bedrock or drift.

For 300 years, it has been axiomatic to hydrology that the hydrological cycle (Figure 3.2) links the important storages and fluxes of global moisture. The land surface is one of the important switching points in the cycle (Box 3.1), and a large number of land surface variables act to control the routeing of precipitation through the land phase of the cycle (see Figure 3.3). Although major 'fixed' controls are operated by relief and climate, the hydrological cascade of storages and flows in the surface zone is important, critically important in many relief and climate zones. In fact, land-use hydrology is very much a *regional science*, with the exact effects (particularly their magnitude) of land use dependent largely on regional conditions, for instance precipitation and evaporation volumes and seasonality in the case of forest effects on water quantities reaching rivers (Newson and Calder, 1989 – see also Table 3.1). Falkenmark *et al.* (1999) write of 'regional challenges' as a

Table 3.1 Regional process controls in forest hydrology

Regional element	*Effects on processes*
CLIMATE	
Rainfall regime	Low intensities/long durations favour interception if other conditions are right
Temperature/sunshine	Higher radiation inputs stimulate physiological water use via transpiration. Radiation climates essentially differ from advection climates
Wind speed	Advection energy and ventilation favour interception but also high rates of physiological stress and hence high transpiration where trees deeply rooted in wet soils
TREES	
Species	Often irrelevant but fast growers use more water if available
Stomatal control	Ofen superior to genetically produced agricultural crops
Rooting depth	Critical control on transpiration rate in dry conditions, especially if soil has good moisture storage (e.g. phreatophyte)
Spatial scale of forest	Controls edge effects v. core effects
SOIL/GEOLOGY	
Permeability	Controls water use and need/effectiveness of cultivation and drainage
Chemistry	Controls impact of acid deposition and need to apply nutrients/other chemicals
MANAGEMENT	Virtually complete control except over crop height and climate

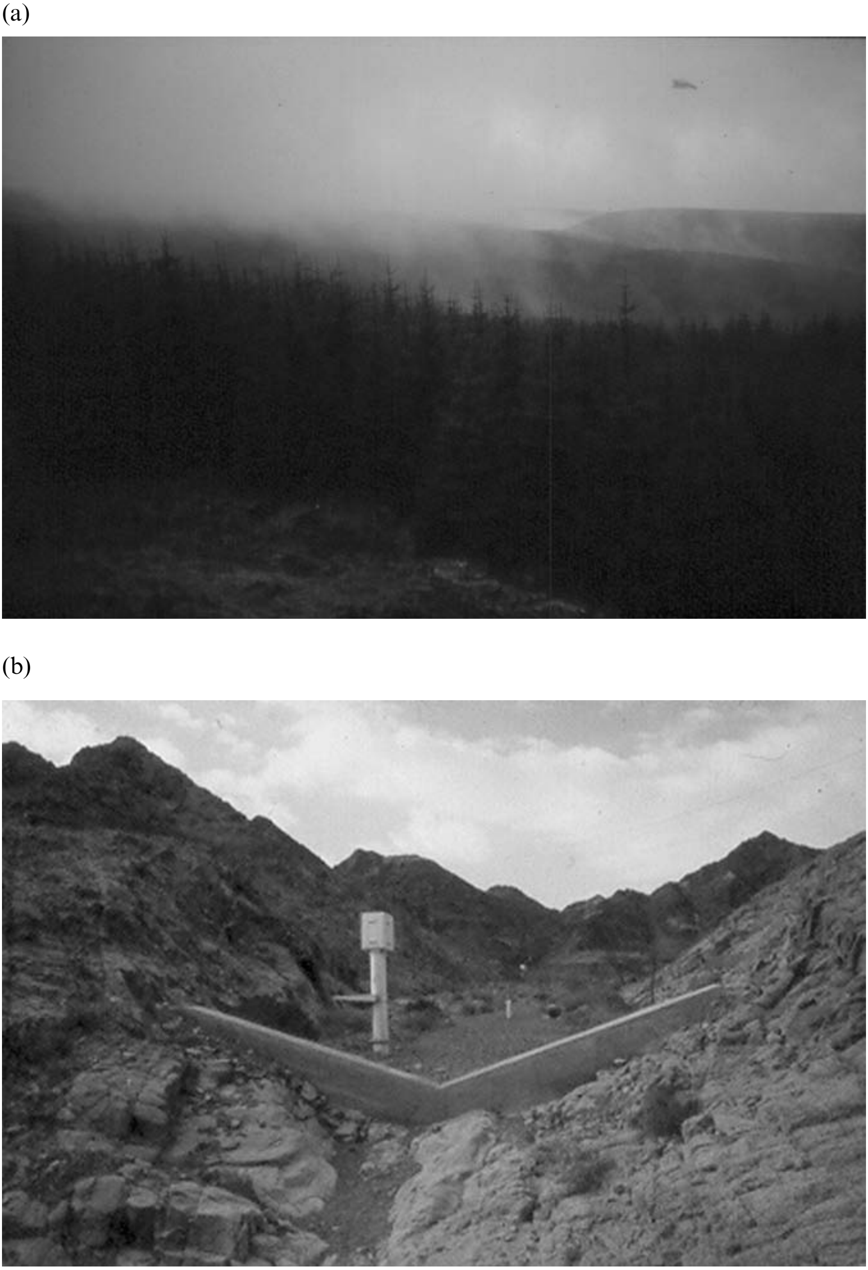


Plate 3.2 Hydrological challenges: (a) the flux away from a commercial forest as intercepted water 'steams' away; (b) waiting for flow: a measurement weir in a wadi in semi-arid Israel.

warning against simplistic translocation of technical fixes including, for example, reafforestation of tropical catchments to boost water supplies (for visual evidence compare Plates 3.2(a) and 3.2(b)).

3.1.1 The hydrological cycle in nature and the role of vegetation: 'green' and 'blue' water

Whilst biological, domestic and industrial demand for water is almost constant, precipitation occurs for a relatively small proportion of the time; even in the humid conditions of the UK there are few places where precipitation falls more than 15 per cent of all time and many regions where the figure is less than 5 per cent. 'Storage is the answer', both *artificial*, in reservoirs, and, more importantly, *natural*, in the pores between soil and rock particles, faults and joints in aquifers, in ponds and lakes and in the channel network. These storages have been calculated as shown in Table 3.2; they can be represented at the river basin scale as a hardware model or as a conceptual model such as that shown in Figure 3.3. We can view storage as a spontaneous regulation function of catchments which has been damaged by development in the interests (deliberate or inadvertent) of 'speeding up' the water cycle.

Table 3.2 Storages and fluxes in the global hydrological cycle

	Values ($km^3 \times 10^3$)	*Percentage of total*
STORAGE		
Ocean	1,350,000.0	97.403
Atmosphere	13.0	0.00094
Land	35,977.8	2.596
Rivers	1.7	0.00012
Freshwater lakes	100.0	0.0072
Inland seas, saline	105.0	0.0076
Soil water	70.0	0.0051
Groundwater	8,200.0	0.592
Ice caps/glaciers	27,500.0	1.984
Biota	1.1	0.00008
ANNUAL FLUX		
Evaporation	496.0	
Ocean	425.0	
Land	71.0	
Precipitation	496.0	
Ocean	385.0	
Land	111.0	
Runoff to oceans	41.5	
Rivers	27.0	
Groundwater	12.0	
Glacial meltwater	2.5	

If we are properly to reflect the vital role of 'green' water in global resource management, the process of *evaporation* needs to be better understood, even by some hydrologists to whom it is the 'loss' from the water balance, leaving river flow as the major variable (i.e. 'blue' water). The roles of biological processes leading to transpiration by plants and of meteorological processes affecting plant canopies (especially tall crops – see below) are particularly significant in 'green' water. Dalton, in 1801, demonstrated that evaporation rates from containers of warmed water were proportional to the vapour pressure difference between water and air; this resistance or *aerodynamic* approach to the phenomenon became less easy to solve for field sites where climatological data made the *energy balance* approach using measurements of radiative power for evaporation more popular. In 1948 Howard Penman combined the two approaches in an equation which was to facilitate estimation of catchment water balances, particularly in the humid temperate zone.

To allow for reduced actual evaporation via the transpiration process when soil moisture is depleted, Penman introduced a concept of the *root constant*, fixed differently according to crop rooting depth. We may take simplistic guidance from this concept that deeper-rooted plants (such as trees) 'use' more water than shallower-rooted plants (such as grasses), a difference which may well hold for warm, dry climates with a plentiful supply of water to roots (e.g. riparian trees or phreatophyte species). Calder (1990) traces the isolation and solution of a more difficult problem with the original Penman equation – one of *canopy height* or *leaf area index*, not *rooting depth*. Penman's aerodynamic calculations are appropriate for short but not tall crops, especially *in windy climates when the canopy is wet*. Under dry conditions the Penman approach has some mutually compensating errors between aerodynamic and radiative terms but the errors are so large (×2) for wet, tall crops such as forests that a separate approach to evaporation under these conditions (i.e. to the process of *interception*) is now the norm for evaporation equations and models. The issue of relative rates of evaporation achieved under different conditions in different climates by interception and transpiration by species of different heights dominates land-use hydrology. It retains scientific prominence in our efforts to understand climate change: natural and crop plants have varying reactions to both the increased carbon dioxide concentration of the atmosphere around them and the climatological impacts of this and other 'greenhouse' gases (see Chapter 6).

3.1.2 Vegetation canopy processes: impacts on water management

As Figure 3.3 demonstrates, the canopy is itself a temporary store in the hydrological cycle. Whilst not constituting a large depth of storage in terms of incoming precipitation (commonly <5 mm), the lateral extent of plant

Table 3.3 Vegetation canopy properties having an influence on the hydrological performance of vegetation cover

Interception (a)	*Transpiration (b)*	*Evaporation (a + b)*
'ARCHITECTURE'	'PHYSIOLOGY'	'SITE'
Crop height	Stomatal cover	Exposure – regional – local
Canopy depth	Seasonal growth	Ventilation
Leaf area (per plant)	Growth stage of plant	Albedo
Leaf shape	Health of canopy	Radiation climate
Crop spacing		Seasonality of site

cover is considerable and therefore volumes are by no means negligible. Whilst storage is only temporary, the small volume and high surface area of each stored droplet and the canopy's large surface area mean that both evaporative and chemical (solute) transfers are efficient. It is important to list the properties of vegetation canopies which influence their hydrological behaviour (Table 3.3). In the early days of qualitative observations on, for example, the hydrological influence of natural forests (Kittredge, [1948] 1973) canopies were seen as exercising a simple, single, umbrella-like influence on rainfall, and a generally protective, beneficial impact was assumed for river behaviour. Issues of canopy effects were often confused with those of soils and soil management (see Section 3.1.3).

Ultimately, clarification has come from a wide variety of scales of research carried out by several disciplines in numerous climates (even so, generally neglecting the importance of vegetation *management*). Vegetation changes may be accidental (fire, disease) or deliberate, but in each case the 'before and after' covers are different, creating the 'experiment' (e.g. trees may follow bracken, or heather, or scrub rather than short grass). Box 3.2 reviews the major outcomes of this genre of hydrological research.

Box 3.2 Hydrological impacts of afforestation and deforestation on runoff volumes and evaporation rates – global compilations

Despite the difficulties of extrapolating data for applications in a regional science (see Chapter 8), it is now generally accepted that, in rain-dominated climates, tall vegetation makes a net demand for water from a river basin. Work by Bosch and Hewlett (1982) has drawn together the results of catchment studies round the world (Figure 3.4) and may be used as an approximate guide to the trade-offs between a canopy cover and the water balance of the catchment. Their review results from 94 catchment experiments involving timber harvesting from climates ranging from <300 mm to >3,000 mm of annual precipitation. There is a consistent increase in catchment yield when

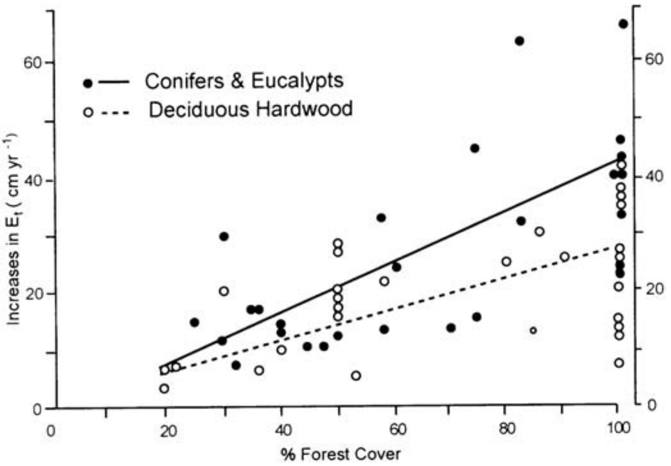


Figure 3.4 Forest cover and increased evapotranspiration: an international review (after Bosch and Hewlett, 1982).

Table 3.4 Changes in runoff from afforested catchments

Afforested from	*Afforested to*	*Number of catchments*	*Change in runoff (%)*
Grassland	Any species	13	–44
Shrubland		8	–31
Grassland or shrubland	Pines	14	–35
	Eucalypts	4	–50
	Other species	3	–39
Grassland only	Pines	9	–40
	Eucalypts	1	–75
	Other species	3	–39
Shrubland only	Pines	5	–30
	Eucalypts	3	–38

Data from Farley *et al.* (2005)

tree cover is removed, though the magnitude varies (positively) with annual rainfall and, obviously, the proportion of the forest cover removed. Forest types are difficult to compare within the same climatic zone but, broadly, conifers and eucalypts cause 40 mm change in annual yield for the loss of 10 per cent cover, deciduous hardwoods 25 mm and brush 10 mm.

The most recent compilation from hydrological studies of afforestation uses 504 observations from all parts of the world and separates groups of pre-forest land use and different forest crops (Farley *et al.*, 2005). The study was motivated by the increasing popularity of afforestation within climate change protocols to achieve carbon sequestration. It reveals a considerable disbenefit to runoff (Table 3.4), and the authors suggest that, where runoff is less than 10 per cent of mean annual precipitation, complete loss of runoff will occur on afforestation.

Perhaps the major outstanding forest hydrology problem facing river basin development is in the humid tropics where timber extraction and its other social and environmental impacts have resurrected many of the myths deriving from simplistic observation or blind translocation of temperate-zone science. Hydrologists have campaigned to bring an understanding of biophysical processes to bear on the tropical forest problem before the undoubted contemporary socio-economic crises are addressed (Bruijnzeel, 1993, 2004; Calder, 2002; Calder and Aylward, 2006). The lack of controlled catchment experiments in the tropics means that we have yet to get a broad regional picture of the subtleties of impacts on rivers (Bonell and Balek, 1993). A clear contrast with other climates is that moisture is not limiting in the soil, but the impact of raindrops and cultivation techniques at the soil surface probably controls both runoff and erosion processes post-felling (Lal, 1993 and Figure 3.5). This is not to say, however, that flooding and sedimentation are inevitable outcomes (Calder and Aylward, 2006). Figure 3.5 is not *the* answer: it simply acts to trigger the precautionary principle where there is no regional information. Box 3.3 condenses the points made by Calder and

Box 3.3 The role of forest canopy cover and its removal (especially in the tropical zone) in modifying the flood behaviour of catchments

Figure 3.5 shows a set of generic impacts of tropical deforestation on flood flows and erosion, without reference to specific conditions of site, climate, the rarity of the flood and many other subtly controlling influences.

Calder and Aylward (2006) seek both to clarify the broad principles of these impacts and to make some specific remarks concerning the dangers of misinterpretation:

- In broad terms, land use can affect the severity of floods in two ways, through affecting channel flow or channel form.
- The severity of the peak flood flow may be affected both by the total quantity of runoff produced during a flood event and by alteration of the timing of the peak.
- The severity of the peak flow results from the addition of volumes and timings from tributaries, an important scaling variable for downstream impacts.

- Channel form changes may result from the construction of drainage ditches or roads or from the obstruction of the channel by sedimentation (from upstream sources or riparian landslips) and infrastructure like bridges.
- Although land-use change effects on floods may be detectable on small catchments, the 'signal' is likely to be weaker on larger catchments because of the differential volumes and timings from tributaries, the progressively reduced proportion of land-use change down-catchment and the reduced likelihood of the most intense storms covering big areas.

For Europe, the recent FOREX project (Robinson *et al.*, 2003) established that increases in flood peaks with *afforestation* occur mainly in north-west Europe, where commercial plantation activity is associated with intensive drainage; felling in this region also leads to short-term increases in peak flows, whilst peak flows from a mature forest cover may be little different to those from unforested land (this is the conclusion for most regions in Europe). Cutting of *Eucalyptus* plantations in the south of Europe also leads to short-term increases in flood peaks.

(After Calder and Aylward, 2006)

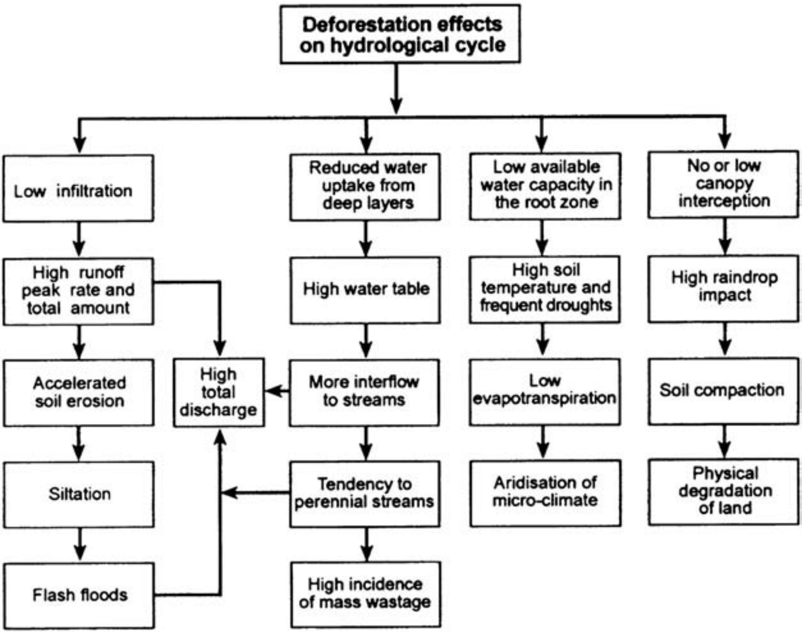


Figure 3.5 Deforestation: hydrological impact assessment, with special relevance to the tropics (after Lal, 1993).

Aylward (2006) on the specific issue of flood generation in tropical forest watersheds. FAO/CIFOR (2005) support and extend these conclusions to the way in which forestry practices can be made more site-specific to support decisions to mitigate against runoff extremes.

In terms of the impacts of tropical deforestation on the sediment system, the review paper by Bruijnzeel (2004) is very comprehensive, encompassing 60 sediment yield studies (whose recorded impacts fall into 12 types) as well as noting the special circumstances of tropical montane ‘cloud forests’, where canopy processes can trap extra precipitation in the form of ‘fog’. Such cautionary perceptions are critical in the light of the widespread economic assessment of tropical timber resources (Chomitz and Kumari, 1996) and the way in which poverty becomes a driver for some of the riskier forms of land-use change and subsequent land management, especially in Central America (Nelson and Chomitz, 2004).

Bonell and Balek (1993) review the important East African catchment experiments (Blackie *et al.*, 1979; Blackie and Robinson, 2007) in which changes in land use from forest to productive systems led to a variety of runoff yield responses. Changing from rainforest to tea plantation reduced runoff yield, from evergreen forest to smallholder cultivation much increased it, whilst from bamboo to pine had no effect.

3.1.3 Patterns of soil hydrological processes

The pattern of slopes, soil catenas and their moisture content and drainage adds another set of regional controls in land-use hydrology. One of the major pieces of empirical progress in twentieth-century hydrology came by exploring the spatial pattern of runoff processes in small headwater catchments. Geographers played a prominent part in the retreat from a concept of catchment-wide *surface runoff* to one in which spatially orientated runoff zones yield permutations of surface and subsurface runoff at various times during a runoff event, for example the flood hydrograph. This development is considered further in Box 3.4.

Box 3.4 Headwater runoff processes: dynamics in space and time

In the early days of hydrological research, the ‘easy’ surfaces which yield conspicuous surface runoff were understood using simple mathematical concepts. However, the ‘real world’ of ‘natural’ slopes covered in varieties of soils and vegetation took until the 1970s to appreciate in terms of the routes (often subsurface) followed by heavy rainfall. Two prominent variants of the ‘new’ conceptual framework were proposed: the *partial contributing area* (PCA) and the *dynamic contributing area* (DCA). Their strengths and validity are both determined by the pattern of rainfall (or snowmelt) interaction with the surface of the soil.

Throughflow processes are shown to be important, both between and within rain storms (Figure 3.6). It is a rate-exceedance rather than a capacity-exceedance, an important distinction to make when considering the regional and local application of the model. 'Overland flow' or 'surface runoff' was assumed to have universal applicability in hydrology and had the further advantage, as conceived by R. E. Horton, of explaining many of the geomorphological features of the drainage basin by focusing attention on soil erosion.

Surface flows remain effective but mainly where soils are saturated, a phenomenon typical of the base of slopes (as shown) and one which can clearly extend upslope in any soil horizon during a rain storm. This extension is the basis of the dynamic contributing area concept. Figure 3.7 illustrates how the saturated areas of catchment at the start of a small flood event expand during the event.

These concepts are now attracting renewed interest in an era when 'hydrological connectivity' is being used as a basis for catchment actions under best management practices (see Chapter 8).

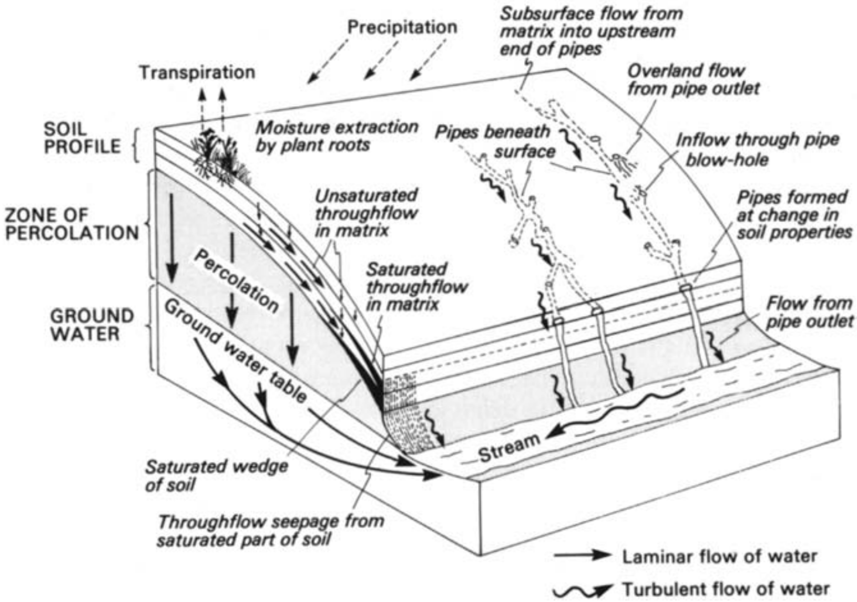


Figure 3.6 Slope section and plan to emphasise saturated zones built up by subsurface flow processes (after Atkinson, 1978).

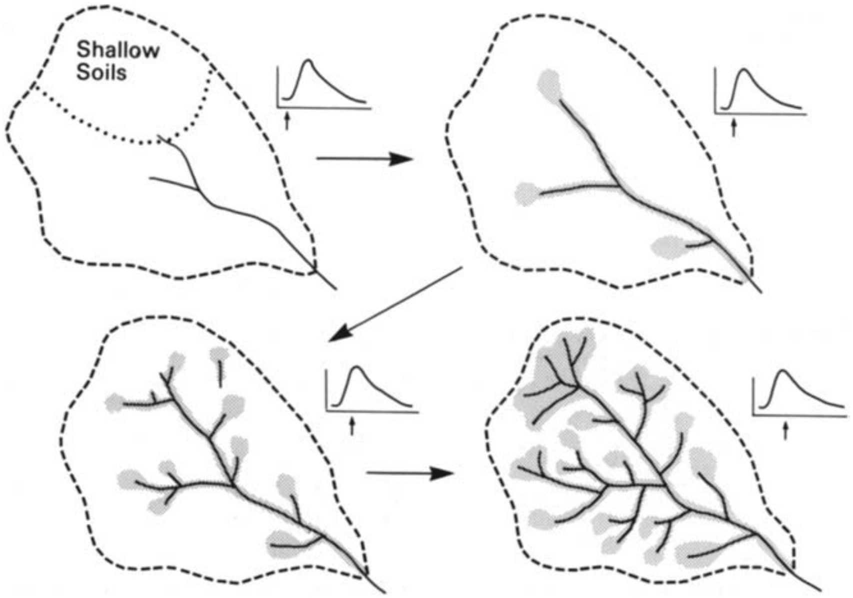


Figure 3.7 Expansion of the dynamic contributing area of a drainage basin into ephemeral channels and areas of saturated soils during the passage of a flood hydrograph (Hewlett and Nutter, 1970).

If canopy processes in hydrology largely underlie the importance of anthropogenic impacts on 'green' water flows, soil processes justify the attention of river basin managers to the 'blue' water route.

The hydrology of *urban surfaces* is much more subtle than suggested by mythological statements (frequent in student essays!) which claim they cause disastrous off-site flooding on a par with that alleged (also in student essays!) to result from tropical timber harvesting. Figure 3.8 illustrates the major river basin influences of forest, bare, urban and cultivated covers. Table 3.5 confirms a considerable variability of impermeability of urban covers; even so, the most obvious urban impact on the natural runoff system is that of re-routeing precipitation at the surface, usually to a nearby drainage system and thence, rapidly, to a river channel.

Table 3.5 demonstrates a measure of flexibility in urban design, and it has become standard practice in North America to mitigate the urban influence on both runoff and sediment yields by innovating with materials to reduce urban impermeability; the drainage system is also being modified with the introduction of storage tanks, hydraulic 'brakes' in sewers and surface balancing ponds. In the UK, the existence of development control legislation ('town and country planning') has facilitated the recent introduction of sustainable urban drainage systems (SUDS – see Box 3.5).

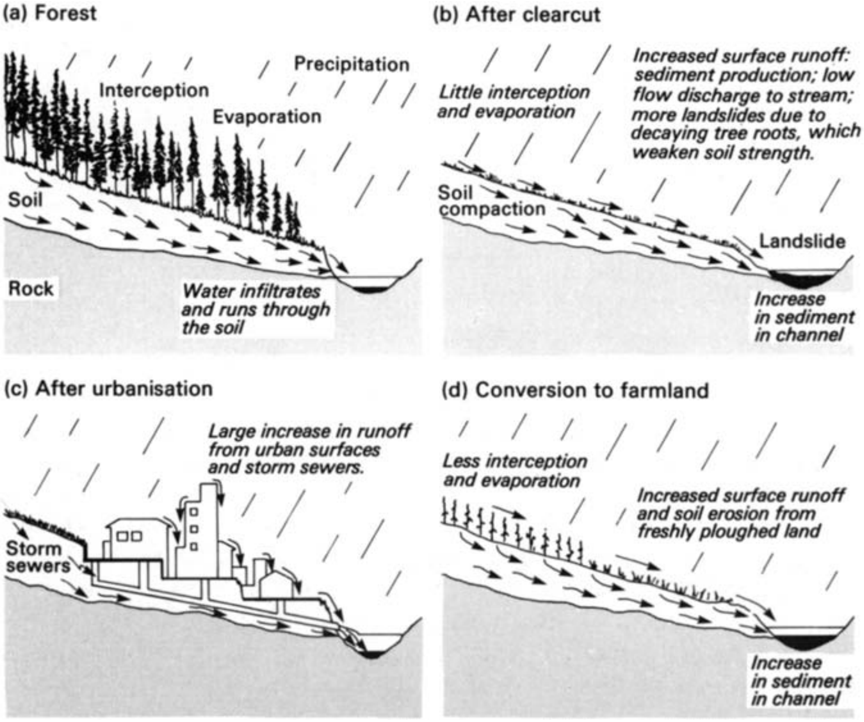


Figure 3.8 The influence of development on slope hydrology, indicating the role of urbanisation and agriculture.

Table 3.5 Approximations of the impermeability of various surfaces

Type of surface	*Impermeability (%)*
Watertight roof surfaces	70–95
Asphalt paving in good order	85–90
Stone, brick and wooden block pavements:	
with tightly cemented joints	75–85
with open or uncertain joints	50–70
Inferior block pavements with open joints	40–50
Macadam roads and paths	25–60
Gravel roads and paths	15–30
Unpaved surfaces, railway yards, vacant lot	10–30
Parks, gardens, lawns, meadows – depending on the surface slope and character of the subsoil	5–25

Box 3.5 Sustainable urban drainage systems (SUDS) and the deceleration/detention of storm runoff in cities and individual development sites

The variety of techniques available to mitigate urban developments in headwaters is described by Charlesworth *et al.* (2003) and it generally appeals to the creativity of the construction industry (whereas abandoning flood-prone sites such as floodplains can be seen as regulatory stricture). However, there are clear trade-offs between, for example, the space required for siting constructed wetlands and the costs incurred by underground works. Hydrologists have also emphasised the need to study the three major components of the performance of any artificial surface: runoff, evaporation and infiltration; they are quite surprisingly variable (Mansell and Rollet, 2006).

Table 3.6 indicates the main elements of SUDS, whilst Figure 3.9 indicates the universal hydrological principle of attenuation – the reduction in amplitude (and hence peak flows) of a flood wave because water is entering storages, naturally provided by wetlands and floodplains but replaced in part by the techniques used in SUDS. SUDS techniques should not be adopted uncritically under the assumption that they will meet with public approval. Table 3.7 illustrates some of the advantages and disadvantages of the major techniques.

Table 3.6 Examples of sustainable urban drainage systems (SUDS)

System	*Examples*
Surface-based	Permeable paving, swales, infiltration basins, wetlands.
Underground	Filter drains, soakaways.
Management	'Brakes' and reservoirs: storage in the storm system

Table 3.7 Some advantages and disadvantages of the available SUDS techniques

System	*Advantages*	*Disadvantages*
Wetlands	Capacity, pollutant removal, environment.	Space demands, safety, maintenance costs.
Surface	Low costs, groundwater recharge.	Not suited to all soils, high deterioration and failure rates, small scale.
Underground	No land requirements.	Construction/maintenance costs.

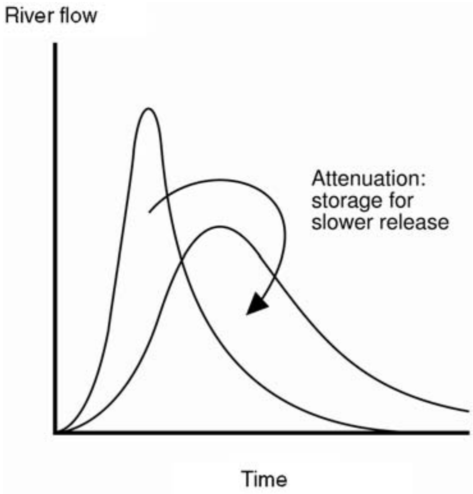


Figure 3.9 The hydrological/hydraulic principle of flood wave (hydrograph) attenuation, a central objective of SUDS techniques.

The very rapid urbanisation rates and styles experienced in the developing world complicate the spatial and temporal picture of impacts yet more, with squatter buildings, sanitation and urban agriculture all having an influence (Ebisemiju, 1989). Even where settlements are planned and sanitation is to a high standard, urban surfaces are normally considered to be a major source of water pollution, and so a broadly defined set of 'water resources' remains compromised by city growth (Center for Watershed Protection, 2003; Hatt *et al.*, 2004).

Disruption of soil processes in the runoff cascade by *agricultural intensification* is also imperfectly understood; again the difficulties of finding experimental sites and of innovating techniques abound – to which one may add the problem of generalising between national and even regional differences in cropping and cultivation techniques. As an example of the problems of generalising land-use effects on hydrology, we may cite the long debate in the British Isles about the effects of farm and forest drainage on the flood hydrograph. At first a separation appeared between sites on peat soils (enhanced response) and mineral soils (reduced response); see Newson and Robinson (1983). Subsequently, for clay soils, detailed investigations revealed that two conditions exist within the same drained area: under wet conditions undrained land responds more rapidly to rainfall than drained land because soil cracks become closed (Robinson and Beven, 1983). Furthermore Robinson *et al.* (1985) revealed the importance of mechanically cracking the soil when draining land and Reid and Parkinson (1984) the importance of landform in controlling soil moisture and hence drainage flow response.

Armed with this appreciation of impacts and their possible mitigation, the agricultural equivalent of SUDS becomes, in the UK, 'Farm Water Management Plans' and, more recently, 'Catchment Sensitive Farming'. Using maps and aerial photographs of typical farms, those managing the land are asked to design in such features as buffer strips (adjacent to stream channels), farm reservoirs (for irrigation and stock), sensitive choice of crops and timings for cultivation or harvesting, bunded stores for chemicals and manure, and well-designed roads and drains. This follows growing public concern with the off-site impacts associated with agriculture in the form of chemical pollution, nutrient enrichment and 'muddy floods' from soil erosion (see Boardman *et al.*, 2003). Concern is now growing internationally that the global energy crisis and the threat of climate change will promote vigorous changes in agricultural cropping, notably to 'biofuels'; climate change will also inevitably influence farmers on the choice of crop they make and the timing of farm operations.

3.2 Groundwater exploitation and protection

Because our perception of river basin development is dominated by images of surface water management (and mismanagement) – dams, canals, pipelines, treatment works, polluted waters and so on – the impact of surface activities on subsurface hydrology is often neglected. Groundwater is important to river basin development for several reasons:

(a) Groundwater forms the major water supply source in many parts of the world, notably in rural areas, especially in the semi-arid and humid tropics.
(b) Groundwater's relative purity, relative constancy and extent (beneath the land area) make it an important resource to moderate and modulate the surface water regime and surface ecosystems.
(c) Groundwater is the principal supply source for many wetlands occupying low spots in the landscape and thus supports a plethora of ecosystem services such as dry-weather flows and biodiversity.
(d) Many of the infrastructure projects of development require foundations or storage capacity underground – thus groundwater is an influence on mining, engineering, construction and waste disposal.
(e) Future infrastructure projects may include geothermal energy exploitation, involving groundwater directly, abstraction of saline groundwater for desalination and the deep burial of waste materials, e.g. nuclear waste.

There are around 40 very large aquifer systems in the world, with surface areas ranging from 100,000 to 1,000,000 square kilometres (Margat, 2007); their depth, in excess of 10,000 metres is just as impressive, and they jointly contain the greater part of continental groundwater reserves. Margat lists rates of abstractions from the 'top 13', which range from 0.22 to 46.7 $km^3.yr^{-1}$. The critical nature of the groundwater resource is clear in countries like Djibouti, 95 per cent dependent on them and yet with a demand rate rising faster than new reserves become available (Jalludin, 2007).

In the developed world, protection for groundwater has been late in coming. The Environment Agency in England and Wales has put forward a strong case for protecting both the quantity and the quality of groundwater in its review *Underground, Under Threat* (EA, 2006). It lists the main issues as excessive demand (one-third of England's population is supplied by groundwater sources), climate change, diffuse pollution, pesticides and land use. Pollution levels have closed almost 150 wells in 30 years, and almost half that pumped requires blending with cleaner water. Groundwater resource use is valued at £8 billion per year, and groundwater stored within the top 20 metres of the two main aquifers represents a volume 16 times larger than the total capacity of all surface reservoirs in the UK; some of this volume is vital for the augmentation of low flows in rivers, and this form of 'conjunctive use' works well enough to be considered a major future supply option. Perversely, if groundwater stops being exploited, its level rises and can flood to the surface or, for example, underground train tunnels; in the case of closed mineral mines (such as coal mines) the rising water carries very significant pollution threats when it discharges into surface waters.

Few parts of the Earth's land surface are truly impermeable, and subsurface waters exist in a broad spectrum of both shallow and deep aquifers. Surface rivers flowing across their own alluvium often interchange water with the alluvial aquifer in the floodplain, with important benefits for water use by both human and plant communities. The interrelationship between aquifers and rivers can be demonstrated even more clearly where groundwater abstraction rates have been allowed to grow to a point where spring-fed rivers all but dry up (as was the case in England during the 1990s). The importance of groundwater-dominated rivers is only now being appreciated (Sear *et al.*, 1999); they have very distinctive characteristics of water chemistry, geomorphology and ecology.

For deeper aquifers in sedimentary rocks, sustainable exploitation entails balancing abstraction with the rate of recharge from the surface and protection against contamination. The more difficult and dangerous situation is where such an aquifer received good rates of recharge in past, humid climates, making the 'reservoir' essentially one of 'fossil' water. Fossil groundwater basins are prominent in the water resources of North Africa and the Arabian Peninsula (Simpson, 1991). In Saudi Arabia non-renewable groundwater provides over 75 per cent of the nation's water needs; the resource is dwindling, saline intrusion of sea water is occurring and the aquifer is drained by abstraction (Al-Ibrahim, 1990, 1991). In such cases the American terms groundwater 'mining' and groundwater 'overdraft' are both expressive and relevant; there is little hope of sustainable development based on this water. Figure 3.10(a) shows those areas of the USA where groundwater overdrafts have been incurred (i.e. withdrawal is greater than recharge).

The relationship between surface land use and groundwater becomes clear from a popular Australian technique for controlling the seepage of saline groundwater into agricultural lands by reducing groundwater recharge (and thereby lowering the water table) through the growth of forest plantations (George, 1990). The original cause of the salinisation problem was the destruction of the natural forest cover in the name of agricultural development (see Chapter 4) – a strongly practical demonstration of the effects of the forest interception process.

Much more concern is now being expressed about the impact of surface land use and land management on groundwater contamination and pollution (United States Environmental Protection Agency (EPA), 1990; RIZA, 1991). The EPA divides the threats according to whether they are on the land surface, subsurface (but above the water table) or below the water table. They are:

- on the land surface: contaminated surface water, land disposal of wastes, including sludge from water/sewage treatment plants, stockpiles and tailings, salt on roads, animal feeds, fertilisers and pesticides, airborne chemicals and accidental spills (e.g. road and rail freight);
- below the surface: septic tanks, landfills, cemeteries, leakage from underground tanks and pipelines, artificial recharge waters, mines and saline intrusion (sea water entering coastal aquifers).

The RIZA report, for the European Communities, divides between rural and urban threats. The most significant rural threat in Europe is from agricultural practices, particularly the use of fertilisers and pesticides. In about 70 per cent of the EC's agricultural soils, nitrate concentrations are above the Communities' target value of 25 mg/l (Figure 3.10(b) shows those which exceed the EC Drinking Water Standard); in 65 per cent of the area the standards for pesticides are, or will be, exceeded. Maps of vulnerability to groundwater pollution have been published (NRA, 1992), and there are models for the calculation of the land areas at the surface needed to protect water sources (Adams and Foster, 1992). Under the regulations of the EU Water Framework Directive, member states are now required to delimit all significant groundwater bodies, the development and indirect pressures on them, to establish monitoring networks and to put in place programmes of measure to achieve 'good status' by 2015.

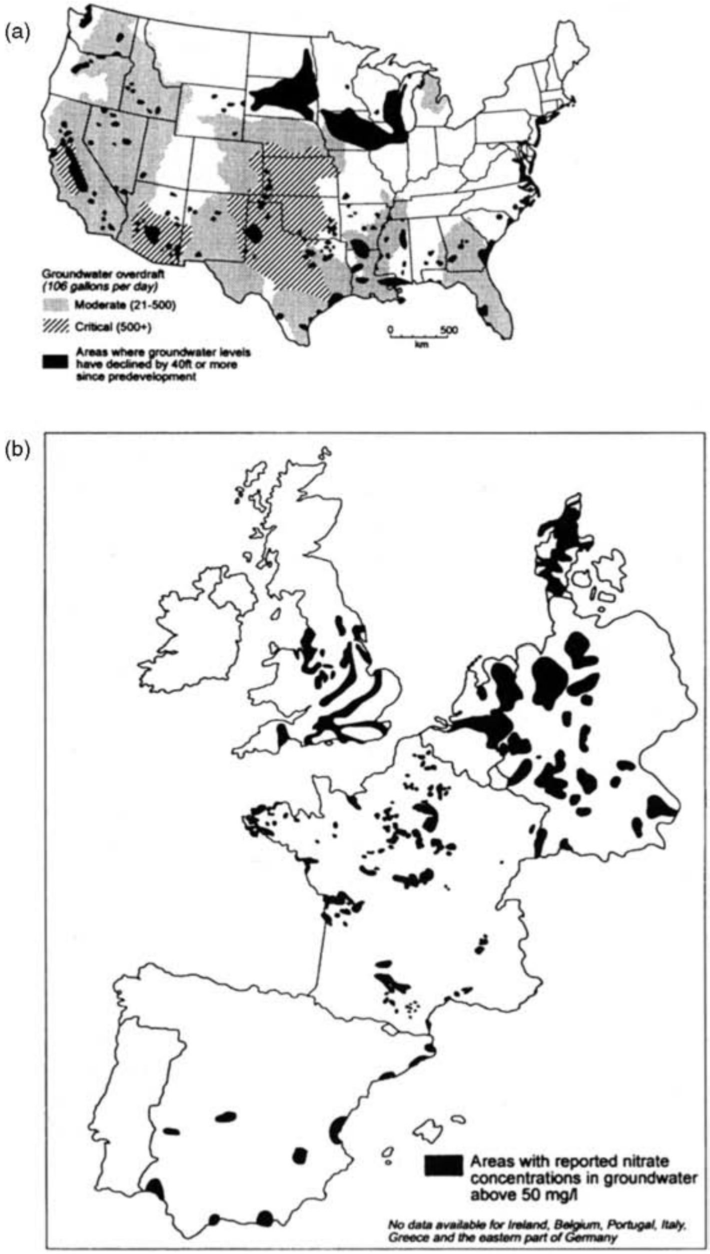


Figure 3.10 Unsustainable management of groundwater: (a) overdraft (withdrawal > recharge) and excessive depletion rates in the USA; (b) nitrate pollution of groundwater in the EU (after RIZA, 1991).

3.3 The devil of the detail: runoff modifications in developed river basins

It is essential to be highly specific when suggesting links between land use or land management and properties of the river hydrograph: merely ‘that land use has altered the river flow’ will not suffice. A major problem of interpretation is the *direct impacts* on river flow behaviour and groundwater fluctuations already made by human exploitation in the developed world. Only against a background of ‘naturalised flows’ (with artificial impacts on volume and timing by dams and structures removed) can the effects of land use and land management be judged.

In land-use hydrology we need to subdivide crop impacts (also stages of the *crop cycle*) of, for example, plantation forestry from those of the infrastructure to grow and harvest it and the cover effects of the urban surface from those of infrastructure, e.g. sewerage. Effectively we can divide between land *use* and land *management*; through management practice we can seek to mitigate undesirable impacts and enhance desirable effects.

One must not neglect the operation of natural controls on the runoff process; for example, basins may differ profoundly in their flood or drought behaviour because of physiographic or geological differences respectively. Figure 3.11 offers a simple guide; clearly the land-use and land-management influence may make its biggest impact in the mid-range of flows but may lose influence at the extremes.

3.3.1 Modifications to runoff volume

Land-use and land-management effects on runoff volume are clearly most likely where a change is brought about in:

(a) evaporative loss from an identical precipitation volume;
(b) surface characteristics of a basin which influence the detention and storage of runoff.

Both cropping (including tree crops) and urban/industrial land uses may be expected to cause such changes – at key switching points between ‘green’ water and ‘blue’ water in the land phase of the hydrological cycle – at the canopy level and the soil surface level. At the canopy level, there is now an emerging empirical consensus amongst hydrologists that a forest cover reduces runoff volume under most climatic conditions.

Calder and Newson (1979) concluded that in the British uplands interception ratios for plantation conifers converge at 30 per cent of annual precipitation (Figure 3.12(a)). During periods in which the forest canopy is moist, interception entirely dominates transpiration, but when the canopy is dry the reverse is true. Consequently, in drier climates the tree’s own physiological control of transpiration may come to dominate its comparative water

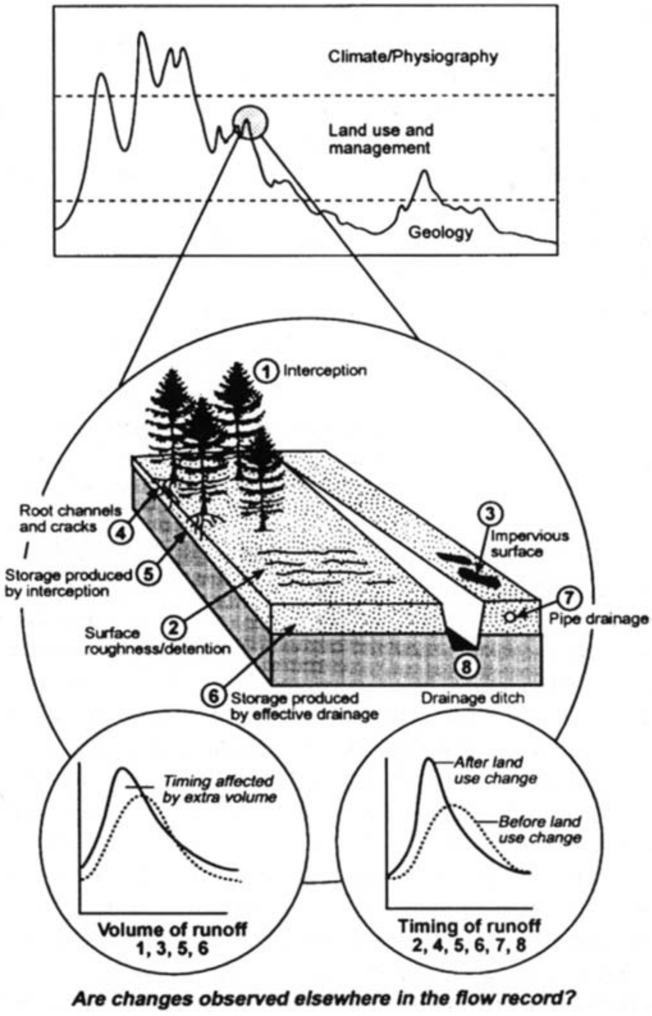


Figure 3.11 Influences on the annual regime of river flow and (outset) the influence of land use and land management on the volume and timing of flow events.

usage in relation to adjacent land covers; in practice understorey vegetation in forests also uses moisture, and Roberts (1983) has concluded that overall forest transpiration is essentially a conservative process with similar annual rates across Europe (approximately 333 mm/yr).

Figure 3.12(b) reveals that, even in larger catchments, there is a clear negative relationship between the volume of annual runoff (as a proportion of rainfall) and the forest cover of the catchment. The headwater 'signal' is

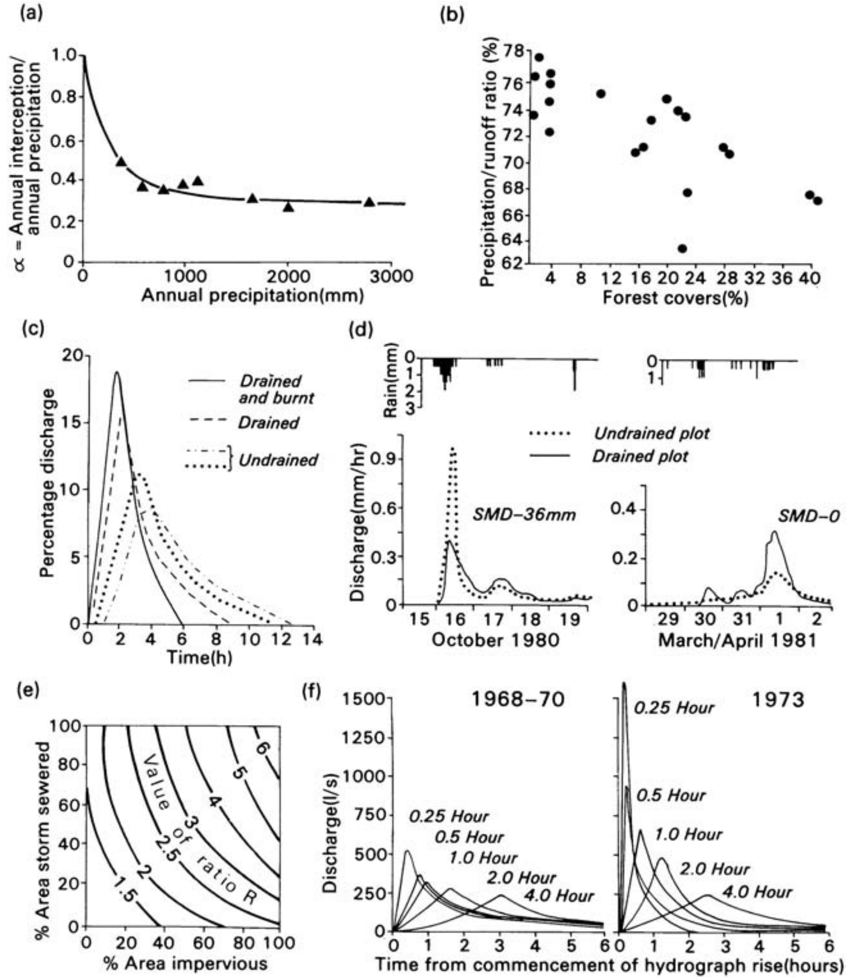


Figure 3.12 Hydrological effects of rural land use and land management:

(a) Interception ratios of mature forest canopies in the UK (Calder and Newson, 1979)
(b) Reduction of annual runoff coefficient with increasing forest cover, Wales (Mas'ud, 1987)
(c) Moorland drainage and the flow hydrograph (Conway and Millar, 1960)
(d) Farm (under-) drainage and the flow hydrograph, indicating the role of antecedent conditions as soil moisture deficit (SMD) in routeing rainfall through/over the soil (Robinson and Beven, 1983)
(e) Mean annual flood increments (cf. natural floods) with increasing urban cover and sewerage (Leopold, 1968)
(f) Flood hydrograph changes after urbanisation (Walling, 1979)

strong on-site, but off-site (downstream) investigations of how, and why, it becomes attenuated, masked or even reversed are rare (but see Archer, 2003; Mount *et al.*, 2005).

3.3.2 Modifications to runoff timing

We have already considered the runoff system as a cascade of storages, and clearly timing of runoff is proportional, in a simplistic system, to the number of storages through which each molecule of runoff passes. Response times vary accordingly, as Figures 3.12(c), (d) and (f) demonstrate. Any land-use or management strategy which significantly re-routes runoff will alter its timing, not only by presenting a different combination of storages but because each route has a characteristic velocity. It should once again be emphasised, however, that timing changes will also bring about volume changes in another part of the system, e.g. urban storm sewers will deprive the underlying aquifers of recharge.

Artificial processes which gather runoff efficiently into hydraulically smooth channels and which reduce the distance to the stream, or increase the pathway gradient, will promote faster flood responses. This is particularly true if some other change has also occurred to promote a higher volume of runoff, e.g. in Figure 3.12(c) where a small peat catchment has been both burnt (sealing the surface) and drained. In the case of subsurface drainage the condition of the soil between surface and drainage pipes has a subtle control on the timing of responses. As already described above, hydrologists in the UK have discovered that a dry, cracked clay soil promotes a more rapid response by drained farmland, but when the same soil is wet (and only slowly permeable) undrained farmland responds more quickly because it routes more rainfall across the surface (Figure 3.12(d)).

The combination of increased volumes of runoff and more efficient drainage from traditionally planned urban areas is shown by Figure 3.12(e), in which the peak of the annual flood is increased in proportion to both the impervious area and the extent to which it is drained. The evolution of the more rapid urban response through time is shown in Figure 3.12(f).

3.3.3 Regulated rivers, an introduction

We leave the main treatment of dams and their impacts on downstream flows until Chapter 6, but it is important to have in mind a background of the large scale of impacts made on river flows by river flow regulation (i.e. the flow pattern created by dam releases of water and sediments). It is a paradox of our subject area in this chapter that, whilst the intention is to substantiate a planned approach to the joint management of land and water, it is water engineering which has produced a more identifiable, and in many cases more marked, effect on river flows.

Many authors are now compiling global impact assessments of the spectacular degree to which the world's river systems are dammed. Data are presented as, for example, volumes stored by dams as a proportion of global river flow, the degree to which the stored water 'ages', rates of evaporation directly from reservoir surfaces and the degree of 'fragmentation' caused by dams to the stream ecosystem. Dynesius and Nilsson (1994) assess the degree of fragmentation in developed parts of the northern hemisphere. Their view is that 'the damming of rivers has been identified as one of the most dramatic and widespread deliberate impacts of humans on the natural environment' (p. 753). Their analysis of total water discharge from 139 large river systems is essentially one of flow volume; it reveals that 39 per cent of the large river systems, or 23 per cent of their total discharge, are still unaffected (using their flow-related definition), but they stress that the options for preserving truly unimpacted rivers are rapidly dwindling. Rosenberg *et al.* (2000) introduce the papers from a meeting designed specifically around the 'big picture' of anthropogenic influences or 'hydrological alterations'; these extend, via fragmentation in terms of discharge, to genetic isolation, accumulation of pollutants, primary productivity and greenhouse gas emissions. The ecological significance of retaining connectivity in river systems is surveyed by Pringle (2003a, 2003b), who stresses that subtleties of impact by dams can be more far-flung than the obvious obstruction to, and alteration of, flow – including reduced silica delivery to coasts by rivers, causing eutrophication.

To the obvious effects of flow regulation by dams we may add the impacts of:

(a) major industrial uses of river water (although this may be returned);
(b) irrigation use of river water, which is consumptive ('lost' by evapotranspiration);
(c) water use by human settlements which abstract substantial volumes from natural or regulated rivers and return this water as sewage.

Table 3.8 attempts a very simple rating of the impacts of both sets of influences and is designed only to show that, in general terms but possibly over greater lengths of river channel, artificial regulation has the more profound anthropogenic effect on flows. Taking the two 'dam' columns together 'scores' 27, in comparison with an urbanisation impact 'score' of 23. Table 3.9 lists the types of changes in volume and timing of flow occasioned by a variety of regulating activities both direct and indirect.

3.4 Land and water: off-site impacts on water quality and biota

This is not a book about water pollution: space doesn't allow; neither does the author's knowledge of chemistry and biology. Some regard water pollution as curable or cured (Lomborg, 2001), whilst others see it as a 'crisis' on

Table 3.8 An attempt to qualitatively assess the impact of dams and catchment land use on physical habitats

	Dams		*Land use*		
Impacted variable	*Dam/reservoir area*	*River system*	*Forests/ deforestation*	*Wetlands/ drainage*	*Urbanisation*
Precipitation	–	–	*	*	*
Aquifers	–	*	**	**	***
Runoff volume/rate	*	n/a	**	**	***
Evapotranspiration	*	–	*	**	*
Mean discharge	n/a	*	*	**	*
Maximum discharge	n/a	**	**	*	**
Minimum discharge	n/a	**	*	**	*
Washload sediment	**	**	***	*	***
Bedload sediment	***	***	*	–	*
Channel stability	n/a	*	**	**	**
Physical habitat	***	**	*	*	**
Chemical habitat	**	*	*	*	***
'Scores'	12	15	18	17	23

Key to 'scores':
– no impact
* impacts local or temporary
** widespread moderate impacts
*** widespread serious impacts

Table 3.9 River regulation: magnitude of effects on flow regime

	Volume	*Timing*	*Downstream distance*
DIRECT EFFECTS			Depends on position and size of unregulated tributaries
Direct supply reservoir	Reduces	Delays flood peak by storage	
River regulating reservoirs	Reduces and increases according to conditions	Tends to delay natural floods	
Hydro-power (dam)	Diurnal or seasonal pulses	Towards artificial regime	
Run-of-river	Little impact	Little impact	
Flood control	Reduces/removes peaks	Delays	
INDIRECT EFFECTS			
Irrigation return flows	Reduces	Little effect	
Sewerage return flows	Redirects/ transfers	More rapid if includes storm drain	

its own (Stauffer, 1998). Clearly, the developing world will continue to face phases of increasing levels of river pollution unless strongly sustainable policies are applied, e.g. to water supply and sanitation: a dilemma already set up in Chapter 1. That technological fixes can be successfully applied and that regulation 'works' can be judged from the new prominence given by the EU Water Framework Directive to the physical habitat of rivers.

Hydrologists have developed detailed programmes of research on river basin water chemistry and its variation with land use. They have been joined by ecologists anxious to investigate links between water quality and habitat; much of this latter research has been done at smaller scales with forests, both natural and exploited, and agricultural lands, both grazing and arable, exciting the interest of many research programmes. Central ecological problems have been those of acidification and eutrophication (enhanced nutrient status), but sediment loading is also a feature of water quality changes brought about by land-use activity, even though the simple correlation of yields with impacts is now seen as naive (Walling, 1999).

Before continuing, it is appropriate to make a simple subdivision between two types of basin effect in this category. Whether the problem is *contamination* (the introduction of new materials and compounds to the system) or *pollution* (the introduction of damaging loads or concentrations of materials or compounds), we separate two sources:

(a) *Point sources* are identifiable, such as the obvious outfalls of irrigation return flows or sewerage systems.
(b) *Diffuse sources* are much more difficult to identify, such as nutrients and pesticides added evenly to agriculture or forestry.

The source may also be continuous or intermittent (Figure 3.13), and there are difficult intermediate categories such as the farm slurry-store which, if it is emptied carefully and spread on the land, becomes a diffuse source of nutrient chemicals but which, if it spills to a stream, becomes a point source. Pollution *incidents* are also, therefore, land use related. It is obvious to those managing river basins that scientific detection of, and legal controls on, diffuse pollution is much more problematic than the equivalents for point sources.

The difficulties associated with diffuse sources mean that proving links between rural land use/management and water quality are much greater than for urban links. Furthermore, scientific studies will find difficulties of extrapolation beyond the boundaries of research sites, in this case far more insuperable than those of scaling a universal physical process such as interception. The *delivery* of sediment and nutrients to stream channels is an umbrella term whose components nevertheless require detailed, often site-specific, incorporation in the modelling tools needed by regulators (Beven *et al.*, 2005). Studies of river sediment systems or water chemistry systems have additional problems of downstream changes in processes and of the

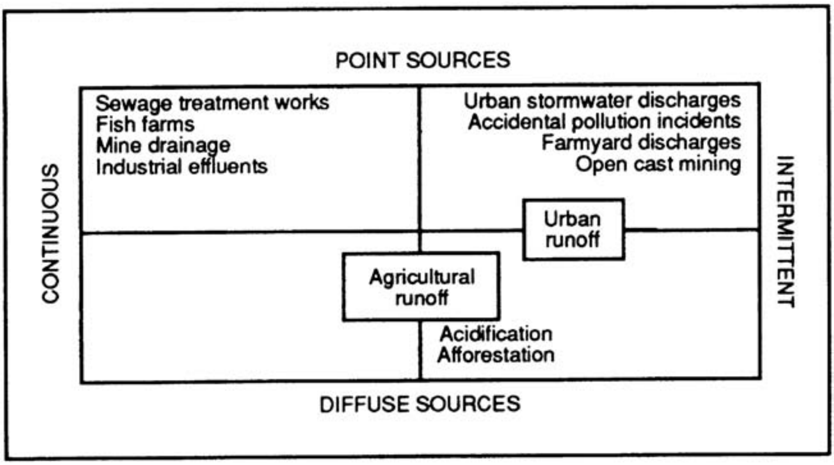


Figure 3.13 Sources of pollution: a simple classification (after British Ecological Society, 1990).

importance of local conditions of culture, climate, soils and rock types. In terms of regulation, Harris and Heathwaite (2005) use an intriguing title, 'Inadmissible evidence: knowledge and prediction in land and riverscapes', and stress that, 'as the medium changes from land to water, different rules, rates and dynamics apply' (p. 4).

3.4.1 Land use and the fine sediment system

In Chapter 2 we were concerned with the formation and maintenance of river channels, mainly the realm of coarse sediments; here coverage shifts to the finer, suspended or 'wash' load which often originates in soil erosion and constitutes a physical pollutant (and/or chemical pollutant *carrier*) downstream.

Archaeologists have revealed in many regions of the world a major erosion phase associated with typical land use of the settlement era. In semi-arid lands the land-use effect is via settled irrigated agriculture. In humid regions of North America, Europe and Asia there are clear deforestation- and overgrazing-related erosion horizons. Often a rival climatic explanation is available but, with close analysis of how basins route the products of soil erosion, it is clear that in certain major areas of basins, notably in hollows and at the base of slopes, land-use practices themselves can account for impressive thicknesses of deposit. We may therefore hypothesise a link between 'land-use sediments' in *colluvium* and 'climate sediments' in *alluvium* (see further debate in Chapter 6).

Figure 3.14 shows how the impacts of development can produce profound changes in sediment yields (see also Table 2.3(a)). For the eastern seaboard of

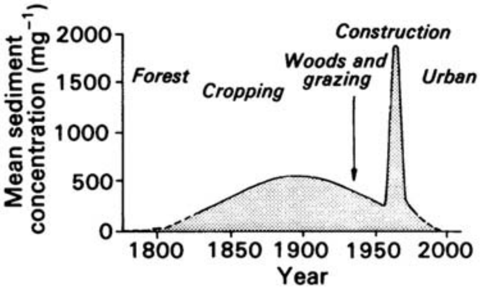


Figure 3.14 Controls on sediment transport: general 'settler' development processes on pristine landscape (after Wolman, 1967).

the USA, Meade (1982) describes how soil erosion was increased tenfold by European settlement; large quantities of the resulting sediment are still stored on hillslopes and valley floors, exaggerating contemporary sediment yields. The impact of modern humans in the region has been to trap the same sediment in reservoirs; the remainder is stored in estuaries and coastal marshes. Knox (1989) has pointed to the fact that river valleys act as huge stores of alluvium from such periods, demonstrating the evidence of prehistoric clearances in Wisconsin.

The question to pose next is whether fine sediments entrained by rivers represent a significant contamination or pollution of the environment. Wood and Armitage (1997) provide a comprehensive review of the biological impacts as well as listing the aspects of delivery already seen as vital to regulation for diffuse pollutants (Table 2.4). Walling *et al.* (2003) have assessed the sources of siltation in the gravels used for spawning by salmonid fishes, differentiating between surface sources and the erosion of river banks. In Scotland, as part of the implementation of the Water Framework Directive, good soil management to mitigate off-site siltation and turbidity can be managed via the General Binding Rules derived from Best Management Practice (Scottish Executive, 2005) – this is a route being taken in many developed countries (see Chapter 4).

Turning to habitat deterioration in turbid streams, a series of laboratory experiments conducted by Alabaster (1972) indicates that the presence of fine materials in suspension seriously exacerbates the toxic effect of certain chemicals in water. Cross-linkages between solid and soluble phases of river flows are emerging from many land-use-related river pollution studies. For example, phosphates become preferentially adsorbed to fine sediments (Walling, 1990). The loss of organic and mineral nutrients from eroded soils can become an accumulating pollution hazard in lakes and reservoirs. In studies of sedimentation from 'hydraulic mining' (in which water is used to expose and sort ores and dispose of waste), the fine fraction of the sediment mix released appears to be an important carrier of the metal pollution downstream (Macklin and Dowsett, 1989) to lakes, slack-water sites on the river and floodplains, where poisoning of vegetation and cattle may continue for decades. One of the consequences of changes to the flood regime of regulated rivers is the accumulation of fine sediments within the matrix of river-bed gravels because of the lack of 'flushing flows' to remove them (Kondolf and Wilcock, 1996).

3.4.2 Solute processes, mineral and nutrient

A protestor arguing against the fluoridation of public water supplies was once heard to object to 'the addition of a chemical to pure water'. Nature conspires to add many chemicals to river water; in some cases the concentration or loading of wholly 'natural' chemicals pollutes water to the extent that it is undrinkable and the stream lifeless. Nature is also behind the chemical solution of limestone landscapes (karst), where the process actually creates the typical river network (an underground one flowing through caves).

Figure 3.15 shows both systematically and pictorially the origins of natural stream water quality (in rural areas). There are both mineral and nutrient cycles, often largely controlled by soil/vegetation systems and agricultural practices, which explain chemical content at any point in the hydrological cycle. Two elements of this system are often neglected by field monitoring campaigns: the chemical characteristics of *precipitation* and the chemical

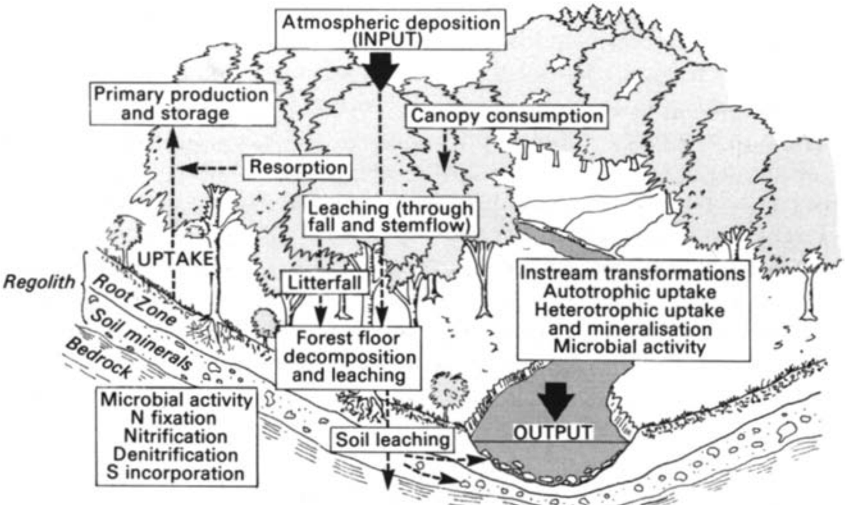


Figure 3.15 Processes leading to the production of stream solute loads in a natural catchment.

modifications produced by *instream processes*, often controlled by stream biota. Indeed it is upon the in-stream processes of chemical 'purification' that we depend across the world when using rivers as conveyor belts for the waste products of housing, farming and industry.

'Natural' water quality is governed by two great sources of mineral salts, the ocean and ocean-deposited sediments containing abundant sodium and chloride, and rock types consisting of lithified marine organisms, rich in calcium and carbonate (Walling and Webb, 1986). Whether introduced by 'natural' processes or by land-use-related modifications, the soil is a primary site for geochemical reactions, and the concentration of ions in drainage water is influenced by both the rate of solution (or production of soluble chemical) and the rate of removal by soil moisture movement. An understanding of flow paths and flow velocities ('hydrological connectivity') is therefore of immense importance in managing water quality problems resulting from land use. For example, nitrate pollution arising from intense production on well-cultivated, freely draining soils can be mitigated as the throughflow drains to the channel via saturated floodplain soils where denitrification occurs (Pinay and Decamps, 1988; Hill, 1990).

In the case of urban and industrial land use, the soil plays a much less prominent role unless waste products are applied to land – an increasingly popular option for sewage sludge, the solid product of urban sewage purification. Mostly, however, urban industrial water quality problems are not routed by the 'natural' hydrological pathways but originate in an industrial process at a site with a clear point discharge direct to a stream (see Table 3.10).

In a perfect world, the location of urban and industrial developments in relation to the river network and sensitive aquifers (and the timing of waste discharges) would ensure that point sources of pollution were controlled by dilution: an ecosystem service. It is, however, the diluting power and biological vitality of streamflow from the less-developed headwater river basins which will allow such waste discharges to be made; thus the loss of purification potential which occurs as a result of increasing rural pollution is highly significant to urban land use, since the world's popular city locations are often riparian and downstream. Figure 3.16 (from Newson, 1995) shows that urban and industrial planning policies can be backed, in other parts of a developed basin, by management of atmospheric deposition (calculating the critical loads for ecosystems), rural land-use policies, protection of aquifers, and implementation of rural 'buffer zones' of natural vegetation next to channels. Protection zones can also be applied to industrial developments where strict controls on emissions and protection measures against pollution incidents are applied. The critical policy need is for land-use planners and water (catchment) planners to coordinate their approach to the carrying capacity of each local freshwater environment, as well as to the needs of the whole basin (Newson, 1994b).

Table 3.10(a) Some sources and causes of water quality deterioration

Effluent	*Factors affecting water quality deterioration*
Domestic sewage	BOD, suspended solids, ammonia, nitrate, phosphate
Vegetable processing	BOD, suspended solids, colour
Chemical industry	BOD, ammonia, phelons, non-biodegradable organics, heat
Iron and steel manufacture	Cyanide, phenols, thiocyanate, pH, ammonia, sulphides
Coal mining	Suspended solids, iron, pH, dissolved solids
Metal finishing	Cyanide, copper, cadmium, nickel, pH
Brewing	Suspended solids, BOD, pH
Dairy products	BOD, pH
Oil refineries	Heat, ammonia, phenols, oil, sulphide
Quarrying	Suspended solids, oil
Power generation	Heat

Table 3.10(b) Point sources and the expected contamination of groundwater

Source	*Inorganic contaminants*	*Organic contaminants*
Urban areas	Heavy metals and salts	Oil products, biodegradable organics
Industrial sites	Heavy metals	Chlorinated hydrocarbons, hydrocarbons, oil products
Landfills	Salts and heavy metals	Biodegradable organics and xenobiotics
Mining disposal sites	Heavy metals, salts and arsenics	Xenobiotics
Dredged sediment and sludge disposal	Heavy metals	Xenobiotics
Hazardous waste sites	Heavy metals (concentrated)	Concentrated xenobiotics
Leaking storage tanks	–	Oil products (petrol)
Line sources (motorways, railways, sewerage systems, etc.)	Heavy metals, salts	Oil products, pesticides

Figure 3.17 illustrates a much more pressing rural water quality problem, that of the increasing activity of nutrient cycling (in this case nitrogen) which is an inevitable corollary of optimised agricultural production systems. Industry and domestic waste are also implicated, as Figure 3.17 shows, but the major and obvious source illustrated for the developed humid temperate zone is ‘bag nitrogen’ or artificial fertiliser. Nevertheless, the relative role of

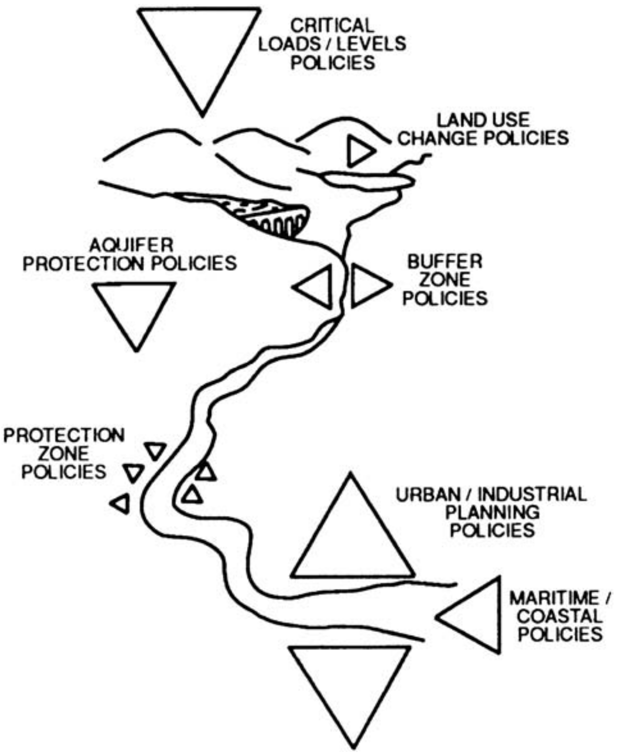
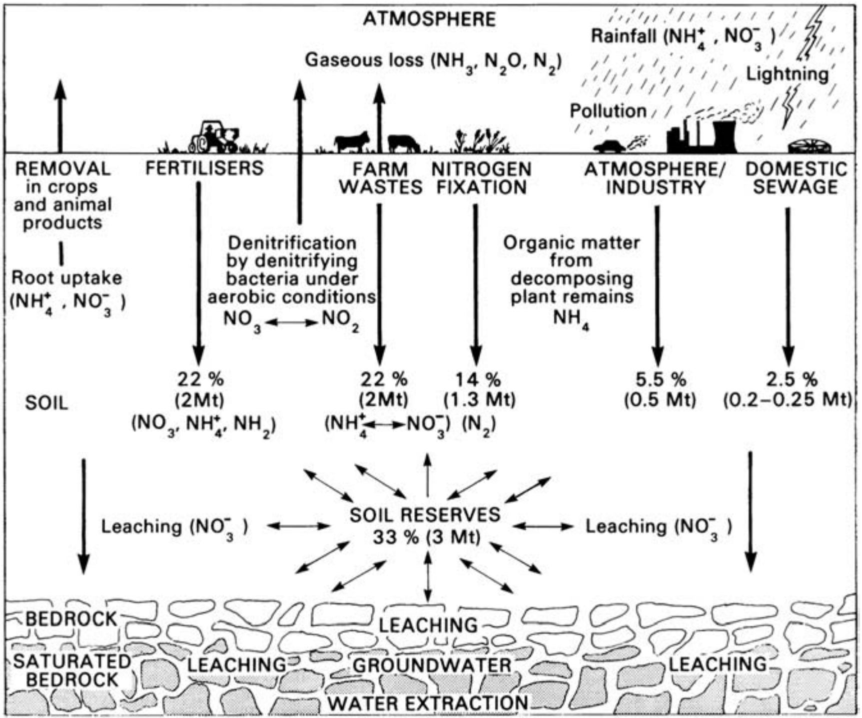


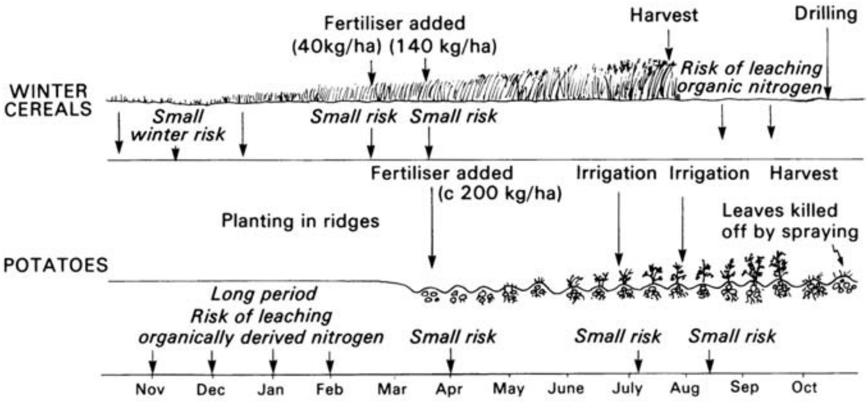
Figure 3.16 A simple typology of planning policies in relation to river and groundwater pollution control.

and time-dependence of fertiliser inputs are not fully understood; Figure 3.17 indicates considerable scope for altering crops, crop patterns or crop cycles to minimise the seasonal mobilisation and loss of nitrate to water courses.

This scope – for encouraging precautionary agricultural practices in respect of nutrients – has been exploited in the UK since 1990. At first, Nitrate Sensitive Areas were demarcated around groundwater sources (35,000 hectares), within which farmers were asked to voluntarily go beyond ‘good agricultural practice’; there was 80 per cent compliance and compensation for profits foregone by the agricultural de-intensification. However, pressure from the European Union then forced a more extensive and more intensive regime to protect drinking water supplies and general water quality against excess nitrate – the Nitrate Vulnerable Zones, designated in 1996 to cover 8 per cent of England and currently to be extended again. Policy remains in flux because of the further demands of the EU Water Framework Directive to protect rivers, lakes, aquifers and the coast from all diffuse pollution (see Chapter 7). Table 3.11 shows the many diffuse pollution pressures identified



Nitrogen is in constant flux in and out of the soil. Part of it enters groundwater, and thus into our drinking supplies. (Figures come from French research.)



Leaching is influenced by the crops grown on the land, climatic conditions and according to the season.

Figure 3.17 The nitrogen cycle for developed land surfaces and the seasonal risk of nitrate leaching for two crops, winter cereals and potatoes.

Table 3.11(a) Diffuse pollution from UK agriculture

Pollutant	*Sources*	*Impacts*
Agrichemicals	Machinery, pesticides, accidental spills, medicines for stock.	Toxic to aquatic species, groundwater and water supply pollution, contamination of stream sediments.
Silt	Runoff from arable land, overgrazing, outdoor pig rearing.	Infiltration of stream gravel beds, filtration needed for drinking water.
Organic waste	Slurry, silage, carcases.	Nutrient enrichment, reduced oxygen in water.
Faecal pathogens	Manure applications, cleaning water.	Health threat to humans.
Nitrogen	Fertilisers, atmospheric pollution.	Eutrophication (see Table 3.11(b)).
Phosphorus	Fertilisers, soil erosion.	Eutrophication (see Table 3.11(b)).

Table 3.11(b) Effects of eutrophication on receiving ecosystems

Effects	*Problems*
Species diversity decreases; dominant biota change.	Human health: toxins produced by algal decay.
Plant/animal biomass increases.	Amenity value of water declines.
Turbidity increases.	Increased vegetation impedes flow and navigation.
Sedimentation increases.	Fish species may die out.
Anoxic conditions may develop.	Water treatment costs escalate.

for regulation in UK agriculture under the WFD, with the pressing problem of eutrophication treated in more detail.

Diffuse pollution from the surface of *urban* areas is a more difficult problem. As Figure 3.18 shows, pollutants collect on urban surfaces such as roads as the direct result of 'normal' urban activity. The British fondness for dog ownership, for example, leads to an annual deposition of 17 grams per square metre of dog faeces which, together with waste oils, litter, de-icing salt and other pollutants, finds its way to streams by virtue of the need to provide efficient road drainage.

An intriguing hybrid form of pollution has tended to dominate research agendas in headwater catchments of North-West Europe and the North-East USA for 30 years now. Wrongly assumed to be a 'problem solved', *freshwater acidification* has as many negative ecological impacts, mostly towards the source zone of rivers, as does eutrophication (mainly downstream). Acidification originates as a largely point-source pollutant in the smoke-stacks of

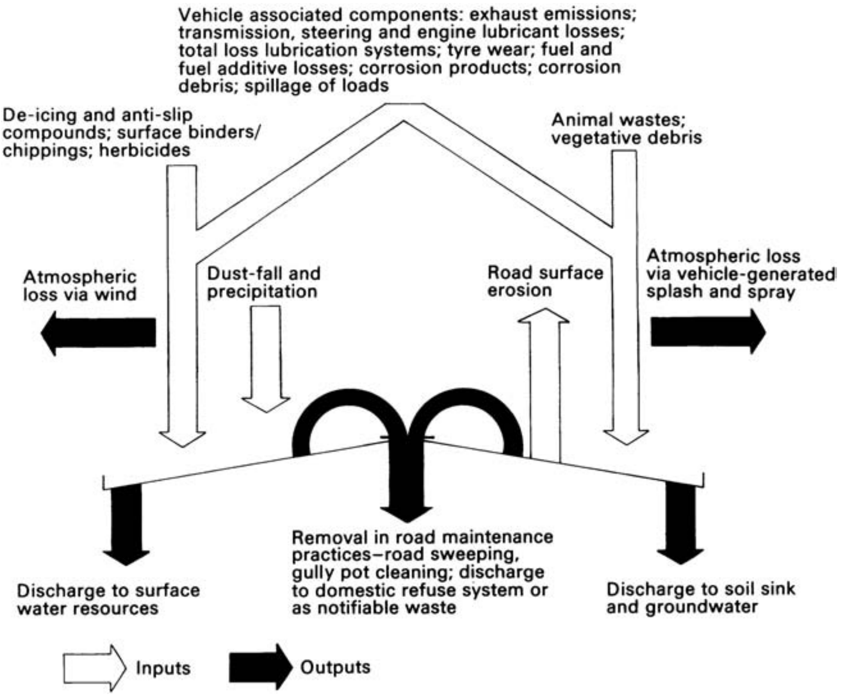


Figure 3.18 Chemical influences on runoff from urban surfaces (Pope, 1980).

coal-burning power stations, though more diffuse sources now recognised include ‘cars and cows’. Close to power plants and in urban areas there is often, quite literally, ‘acid rain’, but this term was to obscure the early research, which as a result tackled damage to buildings and to forest health. ‘Acidification’ implies a much more general environmental phenomenon; for example, we have become alarmed about acidification of the oceans from increased carbon dioxide concentrations in the atmosphere. The power industry steadfastly resisted cleaning its emissions (i.e. a *source* control for the pollution) until the causal chain had been established, during which time urgent mitigation measures such as liming catchments were operated at the *target* end. Sample ecological impacts of stream acidification in the UK uplands are shown in Figure 3.19(b). The decline of pH (i.e. increased acidity) is indicated by a decline in the numbers of a bird species of conservation significance whose food consists of invertebrates. The invertebrates are intolerant of industrially derived acidity which is scavenged from the atmosphere by recent conifer plantations. Liming has proven most popular and most successful in Scandinavia (e.g. Raddum and Fjellheim, 2003), whereas in parts of the UK source controls have made measurable improvements in sulphate and nitrogen loadings (Harriman *et al.*, 2003).

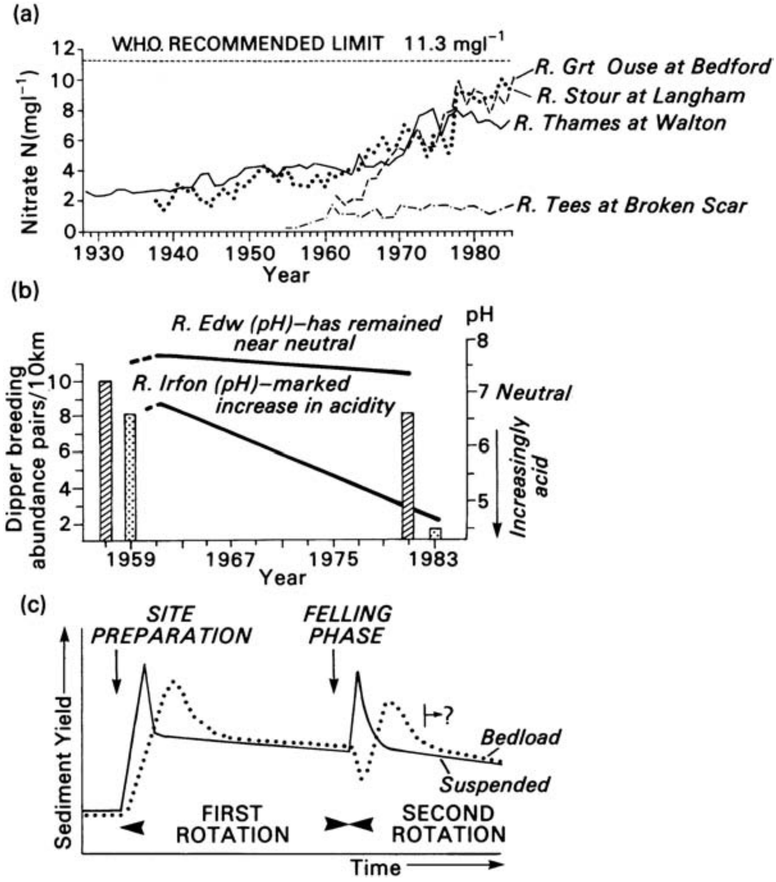


Figure 3.19 Changing river water quality as a result of land use:

(a) Increasing nitrate concentrations in England and Wales (Roberts and Marsh, 1987)

(b) Decreasing pH (increasing acidity) revealed by bird numbers breeding by two streams in Wales; vertical bars refer to inferred pH for the two streams (Tyler, 1987)

(c) Variations in sediment discharge during forest rotation (coniferous plantations, upland UK) (after Leeks, 1992)

The role of upland forest canopies, principally coniferous in the UK, was eventually confirmed as one of (unavoidable, passive) *pollutant scavenging* – often as dry deposition – passing part of the 'blame' to the power generators who implemented source controls. Forest managers, however, began to implement land-management strategies such as leaving 'buffer zones', free of conifers and drainage, adjacent to streams and of planting fewer conifers overall in sensitive locations.

The lie is given to the 'problem solved' myth by recent observations (Kowalik *et al.*, 2007) that episodic acidification (described for a small headwater catchment by Mounsey and Newson, 1995) still occurs from the deposition of anthropogenic non-marine sulphate. Nevertheless, the precautionary actions against acidification taken at many points throughout the source–pathway–target chain are likely to act as a policy model for diffuse pollution control at the catchment scale.

3.5 Conclusions: towards water body 'pressures'

The severe problems of scientific uncertainty encountered in constructing a generalised body of scientific results, operable in river basin management, from a series of mainly small-scale, short-term empirical studies of land-use effects are featured in Chapter 8. Even within the confines of one nation (the UK), catchment experiments have not been deployed to calibrate the hydrological effects of *every significant land use*. New land uses arrive on waves of innovation all the time (e.g. maize growing and intensive pig rearing in rural England). The impacts quantified by catchment experiments have been shown to be partly contingent on where they are performed (e.g. contrasts in forest impacts between Wales and Scotland). In an inexact, environmental science such as hydrology we must at the very least be sure about the errors involved in field studies. As part of 'triangulation' towards a more robust answer the historical dimension (linking historical land-use change to documented or recorded floods) is now being explored (Defra/EA, 2006). Of overriding concern, particularly in the design of catchment experiments, is the requirement that the experimental error attached to the effect being studied is not larger than the effect itself.

The European Union's Water Framework Directive, which we feature extensively in Chapter 7 et seq., configures many of the catchment influences on river quantity and quality discussed in this chapter as 'pressures'. Pressures set up the level of risk of failing to meet the WFD objective of 'good ecological status'. There has thus begun an unprecedented drive throughout the EU to compile, map, extrapolate and model catchment impacts.

The level of investment needed for scientific programmes in this topic means that we remain in ignorance of key relationships in certain types of land-use practice, particularly in the developing world. It has, for example, taken decades before a proper hydrological evaluation has occurred of the growth of eucalypt tree plantations in many regions of water shortage (see Calder *et al.*, 1992, 1997) and of the impact of development in the humid tropics (see Bonell *et al.*, 1993; Bonell and Bruijnzeel, 2005). The humid tropics, like the world's drylands, are in desperate need of hydrological study in advance of rapid urbanisation, de-/afforestation, metal mining and dam building. They constitute nearly a quarter of the world's land area, will soon house a third of its population, have most of the world's uncut forests and most of the unharnessed hydro-electric power, and host much of the planet's genetic riches. An added hydrological component is the critical role of basins such as the Amazon in influencing the water balance of the planet as a whole.

Chapter 4

Managing land, water and rivers in the developed world

An international survey

Geographers and politicians argue over definitions of development, over maps of where it has occurred, is occurring and will occur and over rates of development. However, virtually all definitions imply some form of 'cultural colonialism' by revealing that development is a process and pattern laid down immutably by the 'First World' (Bissio, 1988). We thus need to be aware of 'settler cultures' and their impact on water management and of the humid-temperate climate perspective being woefully, naively applied to tropical and semi-arid developing areas. The trade system directed by world capitalism (a significant part of globalisation) seems to offer international homogeneity; in fact, the field of water projects remains characterised by a 'humid hegemony' of finance and technology transfer. It is useful, therefore, to divide an international 'tour' of land, water and development into two chapters, split by development, although there are also interesting contrasts in both land and water as we 'travel'.

4.1 Development and the river basin

To anyone based in the United Kingdom, a small nation on an island, developed for habitation over thousands of years, the two most startling aspects of river basin development are the *size* of the river basins tackled by both ancient and modern management schemes (consider those shown on Figure 4.1) and the *rapidity* with which technology transfer, through development aid, is now leading to convergence of approaches. Water is experiencing globalisation. Two important new questions then emerge: Are large schemes good schemes? Does convergent technology negate local variation in environment? These cannot be answered until near the end of Chapter 5.

An even more basic question arises as to the precise role of water development in the development process as a whole. In the developing world, the predominating agricultural or primary industrial economy is much more likely to be boosted by deliberate investment in water (Table 4.1). The history of water development in the United States demonstrates that a continuation of government support for 'cheap water', after the initial settler period, leads

Figure 4.1 The world's largest river basins.

inevitably to the low ranking of water as a location factor: 'water follows the plough'. Sustainability arguments and economic instruments for environmental management suggest that pricing drastically influences attitudes to resource use (and hazard avoidance); through the history of 'land, water and development', land has had a market price but water has not.

The basis for a selection of nations in this chapter inevitably involves literature in the English language but also includes the potential for the 'national experiences' of river basin development in the USA, Canada, New Zealand and Australia to exemplify both physical and cultural influences on public policy with regard to rivers. Why is the UK not featured? It is saved for the

Table 4.1 River basin development: prioritising the issues of water-based schemes

	'Developed'		*'Developing'*
Life-permitting	Priorities often domestic and industrial supplies	WATER RESOURCES	Priorities often irrigation and hydro-electric power
	Priorities normally urban centres	FLOOD PROTECTION	Priority is food security
	Major influence associated with property rights	FISHERIES	Subsistence only: little enhancement
	Reacts to 'chemophobia'	POLLUTION CONTROL	Eradication of disease
Life-enhancing	Increasingly	RECREATION	Little known
	Increasingly	CONSERVATION	Little known

longitudinal treatment of institutional issues relating to land and water development in modern times: Chapter 7.

4.2 River basin management in the USA

The USA is essentially two nations in terms of water resource development; although the Mississippi basin (Figure 4.2) appears to integrate a vast internal drainage system, the division between 'humid' and 'dry' America is too profound in terms of history, attitude, law and contemporary problems to be ignored.

The problems of water-based development in the West are well and colourfully documented from the days of the earliest exploration of 'The Interior'. Government finance was used to hold and populate the West against natural hazards and indigenous cultures, making a study of river basins in that region highly instructive. By contrast, in the humid east the water agenda is dominated by issues of industrial planning and environmental protection.

There is also a tension in the cultural and political attitudes to water and other natural resources in the United States. The general 'settler culture' of 'taming the wilderness' remains politically valid, but there is an enduring tension between human liberty and the inevitable constraints of resource management. This latter tension often becomes manifest as rivalry between state and federal bureaucracies and between the many federal agencies with a role in water management (Reuss, 2004 and Table 4.2). Cech (2003) devotes

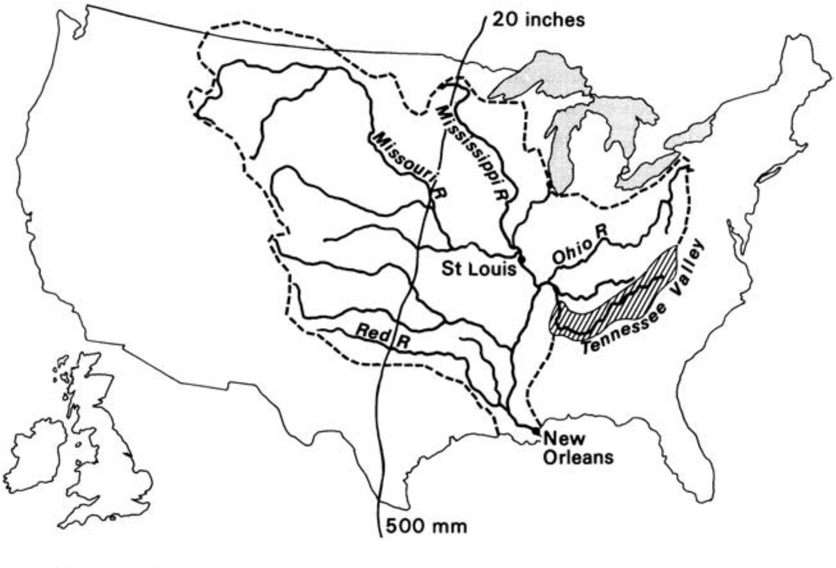


Figure 4.2 The USA, with the British Isles at the same scale, showing the extent and central position of the Mississippi basin.

Table 4.2 American water resources: planners, politicians and constitutional interpretation

Era of American history	*Political syndromes relating to water*
Early days of the Republic	Power and liberty seen as competing; George Washington relied on corporations to bring about public works – no national plans or finance.
Early nineteenth century	Use of money from sales of public lands to fund, for example, Swamp Land Acts (1849–50) for 'reclamation'.
1836	No successful implementation of coordinated public works administration, except through Army Corps of Engineers improving navigation on the Ohio and Mississippi.
Post-Civil War	Many 'Rivers and Harbors' Acts; closer relationship between Congress and Army Corps of Engineers. By 1879 Mississippi River Commission to improve navigation and raise levees.
1902 Reclamation Act	Public land sale profits used to irrigate the West. By 1923 a Bureau of Reclamation.
1917 Flood Control Act	First single-purpose floods Act – role of Army Corps widened to plan navigation, water power, flood control and irrigation for all navigable rivers – 308 reports.
1922	Colorado River Compact (1928 approval for Hoover dam).
1930s	'New Deal' for depressed south-east: the Tennessee Valley Authority.
1936 Flood Control Act	Introduced benefit–cost to flood protection design and construction.
Post-Second World War	Gradual rise of federal funding, but successive presidents attempted to reduce power and then budget of agencies, culminating in Water Resources Development Act 1986 forcing local communities to find 25–35 per cent of costs. Environmental Impact Assessments required from 1969.

Drawn up from Reuss (2004)

two chapters (8, 9) of his book to laying out the roles and responsibilities of federal, state and more localised water management agencies in the USA. Loucks (2003) bemoans the lack of a federal champion for IWRM/IRBM, saying (p. 27), 'Instead of broadly supported regional solutions that identify and address efficient tradeoffs among multiple needs and competing uses, we get more narrowly focused and often more inferior, contentious, uncertain and expensive solutions.'

The tirade against fragmented and ineffective institutional management of American rivers continues with Doppelt *et al.*'s (1993) critique of the whole panoply of US legislation concerning the ecological health of rivers: increasingly 'disconnected' in the view of Wohl (2004). Wohl's book charts the history of the disconnection (and hence decline) of American freshwater ecosystems: the disconnection is principally that between rivers and landscapes rather than that between segments of channels by dams, though these are heavily featured. However, in the decade since the second edition of this book, science-led, evidence-based activity has increasingly permeated river basin management in the USA, often led by grassroots community action but increasingly followed by a large measure of federal coordination and facilitation.

4.2.1 Exploration, exploitation, destabilisation

In 1803 the USA completed the diplomatic coup of doubling its land area by the purchase from Napoleon of Louisiana; 'at four cents an acre' (Cooke, 1973), the opening of an interior for the young nation was a critical development for the president, Thomas Jefferson. We know that by 1804 Jefferson had despatched Lewis and Clark on an expedition, largely routed along rivers, to explore the new hinterland, to survey and to make records of all natural resources (de Voto, 1953).

Whilst Lewis and Clark's three-year expedition contributed an essential knowledge base to the 'Go West' mentality which continues to pervade the USA (*vide* the continued growth of the 'Sun Belt'; see below), a more important journey in terms of water development was that made by the Civil War veteran John Wesley Powell. Powell it was who first spoke of 'reclamation' for the harsh habitats of the West; he favoured a careful and conservational application of damming and irrigating, but the US government reacted slowly. However, in the year of Powell's death (1902) the Reclamation Act was passed by Congress, paving the way for federal intervention in the financing of water schemes in the West. The Mormon settlement of Salt Lake City provided, perhaps, too inspiring a vision of what could be achieved by irrigation. James Michener's epic historical novel *Centennial* (1975) contains abundant factual evidence of the impacts of 'reclamation' on the lives of settlers in the Colorado township which gives the book its name. The development of water resources is at first a private venture, steered by Russian immigrant Brumbaugh; he immediately concludes that the eastern seaboard's law of *riparian rights is* totally inappropriate for his grandiose scheme for diverting water from the River Platte ('too thick to drink; too thin to plough') on to his land so as to convert from an extensive livestock to an intensive arable economy.

The triumph of an alternative, settler-driven code of *prior appropriation* ('first in time, first in right') was not inevitable, because much of the land in the West was in federal ownership; however, the earliest rulings were made in the legacy of mineral rights and a 'gold rush' mentality. The translation to water 'capture' for irrigation was easy under the prevailing political ethos of expansion. Bates *et al.* (1993) quote the Colorado Supreme Court in 1872:

> In a dry and thirsty land it is necessary to divert the waters of streams from their natural channels, in order to obtain the fruits of the soil, and this necessity is so universal and imperious that it claims recognition of the law.

A Secretary of the Interior described irrigation in 1893 as 'the magic wand', and there was a common impression of the climate of the West that 'rain follows the plough'. In fact the outcome was put in doubt. The USA's colonisation of the more extreme climatic zones of its land led in the 1930s to disaster: successive droughts led to the Dust Bowl, which forced millions of farming people to migrate, often to other dry areas without a soil erosion problem.

The prior appropriation doctrine continues to frustrate the transfer of water rights and thus compromises the whole approach to seeking more efficient water use and also to redressing social problems deriving from historical property rights (Gardner, 2003).

4.2.2 The Colorado basin

Reisner (1990) has labelled the Colorado an 'American Nile' because the river, despite its moderate size (Figure 4.3 and Table 4.3), is 'the most legislated, most debated, and most litigated in the entire world' (p. 125). It has the

Table 4.3 Essential data for the Colorado basin, including global indicators

Data/indicator	*Value*
Basin area	703,132km^2
Population density	10/km^2
Urban growth rate	2.1%
Large cities	7
Total fish species	121
Fish endemics	42
Threatened fish species	8
Endemic bird areas	1
Ramsar sites	0
Protected areas	8%
Wetlands	1%
Arid	89%
Forest	23%
Cropland	1%
Irrigated cropland	86%
Developed	8%
Shrub	55%
Grassland	12%
Barren	0%
Original forest lost	43%
Deforestation rate	–
Eroded area	1%
Large dams	265
Planned major dams	–

From Revenga *et al.* (1998)

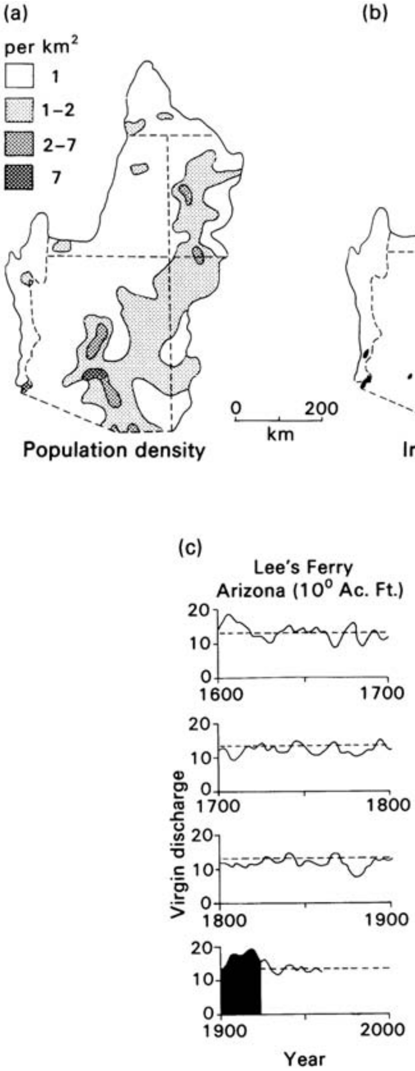


Figure 4.3 Features of the Colorado basin, an 'American Nile':

(a) Population density
(b) Irrigation schemes
(c) Time series of natural ('virgin') discharge, illustrating the wetter period preceding the negotiation of the Colorado Compact (all from Graf, 1985)

largest population and industrial base of other world rivers of a similar level of exploitation and management. It is, in most years, all used, its delta being dry (Graf, 1985).

The waters of the Colorado were first used for a major irrigation project in the Imperial Valley of California in 1901. Dams were built on tributaries from 1910, but by 1922 there was sufficient competition for the relatively modest annual flow of the Colorado itself that the Colorado River Compact was arranged to split this resource between the upper and lower (altitude) states along its steep, often gorge-like course (Table 4.4). The Compact assumed an average flow for the river which was 33 per cent higher than the true value (despite flow gauges set up on the river system since 1895: Graf, 1992), a mistake which works to the disadvantage of an upper basin obliged to deliver a set quantity to Lee's Ferry, the 'hinge' point with the lower basin. The Compact also failed to consider the water entitlements of Indian tribes and did not fully address the water needs of Mexico. There are recent and continuing implications for both errors (e.g. Burton, 1991, on the restoration of Indian rights). In 1928 approval was given for the Boulder Canyon Project in which the Hoover dam was built by 1935. Since that moment, and largely as a result of federal activity (by the Bureau of Reclamation or US Army Corps of Engineers), the river has been comprehensively dammed and diverted, at first to feed the irrigation of high-value arable crops in the south-west but also in the interests of 'high-altitude irrigation' (mainly for livestock farming) in the upper basin; clearly, the result of federal projects is cheap water. Reisner (1990) remarks that 'in the West water flows uphill towards

Table 4.4 Summary of Colorado River Compact components

Date	*Component*	*Actions*
1922	Colorado River Compact	Divided basin into upper and lower to allocate water resources.
1928	Boulder Canyon Act	Authorised Hoover dam and All-American Canal to Imperial Valley, California facilitating Compact of 1922.
1938	Rio Grande Compact	Allocated Rio Grande waters between Colorado, New Mexico and Texas.
1944	Mexico Treaty	Allocated international waters – USA and Mexico in the case of the Colorado.
1948	Upper Colorado River Compact	Allocations between upper basin states previously approved in the Compact.
1956	Colorado River Storage Act	Authorised construction of Glen Canyon and three other dams on the Colorado.
1963	*Arizona* v *California* legal action	Dispute resolved: judged that Boulder Canyon Act and what followed complied with Compact.
1968	Colorado River Basin Act	Authorised Central Arizona Project.
1970	Coordinated operation of reservoirs	Criteria agreed to coordinate long-range storage of diminishing available water.
1974	Salinity Control Act	Set upper limits of salt content for Colorado waters supplied to Mexico: 115 parts per million.

Adapted from Rast and Holland (2003)

money' – and in this case the money is that of the taxpayer or of those paying for the expensive electricity produced by the dams. Graf (1985) likens the Colorado to 'the world's largest plumbing system' because of the dams.

In the lower parts of the Colorado a continuing battle occurs between California and Arizona over rights to the Colorado. Growth of the 'Sun Belt' continues and puts further pressure on the entire Colorado resource system; the gambling 'oasis' of Las Vegas is approaching its carrying capacity in terms of water supply from mining of groundwater and a feeder from the Hoover dam (Poyner, 1998). Graf (1985) undermines the basis of allocating the average flow of the Colorado between competing states on the grounds of a number of natural instabilities in the basin. There is inherent climatic variability in the south-west USA, the result of oscillating positions of the jet stream (Figure 4.3(c)). For example, the period for calculating discharge averages prior to the Compact was wetter than long-term figures now available; the 1940–60s, a period of the urbanisation of floodplains, were largely flood-free. As Graf puts it, 'Planning for variability rather than for averages is therefore the most likely route to success' (p. 154). Despite these problems, Graf asserts that 'a factor common to the ancient and modern approaches is a perspective on the river basin as an holistic entity, a complex grouping of individual parts that function together' (p. 3).

In 1986 the US Bureau of Reclamation commissioned an environmental assessment of Glen Canyon dam (built in 1964) and its operating rules. Significantly, one of the recommendations was that future research should 'use an ecosystem perspective to avoid the isolated implementation that has created problems in the past'. Concluding the symposium at which the assessment was presented, Leopold (1991) stressed the need for interactive management of the Colorado in view of its inherent changeability, for more data collection and monitoring and for different management scenarios to be explored to give flexibility in response. Geomorphology has much to offer the restoration of the Colorado's fish habitats. Papers by van Steeter and Pitlick (1998) and Pitlick and van Steeter (1998) stress the morphological changes of the last half-century and the degree to which joint management of channel capacity and flows sufficient to transport sediment can be used to this effect.

In March 1996 an artificial flood was released from Glen Canyon dam to redistribute channel sediments through the Grand Canyon, re-establishing bars and shoals 'lost' since the regulation regime from Glen Canyon began. The impacts were mediocre (e.g. those reported by Speas, 2000), decorating rather than rebuilding sedimentary features and not rehabilitating threatened fish species: a *series* of spring floods might do more to restore the fishery. Instead, the federal government, together with the states of California, Arizona and Nevada, has adopted a 50-year plan to support native wildlife through creating 8,130 acres of riparian habitat along a 400-mile leg of the Colorado between Lake Mead and the Mexican border.

4.2.3 The Tennessee Valley Authority (TVA)

Given the enduring political legacy in the Colorado basin of the 'settler culture' (uncoordinated, often unregulated exploitation, creating environmental damage such as fish extinctions), it comes as a surprise that another US river basin became managed under an institution which has been much imitated in the developing world. The USA has no cultural appetite for such bodies (see below). Reuss (2004) gives a clue to the TVA's origins when he writes 'Only as a last resort, and then with resignation, not enthusiasm, as during the Great Depression, do Americans turn to the national government to solve their problems' (p. 51).

The Tennessee River is a tributary of the Ohio, itself a tributary of the Mississippi which occupies half of the continental USA (Figure 4.2). The Tennessee is itself huge, making up an area 80 per cent that of England and Wales, with a flow which is 24 times that of the Thames or 70 per cent that of the Nile. A hydro-electric power dam, on the River Tennessee at Muscle Shoals, was to be the first act of the TVA, a powerful river basin institution set up in 1933, charged with both land and water management, which President Theodore Roosevelt called 'a corporation clothed with the power of government, but possessed with the flexibility and initiative of a private enterprise' (Palmer, 1986, p. 34). As Palmer writes, 'New dams were at the cutting edge of the TVA and the national attitude about rivers was reflected and shaped by the agency.' Later, President Truman tried to create similar authorities for the Missouri and Columbia rivers but Congress refused. The dams on the Tennessee (nine major sites) and on tributaries (42 sites) created a longer lake shoreline than on the Great Lakes; however, despite the heroic achievements of this conservation scheme (in the sense of the word 'conservation' in vogue at the time), it has been much criticised.

Chandler (1984) points out that the costs were far more than the $1.5 billion spent on capital schemes: 10 per cent of the Valley's best farmland was drowned and most of the benefits of flood control were enjoyed by a single city – Chattanooga. Saha and Barrow (1981) dismiss the TVA as 'a massive electricity generating utility' and have drawn attention to the use of that power for polluting activities such as fertiliser manufacture and to the subsequent generation by the TVA of coal-fired and nuclear power. The availability of local power has, however, led to a regeneration of regional prosperity; the navigation improvements built into each dam scheme have also aided the connectivity of a 'backwoods' area (originally isolated by the 37-mile-long rapids at Muscle Shoals).

The TVA pioneered soil and water management because of its approach to erosion control; 'watershed management' was a term first used there, and an agency spawned by the approach – the US Soil Conservation Service – was to have a major influence throughout the world, often by reversing TVA scales of operation and concentrating on small dams and on-farm techniques. The reach of the TVA, via government agencies, to farmers has been impressive by way of:

(a) land reclamation from gullying;
(b) soil conservation;
(c) use of fertilisers (many produced at Muscle Shoals);
(d) demonstration farms – crop diversification;
(e) cooperatives for marketing.

In a recent review of the environmental effects of dams, Brown and Shelton (1983), both employees of the TVA, strongly support the record of their dams in making the Tennessee River 'one of the most useful in the world' (p. 139). However, they also admit to problems in responding to 'environmental and societal effects in the planning and decision-making process (p. 150). Feldman (1991) points out that the TVA continued to promote dams (such as Tellico – see below) in the 1960s 'even though few economic or environmental justifications could be offered'.

4.2.4 Dams and development in the USA: from solution to problem

Graf (1999) reports a census of US dams, deriving a figure of *c.*75,000, storing *c.*5,000 cubic metres for each person; the data are then mapped and given time-lines of construction by region. There may in fact be as many as 2 million structures capable of impounding water. Palmer (1986) describes the USA as having a 'culture of rivers, free-flowing and luxuriant with habitat', an attitude which, whilst latent throughout the twentieth century, peaked in the successful campaigns to prevent dams in Grand Canyon and the Green River Canyons in the 1960s. He sets up a chronology of river abuse up to this time, including the activities of the US Army Corps of Engineers in the East through their flood-control dams as well as the irrigation schemes of the Bureau of Reclamation in the West. Conservationists had begun to oppose dams in the celebrated Hetch Hetchy of Yosemite National Park; at this stage they faced other conservationists who interpreted the term as meaning careful, rational exploitation of resources (American civil policy enshrined this latter definition throughout the early years of the twentieth century). The protests failed; in 1908 the Hetch Hetchy dam was approved.

However, environmentalism grew stronger in the 1960s and 1970s, and the new spirit had an unexpected outcome in the case of the Tellico dam, proposed for the Little Tennessee by the TVA in 1966 but delayed by protests from fishermen; in 1973 a zoologist discovered a rare fish, the snail darter, in the river near the dam site and it was placed on the 'endangered species' list. Progress on the dam was halted but, despite an excellent case against the dam for many other reasons (President Carter had long opposed dam construction), the conservationists' case based on the snail darter was lost and the

Tellico dam was completed. By 1968 the National Wild and Scenic Rivers Act extended protection for eight rivers, with a reserve list of 27; Doppelt *et al.* (1993) describe the Act as 'more doughnut hole than doughnut', offering as it does compromises with developers and protecting less than 2 per cent of US rivers. The Act prohibits dams or other federal projects which would damage listed rivers; the list has been extended through the surveys of the Department of the Interior. In the State of the Union address of February 1997, President Clinton designated ten rivers (later extended to 14) as 'American Heritage Rivers' in an attempt at more holistic treatment to 'integrate the economic, environmental and historic preservation programs and services of federal agencies to benefit communities engaged in efforts to protect their rivers'. To replace existing legislation, Doppelt *et al.* (1993) demand a federal lands watershed management Act as well as a national riverine and riparian conservation Act.

Another long-running act of contrition about the impact of dams in the USA has been the effort to restore the migratory fishery on the Columbia River in the north-west. The Columbia Basin Project – irrigation and power dependent originally on the Grand Coulee dam – created enormous national (federal) pride by creating employment during economic depression. The system now has 66 major hydro-power dams and barrages, the power-base of the region's economy but one which has, since 1933, ruined the rights of both Native Americans and sport fishermen to catch the river's fish, including the indigenous Chinook salmon (Ortolando and Cushing, 2002). Salmon and steelhead became protected under the Endangered Species Act of 1973. In 1980 the North-West Power Planning Council was formed to mitigate some of the barrier and regulation effects of the dams; progress has, however, been slow enough for environmentalists to invoke the Act for the salmon, and there has been territorial litigation by Indian tribes. The work of an Independent Scientific Group of the Council is described by the authors gathered by Williams (2006), but the Columbia's 'plumbing' has also been critiqued by campaigning authors such as Harden (1996) and Palmer (1997). The Columbia River crosses the boundary with Canada, and Hume (1992) has listed the objections of Canadian environmentalists to the river's dams. Lee (1993) devotes a chapter to the Columbia because it was his service on the North-West Power Planning Council that provided much of the empirical, pragmatic evidence of the need to deliberately integrate science and politics for the environment.

Thirteen different salmon and steelhead groups listed under the Endangered Species Act are impacted by the 14 federal dams in the Columbia River basin. In the Snake River, coho salmon were declared extinct in the 1980s; this and other threatened species generate billions of dollars of environmental *goods*, whilst their main *service* is to be a keystone species in the ecosystem including wolves, bears, chipmunks, otters and fish eagles. There have been serious proposals to decommission dams on the Snake, but the Army Corps of Engineers prefers to improve fish passage and hatcheries and to make other wildlife habitat improvements around the four major problem sites. Given the serious climate change predictions for the West, Barnett *et al.* (2004) suggest that some salmon species may become extinct in the Columbia system regardless of any current or future water policies.

Another problem with the American proclivity to dam building has been the relatively scant attention paid to *safety*, despite the excellence of the national standing in hydrological research. Shuman (1995) reveals that the current focus for dam-related environmental impact studies is the *removal* of dams which have served their purpose, are unsafe or have had undesirable effects on migratory fish (e.g. dams on the Elwha River in Washington state). Shuman lists six dam removals between 1962 and 1992 and four current proposals. The dam removal campaign in the United States attracted some influential advocates, like Bruce Babbitt, US Secretary for the Interior, and on his 'sledgehammer tour' he made calls to move beyond the removal of relatively small, often hydro-power, dams to those whose removal might have much bigger, system-wide, impacts on freshwater ecosystems:

> In some cases the best prescription for river restoration is simply to tear down the dam that is causing the problem. Last December I took a sledgehammer to the Quaker Neck dam on the Neuse River in North Carolina. As dams go, the Quaker Neck isn't much: it's only six feet high and it doesn't generate much power. But to the American shad trying to spawn upstream that six feet might as well be six hundred, blocking off 900 miles of upstream spawning waters.
>
> (Babbitt, 2000, p. 11)

Given the high levels of uncertainty about the immediate and longer-lasting impacts of dam removal, the Heinz Center for Science, Economics and the Environment has coordinated the evidence to permit a precautionary approach as dams reach the end of their safe lifetime or economic utility. Dam removals can be controversial, and sediment-related problems from the release of stored silts can also have environmentally harmful impacts (Heinz Center, 2002; Graf, 2003).

4.2.5 The rise of land-use issues in US river basin management

It is typical of water management in a developed nation that there have been resources to put into data collection for monitoring and research. Ffolliott *et al.* (2002) offer a 'retrospective' on the results emerging from this work in the last 50 years (whilst making the point that transformation to 'tools and technologies' involves another process). The research catchment programme is very active in the USA; the United States Geological Survey (the primary government agency for hydrology and geomorphology) participates largely through involvement with state water resource institutes. Additionally the

US Department of Agriculture, especially the Forest Service, carries out its own research into farming and forestry effects. Because such agencies also own and manage a large amount of land there is a good deal of immediate practical benefit from land-use hydrology. However, as a recurring theme, we see American political culture seemingly unwilling to depart from the individual freedoms of the settler culture, and the creation of institutions to manage land in relation to water has proved very difficult.

The ill-fated National Water Commission (1968–83) carefully considered the benefits of the land-use management option in a national water resource strategy (US National Water Commission, 1973). The core issues listed by the Commission were:

(a) forest and brush management, critical because of the 1,000 mm average rainfall of the US forests (cf. 610 mm on other land uses): there is a strong case for a 'joint product' (timber and water) from, for example, the sub-alpine forests of the Upper Colorado;
(b) phreatophyte management, already referred to in connection with the Colorado but constituting 6.5 million hectares in the south-west;
(c) management of snow packs by vegetation (largely forest) management: in Colorado 20 per cent of the state's water resources come from snow, and in California the proportion stands at 51 per cent;
(d) soil surface treatments to improve runoff characteristics.

In a move to revive interest in catchment management, Satterlund and Adams (1992) assembled a guide, *Wildland Watershed Management*, essentially a headwater hydrology manual, from which Figure 4.4 is taken, to show the proven water resource values of brush management in semi-arid Arizona and the importance of patterns of land management in felling forests to increase runoff. The explanation of the effect of these patterns lies in the fact that interception losses from forest canopies require ventilation around the edge of the canopy – the more edge the greater the losses during and after rainfall. In another formative publication, Bates *et al.* (1993) entitle their recipe for a fundamental re-think of policy *Searching out the Headwaters: Change and Rediscovery in Western Water Policy*, concluding that 'the test of the principle of ecology should be applied, together with the principles of conservation and fair distribution'. As an example of the basin-scale research projects encouraged in the West by this new approach, Inyan and Williams (2001) set up a landscape ecology GIS to guide headwater protection policy in the San Miguel basin, Colorado.

At a national scale, the production by the National Academy of Sciences and National Research Council of a series of reports, including *New Strategies for America's Watersheds* in 1999, is very influential indeed. Under a heading 'Why watersheds again?' (p. 31), the report suggests:

- frustration with the fragmented 'command and control' approach;

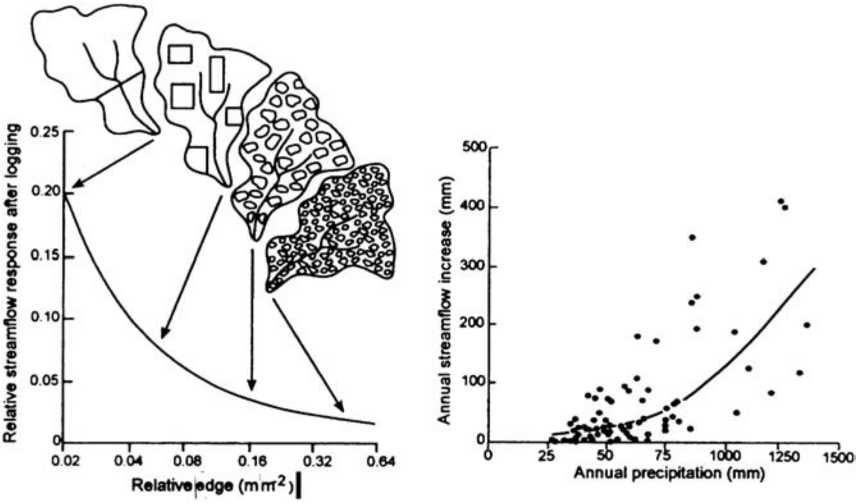


Figure 4.4 Detailed canopy management and streamflow response in the USA (after Satterlund and Adams, 1992):

(a) Pattern of tree cover removal (25 per cent removed) and streamflow response
(b) Removal of brush cover on semi-arid watersheds in Arizona and streamflow response

- significant political change with devolution to 'nonfederal entities';
- tight budgets for environmental management and the need for cost-effectiveness;
- integrated planning beginning to demonstrate success in other sectors;
- realisation that decentralised water economics can be an effective alternative to centralised allocation.

Nevertheless, the report still points at bureaucratic dysfunctionality as a major obstruction, with 19 federal agencies alone covering 15 river basin functions. Perhaps it is just as well, therefore, that NGOs like River Network (founded in 1988), its River Smart project for public education and the Center for Watershed Protection with its urban, forestry and river restoration tool boxes have taken the overview, advisory (BMP) position amongst so much federal overlap and competition. The Center's evaluation of the impacts of impervious surfaces represents a very comprehensive review of the relationship between development and water quality (CWP, 2003), allowing it to develop a simple impervious cover model and to grade the strength of evidence for negative impacts on 26 categories of stream quality. Accessible information such as this makes large contributions to the acceptance of public participation in US catchment management (Creighton, 2004). Direct action to detect and prosecute polluters also occurs through the 'Waterkeeper' organisations which now keep watch, often with their own patrol boats, on 155 US water bodies. Lant (2003) charts the rise of new issues in the management of American rivers that, whilst guided by changes in emphasis by federal agencies, are being made operational at grassroots level by NGOs and the use of economic incentives. Doppelt *et al.* (1993) saw localisation as inevitable, given the ineffectiveness of federal bureaucracy, notably the Wild and Scenic Rivers legislation (Oregon developed its own state Act).

4.2.6 Severe floods and their impacts on water policy reform

Since the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973 a major change of approach to land use has occurred in relation to floodplains. One-sixth of all urban land in the USA lies within the 100-year flood line. Since the 1937 Flood Control Act the federal government has spent $25 billion on structural flood control works, but annual flood losses now amount to $2 billion. Flood-prone communities in the USA are encouraged to practise land-use regulations under the National Flood Insurance Program, introduced in 1968 but amended in 1973 and 1994 (Muckleston, 1990; Burby, 2001); after defining the hydrological risk from maps, developers insure against damage through coordinated national rates of commercial premium. The federal government is allowed to purchase land with persistent flooding problems, rather than protect it at great expense and to the detriment of downstream settlements. In this case the federal influence has been too gentle in the face of state, community and private involvement; the results can often be unintended via statistical uncertainty or deliberate exploitation of loopholes (Burby, 2001). Montz and Gruntfest (1986) claim that the Flood Insurance Act has only worked well where success is easiest; flood damage continues to rise, and floodplain encroachment has not been halted in growing urban areas. Here is a real case for a single authority at the basin scale; possibly the Mississippi floods of 1993 and Hurricane Katrina (which devastated New Orleans in 2004) will encourage such an approach for the nation's most important river.

Prince (1995) reports the devastating flood on the Mississippi during July and August 1993; peak flows were the highest on record at 42 gauges and in excess of the 100-year recurrence interval at 46. The loss of life totalled 48 (Table 4.5), 42,000 homes were destroyed and 21,000 square miles went under water. Federal expenditure after the flood totalled $4.2 billion; damage insured reached $10.5 billion and crops lost $6.5 billion. 'Verdicts' on the flood pointed to the implications of the almost total loss of wetland flood storage in the upper basin (Illinois, Iowa) and to the impact of stream channelisation. Almost half of the Corps of Engineers' 229 'federal' levees were overtopped, bringing the Corps to the view that the lack of a comprehensive

Table 4.5 The 1993 Mississippi flood: flood damage statistics

State	*Flood-related deaths*	*Property damage ($ million)*	*Agricultural loss ($ million)*
Minnesota	4	51	865
North Dakota	2	100	420
South Dakota	3	26	725
Iowa	5	1,250	450
Nebraska	2	50	292
Kansas	1	160	434
Wisconsin	2	101	800
Illinois	4	930	565
Missouri	25	2,000	2,000

Source: The Flood of '93, Associated Press, New York

floodplain plan for the upper Mississippi basin results in a wasted investment. As one American engineer put it, 'The river owns the land. We should not forget that fact. When we do it targets our error.' Pitlick (1997) is, however, cautious about inferring land use as a direct cause: this was undoubtedly the rarity of the rainfall. Pitlick considers that the land-use factor diminishes in importance as the magnitude of flooding increases and as we move downstream in any basin, quoting simulations for the 1993 flood of both a 'natural' Mississippi floodplain and restored wetlands throughout the basin. The facts, however, meant less than the growing myth of the prime importance of catchment land use. According to Pitlick, there is considerable justification for restoration, but for 'legitimate economic and ecologic reasons'.

Following the badly managed Katrina disaster, there are very big issues to debate over the sustainable future of Mississippi management. Whilst the uncoordinated plethora of levee authorities offers a clear institutional challenge (given the culture of US administration), the uncertainty over desirable hydrological and geomorphological responses to a sinking river estuary and rising sea levels creates a bigger dilemma. One current proposal is that the Mississippi in Louisiana should be allowed to re-meander across its floodplain beyond the levees, thus acting as flood and sediment storage. However, the sediment flux is already substantially reduced by trapping in 29 upstream dams, reducing the capacity for floodplain, estuarine and coastal wetland renewal. Rodrigue and Wright (2003) champion the lower Mississippi alluvial valley 'bottomland hardwood forests' as a target for functional wetland restoration in four states; incentives to farmers have already delivered 121,000 hectares to conservation uses under the Wetland Reserves Program. Coastal and estuarine wetlands have also been decimated by commercial expansion of the Mississippi delta; reinstatement is a cheaper form of protection against storm surges than levees, offering a one-foot flood level reduction for every square mile of wetland restored.

Wetlands in general have been a victim of 'progress' in the United States. Fletcher (2003) cites successive Swamp Land Acts, from 1850, as the origin for most of the more than halving of the original area. Wetlands became protected under fisheries legislation which succeeded in curtailing the excavating and dredging activities responsible for 'reclamation', but, by 2001, 34 states had their own wetland protection laws. Developers are required to engage in 'wetlands mitigation banking' in which any loss of ecological services lost in the developed location are replaced in another. However, whilst the principle is forward-looking, the model is simplistic, with no actual evaluation of the value of services involved (Ruhl and Gregg, 2001), another example of the difficulties of 'hands-off' environmental regulation via the private sector.

The momentum for river restoration has been growing too, with the US government spending more than $1 billion per year on this activity since 1990, not including huge projects like Everglades wetland restoration. The wetlands of the Kissimmee River in Florida, whose channel and floodplain wetlands were severely damaged by the Flood Control Project of 1954, are now being restored at a cost estimated at between $280 million and $420 million (Wohl, 2004), part of the overall Everglades restoration budget of $7.8 billion.

4.2.7 Land-use planning in river basin units

There have been several phases of interest in river basin planning authorities subsequent to the Colorado Compact in 1922 and the Tennessee Valley Authority in 1933. The Water Resource Planning Act 1965 (Black, 1982) established river basin commissions as much more proactive in planning; these paid the penalty of being recommended by the National Water Commission as 'new and unique regional institutions', and clearly regional institutions figure very little in American policy. Feldman (1991) considers that a fundamental constraint on the work of the National Water Commission was that it was expressly forbidden to consider interbasin transfers of water because this would have created an environment in which interstate, basin-wide authorities were inevitable.

However, there are other river basin compacts between states where the federal government is also involved, e.g. the Delaware River Basin Compact (DRBC) (see Majumdar *et al.*, 1988). The Commission which administers the Compact comprises the governors of Delaware, New Jersey, Pennsylvania and New York (which has created 90 per cent of the water storage capacity as dams in the upper basin), together with the Secretary of the Interior. Patrick (1992) considers that the DRBC has had major successes in cleaning up water quality in the Delaware estuary – largely through using a system of tradeable permits to discharge pollutants up to the point where 90 per cent of the water's natural capacity to dilute and disperse is utilised. However, the DRBC has failed to reconcile differences in the planning styles and structures, e.g. between New Jersey and Pennsylvania (Polhemus, 1988).

Whilst California has watershed planning systems to coordinate the work of agencies in support of the State Wild and Scenic Rivers Act (Watson, 1980), other states have not followed suit, and the other examples of basin planning are either urban or part of the brief of interstate and interagency planning for large basins (see below). One exception is in Oregon, where there are Watershed Councils, supported by the Oregon Watershed Enhancement Board, and acting to pool knowledge and resources to create and maintain healthy watersheds in support of thriving communities and vibrant economies (Hibbard and Lurie, 2006).

There is clearly plenty of scope for land-use control, given the very large range of evapotranspiration rates in the USA (see Table 4.6), but in practice most of the compliance by land owners and managers is coming from the threat of pollution legislation rather than from proactive rural planning. It may well be that concerns with water quality will be paramount in driving river basin management policy in the USA towards further basin-wide authorities. As in Europe, there is a new offensive to regulate diffuse, i.e. basin-wide, pollution, and innovative measures and tools designed in the USA are becoming adopted elsewhere (Box 4.1). Americans are sophisticated

Table 4.6 Measured evapotranspiration rates reported for phreatophytes and other riparian vegetation in the south-western United States

Species	*Rate (mm water per year)*
Bare Ground	640–810
Phreatophytes	
Cottonwood	1,540–2,480
Mesquite	1,014
Tamarisk	340–2,800
Willow	770–1,390
Shrubs	
Arrowweed	2,440
Fourwing Saltbush	1,090
Grasses	
Bermuda	1,070–2,760
Blue Panic	1,240–1,330
Alta Fescue	1,820
St Augustine	1,660
Alkalai Sacaton	430
Saltgrass	540
Crops	
Alfalfa	1,750–2,130
Barley	300–1,120
Cotton	650–1,050
Wheat	660–1,120

Source: Graph (1985)

Box 4.1 Regulatory approaches to diffuse pollution in the USA

The focus of most controls for non-point (diffuse) pollution is rural. 'Best management practices' (BMP) for forestry activities were instituted by amendment to the Federal Water Pollution Control Act 1972 ('Clean Water Act'). BMP procedures link pollution or other damage hazards to slope angle and distance to streams (McClimans, 1980).

Watershed management principles have since gained widespread acceptance as a tool in the control of water quality – particularly of non-point pollution – in the USA. The US Environmental Protection Agency (USEPA) requires states to establish water quality standards appropriate to a designated river, lake or estuary use and to enforce limits on deterioration using total maximum daily loads (TMDL), e.g. for silt and agricultural chemicals (Logan *et al.*, 2005). USEPA (1986) has divided the nation into 76 'ecoregions', representing statistically significant combinations of natural controls on water quality. State quality control programmes then monitor the physical, chemical and biological background quality of indicator watersheds in order to set local standards. In some states (e.g. Illinois) homogeneous land uses receive similar monitoring. The Illinois study tabulated the characteristic pollutant loads contributed from each major land use (Polls and Lanyon, 1980).

Papers outlining the new theme, notably the role of biological assessments of freshwater ecosystem health, are brought together by Roesner (1997). In some respects the traditional sensitivity of US land-management policy to issues of *soil loss* creates appropriate regulatory routes towards dealing with all diffuse (NPS or non-point source in US parlance) pollutants. For example, the Conservation Reserve Programme, set up in 1985, can be used to promote riparian land 'retirement' or the conservation and recovery of wetlands (Lant, 1991).

USEPA retrospectively publishes annual monitoring reports; the top causes of river impairment in 2000 were siltation, nutrients, bacteria, metals and oxygen-depleting chemicals. Only 19 per cent of the total river length was surveyed that year, with 39 per cent of that sample being 'polluted'; prime causes were identified as agriculture, flow modification and channel modification. There is also a problem, shared with much of the developed world, of an ageing infrastructure of wastewater treatment and stormwater overflows via sewers. Whilst there is a large degree of subsidiarity in the fixing of TMDLs by states, arguments and litigation still occur with the federal Environmental Protection Agency, with one senator describing the situation in Arkansas as follows: 'Today's signing of the final TMDL rule is a slap in the face for Arkansas farmers, business owners and private landowners. The White House has gone too far in their zeal to overregulate.' Despite this litigious environment, the EPA's ecoregion, BMP and TMDL approaches have spawned a new spirit of collaborative watershed management (Blood, 2003; Sabatier *et al.*, 2005).

consumers, followers of diets and fitness routines; this may help explain why the poor quality of New York's public water supply has driven a spectacular basin management response from the city authorities (Pires, 2004). The Catskill/Delaware system, with six major reservoirs, delivers 90 per cent of the city's water (1.3 billion gallons) but has been severely impacted by agricultural runoff and discharges from wastewater treatment plants (sewage works). Faced with a major new investment (cost $6 billion plus $300 million annual running costs) to treat the 'raw' water, the city decided, instead, to acquire and manage land in the catchment, restoring streams, managing farms and promoting sustainable forestry (this is a humid catchment, not short of water quantity). The second option is estimated to cost $1.5 billion (Salzman *et al.*, 2001).

4.2.8 Cultural, political, legal attitudes

It may be that the 'regulatory crisis' (Gandy, 1997), which led the New York authorities to taking an environmental, basin management approach to water supplies, represents a flagship trend in American politics; however, there is a big backlog of resistance in the federal system. How can the USA now escape from the grip of an attitude to water management that led to the unsustainable situation west of the Mississippi?

Worster (1992) describes three stages of the growth of unsustainable water-based growth in the American West, beginning with the Mormon settlement of Utah (1847: 'incipience'), boosted by the Bureau of Reclamation (1902: 'florescence') and finally 'empire' from the 1940s onwards when 'the two forces of government and private wealth achieved a powerful alliance, bringing every major western river under their unified control and perfecting a hydraulic society without peer in history' (p. 64).

It will be extremely hard to break the law of prior appropriation in the West. Even though the law allows rights to be established only to the extent of 'beneficial use' of the water abstracted (Gangstad, 1990), only the most profligate uses are frowned on by the courts (Bates *et al.*, 1993, quote the use of a river to flood a field in order to drown gophers as being non-beneficial use). The *sale of water rights* is perhaps the major way in which current patterns of water requirements can be represented in property rights, but it gives no guarantee that ecological uses of water will be respected, other than in wild and scenic rivers.

Not just surface water resources are involved. The Ogallala aquifer underlies the High Plains between South Dakota and Western Texas. From the close of the Second World War, in an era of cheap energy, its waters have been pumped on to the drought-prone lands; by now, as Reisner (1990) puts it, the aquifer is overdrawn by an amount equivalent to the flow of the Colorado. Groundwater protection and management are likely to be high on the agenda of US water management policy-making in the next decade (Figure 3.10 in our review of groundwater protection). Glennon (2002) maps the proportion of the population of each state using groundwater for drinking water: in the West this ranges from Colorado (22 per cent) to New Mexico at 90 per cent and Idaho at 96 per cent. He describes, with case studies, the 'Water Follies' perpetrated during the development of water supplies across America. Already 27 states have statutes allowing intervention to control 'groundwater mining' but, significantly, those states with a large irrigation need have relied on a 'good neighbour policy' amongst local users (Bowman, 1990). In New Jersey, by contrast, the state has a groundwater strategy, targeted at pollution control as well as water resource allocation (Whipple and Van Abs, 1990). Florida's groundwater supplies are increasingly threatened by salt-water intrusion as sea level rises and the coast retreats; over-pumping then creates a favourable gradient for the inflow from the sea. Of Florida's 16 million residents, 93 per cent depend on groundwater for their drinking water; desalination is an attractive option, despite its energy costs, and the state has become the leading source of desalination membrane plants in the world.

Average public and domestic water use in the USA remains extremely high at over 350 l/person/day when the water is privately supplied and almost 480 l/person/day under public schemes (illustrating the effects of costs and pricing). Given the severity of droughts in the USA from the 1980s, the discrepancy between supply and demand in some regions is likely to grow; perennial drought may be the 'natural' climate for the West, with the twentieth century a more humid 'blip'. Under present trends in rainfall, Glen Canyon dam may cease generating electricity very soon, with precipitation declining further by 10–25 per cent by 2050; reduced and retimed snow packs on the Rocky Mountains are of particular significance (Service, 2004). Climate change studies in the USA (see also Chapter 6) are targeting the Colorado basin and stressing the differences between climate drivers for the upper and lower divisions established under the Compact (Balling and Goodrich, 2007; Meko *et al.*, 2007). Droughts in the two parts of the basin are seldom synchronised, and the climate of the upper basin cannot be predicted from a knowledge of periodicities like the Pacific Decadal Oscillation. Barnett *et al.* (2004), introducing a significant collection of climate change projections, found 'the fully allocated Colorado system to be at the brink of failure, wherein virtually any reduction in precipitation over the Basin, either natural or anthropogenic, will lead to the failure to meet mandated allocations' (p. 7).

Demand management is not going to be popular, even though per capita demand has dropped by 25 per cent from its peak in the 1970s according to the United States Geological Survey, largely through greater efficiency of supplies to new developments. However, supply management is not dead! The most extensive water scheme of all for the western USA remains a gleam in the eyes of dam builders; the North American Water and Power Alliance (NAWAPA) was devised by a Los Angeles water and power engineer in the early 1950s. Environmentalists are appalled by its scope to bring water south from the Canadian Rockies; Canadians feel threatened by it, especially in the light of their own shortages in British Columbia and Alberta. Reisner (1990) remarks that, if built, the NAWAPA network will destroy what is left of the natural West and require the taking of Canada by force! Despite this, the International Joint Commission, established with Canada to regulate water issues along the international boundary and Great Lakes, is an institutional example to the world (Box 4.2).

Box 4.2 An international approach to sustainable water management: the IJC

The International Joint Commission (IJC) dates back to 1909 under a Boundary Waters Treaty (Blood, 2003); its responsibilities extend along the whole USA/Canada border, not just in the Great Lakes region. The IJC acts as *neutral adviser* in disputes and *factfinder* (researching key strategic issues), whilst many of the problematic issues of boundary cooperation are retained by individual states and provinces (Colborn *et al.*, 1990).

The Great Lakes fluvial system comprises over 80,000 inland lakes, 750,000 kilometres of rivers and a groundwater system providing drinking water for the 7.5 million residents of the basin. However, there is a desire to treat this problem in ecosystem terms and to include the wider environment of air and land resources and hazards. The framework for international action between the 1970s, when pollution became a scandal (Lake Erie was labelled ‘dead’ or ‘dying’), and the 1990s was given by the Great Lakes Water Quality Agreements of 1972 and 1978, which achieved significant improvements, ‘given the substantial differences in political philosophies between the United States and Canada’ (Colborn *et al.*, 1990, p. 195). Rast and Holland (2003) have a different take on the relationship between the two nations, suggesting that the IJC is a model for modern international water management thanks to their advantageous level of development: ‘the United States and Canada have similar cultural and environmental values, as well as significant financial and intellectual resources at their disposal, thereby facilitating their bilateral actions’ (p. 312). The IJC has also recently received praise for the degree of public participation in policy deliberations such as flood protection for at-risk areas of the Red River basin of Manitoba (Kolba *et al.*, 2002).

Improvements to municipal waste treatment has considerably reduced the phosphate content of the Great Lakes, but their waters are still said to contain 800 toxic solutes. During the 1980s high lake levels caused hundreds of millions of dollars' damage to both sides of the border. Proposals were made to curtail Canadian transfer schemes in Ontario and to augment the Lake Michigan transfer out to the Mississippi. However, as early as 1990 climate change scenarios for the Great Lakes basin suggested caution, and the new international debate became one of whether the USA's profligate use of water, especially in the West, could ever justify further transfers; Annin (2006) refers to 'Great Lakes Water Wars', citing case studies of crisis within the American part of the basin and describing 'Annexe 2001', an amendment to the Great Lakes Charter. Under this, water withdrawals must be returned to the basin and compensatory conservation actions taken (both in water use and for the ecosystem). The issue of changing demands on both sides of the border under climate change remains unresolved: 20 per cent of the liquid fresh water on Earth is at stake (Rast and Holland, 2003).

4.3 Canadian river basin management

Canada is a land of rivers and lakes, surface water forming 8 per cent of Canadian territory. Rivers, referred to as 'lordly' in the national anthem, were the routeways through which the nation was explored and integrated (unlike the waggon trains of the USA to the south). Nine per cent of global runoff serves a population of only 34 million people. Nevertheless, Canada has problems of water being abundant in 'the wrong places' (e.g. the cold North) but scarce by season in the West, on the prairies and in the urban agglomerations of the East (Figure 4.5). The provinces have controlled water development, though federal agencies have more say in land issues. Federal interests have retained control of fisheries and navigation. There is, between federal and provincial interests, a culture of negotiation and compromise which has at times been less productive than a standoff.

In such a climate there have been major openings, as in the USA, for third-party, NGO and community groups to take on ambitious schemes of coordination and improvement, e.g. the Fraser Basin Council (Watson, 2004; Blomquist *et al.*, 2005). Canada certainly demonstrates cultural and political *will* to follow lines of sustainable river basin management, but the realisation can fall short of the vision.

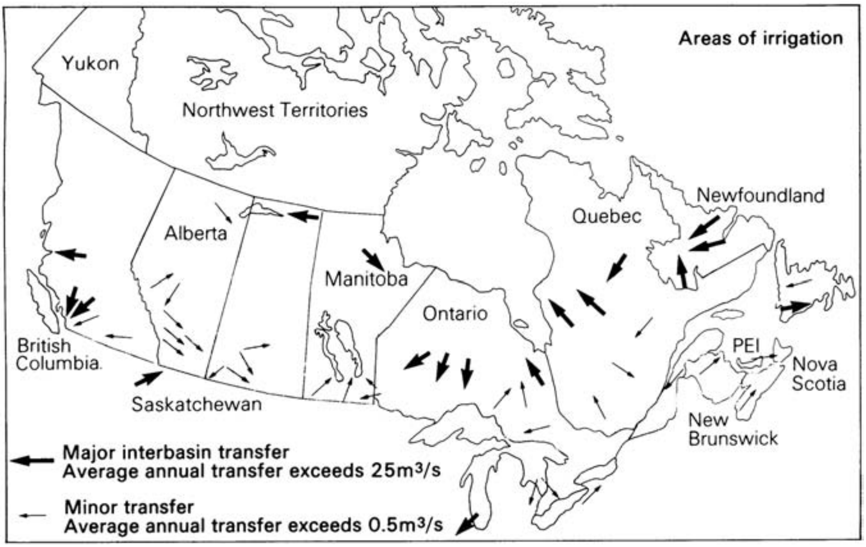


Figure 4.5 Canadian interbasin transfer schemes and irrigation (Day, 1985).

In 1970 the Canada Water Act sought to provide integrated planning between federal and provincial agencies; one of the aims was to improve public consultation and awareness. The enormous scale of Canadian water projects made this a dire necessity. For example, the La Grande project in Quebec involved a work site the size of England, under almost tundra conditions, lasting over 13 years, during which four dams were built to divert and double the flow of the La Grande in order to generate 70,000 GWh of electricity. By excluding the St Lawrence and Mackenzie rivers, roughly one-third of all Canadian flow is transferred across basin boundaries (see Figure 4.7).

4.3.1 Water transfers: a Canadian speciality

The dominant schemes comprise the La Grande, the Churchill Falls project ($665 million) completed in 1974, using two diversions, and the Lake Winnipeg, Churchill and Nelson project completed in 1977 ($1.36 billion). By this time Canadian water transfer flows had exceeded those of the USA and the Soviet Union combined. These schemes had a number of undesirable social and environmental effects. For example, the Lake Winnipeg scheme threatened the environment of the Lower Churchill and South Indian Lake; a considerable change of lifestyle was implied for the communities affected. A representative body was established for discussion of implementation of the scheme, a northern development programme was established and a wide range of ecological monitoring was carried out.

Day (1985) concludes that yet more attention is needed on biophysical and social questions in Canadian transfer schemes. 'Enormous overbuilding of diversion-related hydroelectricity capacity has been costly to the Canadian public' and native groups need more equitable treatment, he claims. The French Canadian perspective in Quebec has implications for such projects as the James Bay scheme. As Hamley (1990) reminds us, Quebec has pretentions to autonomy but little oil, coal or gas; the province has worries about becoming industrially unattractive. To be regarded as 'electricity Arabs' in the north-east corner of the continent would be more useful to Quebec than the beaver pelt exports of the Cree Indians, now reduced to 1.3 per cent of their national lands because of the dated gigantism of the James Bay project, Quebec's monument to a faded vision of modernism. More recently, although the Cree settled for $100 million for their resource sacrifices related to the La Grande phase of James Bay they used the James Bay and Northern Quebec Agreement (Peters, 1992) to hold out against the Great Whale phase, a $13 billion extension to the scheme.

Between 1992 and 1996 the Canadian government, in collaboration with the provinces of Alberta and Northwest Territories, carried out the Northern River Basins Study under the Northern Rivers Ecosystem Initiative (NREI). The Study recommended urgent study of human impacts on this vital reservoir of fresh water, and the initiative lasted between 1998 and 2003. In 1997 British Columbia, Saskatchewan and Yukon joined the group to sign the Mackenzie River Basin Transboundary Waters Master Agreement, establishing a Mackenzie River Basin Board. Ecosystem integrity, sustainable development and equity of use are all major themes, but probably the best indications of the likely success of such institutional changes come from elsewhere in Canada, e.g. in the Fraser River basin of British Columbia (see Section 4.3.3).

4.3.2 Land-use issues in basin development

The European settler/pioneer ethos in North America has, until recently, politically contained an environmentalist backlash against the political supremacy of primary resource exploitation. However, as with the tactics south of the border which led to the Wild and Scenic Rivers Act, activists in Canada (especially in the forested lands of the west) have recently begun an orchestrated campaign in favour of the cultural values of their wild river ecosystems (see, for example, Hume, 1992).

British Columbia is now a pioneer in the Canadian government's attempt to manage all its natural resources sustainably. It uses collaborative planning to set up land and resource management plans. The province's lower Fraser River basin has been chosen as a unit for state-of-the-environment reporting because of its mixture of air, water and land resource pressures (Environment Canada, 1992), making it one of the first river basins in the world to become an ecoregion for environmental management purposes. Amongst the problems listed for urgent action are:

- industrial and municipal discharges and urban runoff;
- wastewater discharges resulting in nutrient overloading and oxygen depletion;
- bacteriological contamination from agricultural runoff;
- leachate from landfill;
- degradation of shallow aquifers by agriculture;
- water shortages and seasonal conflicts between users.

Hume (1992) lays out the river-based case against uncontrolled felling of the native temperate rainforest in the Pacific coastlands of British Columbia; 40,000 hectares of forest is logged each year, and only one-third of the original 6 million hectares of this land cover remains. Hume puts his case severely:

> The forest industry, which spends millions of dollars a year on campaigns portraying loggers as harvesters of the land, has not yet been able to figure out how to clearcut a watershed without severely affecting the entire hydrology of a valley. . . . Gravel spawning beds fill with suffocating silt. . . . The clear water runs brown whenever it rains.
>
> (Hume, 1992, p. 189)

The prairie provinces of Canada also have land-management problems in relation to river flows; the prairies lose many millions of tonnes of soil by both wind and water erosion. Seepage of salinised groundwater to hollows is also a problem: in some areas 15 per cent of irrigated land is salinised. Lake Manitoba is alkaline and brackish from prairie runoff, and the sedimentation rate has increased in the last 100 years.

4.3.3 *Improving the integration of policies*

By far the biggest stimulus for basin-scale integrated management has come from provincial governments. Two problems are identified by Shrubsole (1990): the 'myth of superabundance' (of water resources) and the fact that nearly every province shares its river and lake resources with a neighbour.

The provincial government of Ontario has, however, long favoured river basin authorities to develop local initiative, to promote cooperation with municipalities and to encourage conservation and recreation. The Conservation Authorities Act developed from a conference in Guelph in 1941 and has operated since 1946. The Conservation Authorities themselves (38 in number) are formed by purely local initiative, are largely municipal, and have the power to purchase land in order to promote rational management of the river resources. Unfortunately, the addition of a third layer of organisation to national and provincial interests has proved problematic; Conservation Authorities (Figure 4.6) have tended to become active in recreation but not in the 'big issues' of basin management. However, the role of Conservation Authorities is important in flood control, and this has allowed them to take on a planning role. They have mapped flood hazard areas, they provide flood warnings and they have carried out structural works. Their success in two fields of water management, recreation and flooding, illustrates that these schemes are not duplicated by other interests, and both attract the considerable local interest which the authorities are able to mobilise.

The most recent extension of this policy of 'intervention with care' in the planning system states that one of the aims of development planning in the

Figure 4.6 Ontario Conservation Authority areas in the Lake Ontario area (Ministry of Natural Resources, Ontario, 1986).

river basins of Ontario is 'to encourage a coordinated approach to the use of the land and the management of water'. The Conservation Authorities, where they exist, are given the hub role of providing information and reviewing proposals. For example, the Grand River Conservation Authority has a Master Watershed Planning Committee (Gardiner *et al.*, 1994) which sees as its role 'the promotion of watershed management of small tributary watersheds in an effort to facilitate orderly development and the most suitable types of development whilst not compromising environmental quality'. The possible reasons for Ontario's success in such a holistic vision are the small/moderate size of the basins involved, the fact that river basin boundaries do not cross prominent administrative boundaries and a traditionally high level of support from provincial finances for municipal efforts. Ferreyra and Beard (2007) describe how the agricultural, diffuse pollution threat is being addressed by 'collaborative, integrated water management' (CIWM) in the Maitland watershed, discharging into Lake Huron: addressing 'difference, diversity and divergence' has been a major success at this level.

However, most of the plans cover relatively small areas, compared with the 238,000 square kilometres of the Fraser River basin in British Columbia, home to 2.7 million people. Perhaps encouraged by a sense of geographical separation, the quality of the 'natural' elements of the environment or the early identification of environmental 'crisis', the Fraser River has long attracted both the scientific study and the institutional adjustment capable of feeding sustainable vision to deliverable success. As Blomquist *et al.* (2005) put it, 'The Fraser Basin case is not one of government decentralization, but of the creation of a non-governmental body facilitating the coordination of a number of decentralized private-sector and public-sector activities within the river basin' (p. 4). These authors also see the Fraser Basin Council as bravely adopting an overall concept of basin sustainability, thereby addressing social and economic issues. The size of the basin, its environmental challenges and the diversity of the stakeholders make the concept of planning a daunting one, and the issues of federal/provincial/First Nations overlap in responsibility add to the dilemma: 13 government agencies have a say in water resource management. However, these combined to carry out a five-year Fraser Basin Master Program from 1992, at the end of which a Charter for Sustainability was drawn up by the new Fraser Basin Council comprising four directions and 12 principles (Table 4.7).

Canada is far from unconcerned about climate change, despite its generous allocation of the world's fresh water; the potential northward movement of hydroclimatic zones will produce drought conditions on its prairies, lower Great Lakes levels by up to a metre and severely disrupt the Mackenzie River basin's permafrost. Additionally, the degree to which the USA enters water 'crisis' will have a political, if not material, bearing on Canada's water policies.

Table 4.7 The Fraser Basin Sustainability Concept within the vision: the Fraser basin is a place where social well-being is supported by a vibrant economy and sustained by a healthy environment

Four directions:	
Understanding sustainability	Governments, community groups and individuals recognise why and how they can contribute to building vibrant communities, developing strong and diverse economies, and maintaining the air, water, land and living species that make up ecosystems.
Caring for ecosystems	Individuals are all stewards of resources such as water, forests, fish, wildlife and land. Individuals, as stewards, conserve and enhance ecosystems to maintain strong and diverse economies and to support growing communities. In this way, people not only enjoy a natural environment, but also conserve it to support a high quality of life.
Strengthening communities	Communities benefit from local experience, skills and values. Strong communities are built on a diverse economy, an educated workplace, safe neighbourhoods, accessibility to basic commodities, shared goals, local action and a sense of belonging.
Improving decision making	Decision making is shared and people work together to reach creative agreements and achieve common goals. These reflect the interests of a growing population mixed in gender, culture, religion, age and interest; and where aboriginal rights now being defined are reconciled in a just and fair manner.
Twelve principles:	
Mutual dependence	Land, water, air and all living organisms including humans, are integral parts of the ecosystem. Biodiversity must be conserved.
Accountability	All residents are responsible for the social, economic and environmental consequences of their decisions and accountable for their actions.
Equity	All communities and regions must have equal opportunities to provide for the social, economic and environmental needs of residents.
Integration	Consideration of social, economic and environmental costs and benefits must be an integral part of all decision making.
Adaptive approaches	Plans and activities must be adaptable and able to respond to external pressures and changing social values.
Coordinated and cooperative efforts	Coordinated and cooperative efforts are needed among all government and non-government interests.
Open and informed decision making	Open decision making depends on the best available information.
Exercising caution	Caution must be exercised when shaping decisions to avoid making irreversible mistakes.
Managing uncertainty	A lack of certainty should not prevent decisive actions for sustainability.
Recognition	There must be recognition of existing rights, agreements and obligations in all decision making.

(Continued overleaf)

Table 4.7 Continued

Aboriginal rights and title	We recognise that aboriginal nations within the Fraser basin assert aboriginal rights and title. These rights and title now being defined must be acknowledged and reconciled in a just and fair manner.
Transition takes time	Sustainability is a journey that requires constant feedback, learning and adjustment. In the short term, the elements of sustainability may not always be in balance.

4.4 Australia: lessons learned late on a settler legacy

'Drought is not an occasional aberration in Australia but a repeated feature of the climate' (Smith and Finlayson, 1988). These authors go on to demonstrate how both the small amounts and the high variability of rainfall (Figure 4.7) make almost all of Australia's vast territory poorly suited to rainfed agriculture; the fact that the average runoff coefficient is 10 per cent also means that irrigated agriculture based on water storage is a poor bet to cope with the aridity of the interior. Smith and Finlayson also say that 'The aim of Australian farming should be to manage land and water to preserve the soil.' They contrast this with the settler ethos of 'if it moves shoot it; if it doesn't cut it down' and perhaps 'if it flows dam it': the reality of the European approach to this huge dryland for most of the last 200 years. Paradoxically, but as is so often the case in issues of land, water and development, the Aboriginal culture of Australia is built around a cosmology and a landscape identity which copes sustainably with just the physical extremes which have made incoming settlers so vulnerable (Strang, 2002). At last, Aboriginal rights have become a major issue in negotiating land and water reforms in Australia.

The climatic background to drought in Australia is vividly described and illustrated by Lindesay (2003), whilst the government's responses are reviewed by Botterill (2003). Even more than the West of the USA, Australia demonstrates the problems of dryland development (in contrast to its neighbour New Zealand, which has different land and water problems – see below). Since a major review ('Water 2000') published in 1983, Australia has made rapid moves to planning joint use of land and water resources. *Implementation* of plans has been more of a problem and, in common with New Zealand, the harsh realities of market economics, together with changes in governance, are currently seen as an operational way forward from the strategic base. A national strategic assessment of water resources in 2000 revealed serious reasons for even tighter controls, with 26 per cent of surface water management areas close to or beyond sustainable limits and 30 per cent of groundwater units in the same perilous position. Brierley *et al.* (2006) suggest

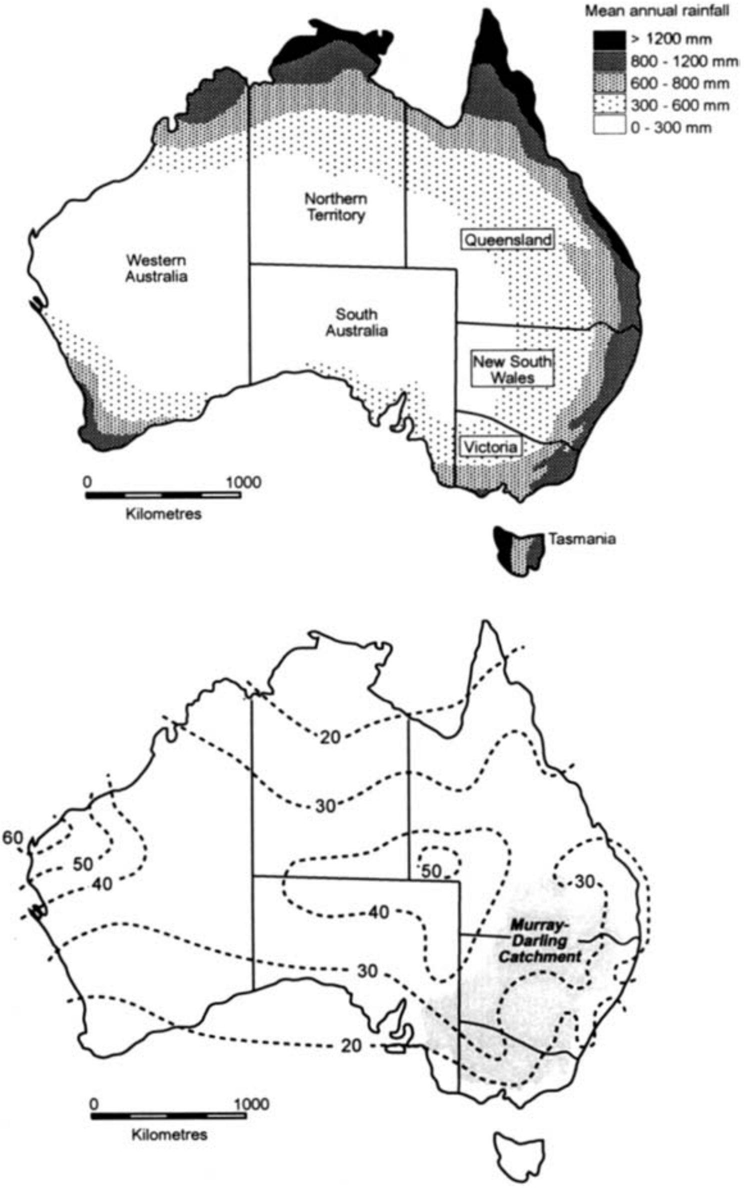


Figure 4.7 Problems of water resource management in Australia (after Smith and Finlayson, 1988):

(a) Mean annual rainfall
(b) Rainfall variability (per cent)

that Australia and New Zealand are showing a similar trajectory towards catchment-framed approaches, explained by a cultural conscience about settler impacts, continuing exploitation up to and beyond limits and the cultural messages from their indigenous peoples that sustainability demands respect for environmental limits.

Australia has a mean annual rainfall of 465 mm, making it the driest of all inhabited continents; annual evaporation rates are in excess of 2,000 mm (Schofield, 2004). The population congregates in the coastal strip (79 per cent) and in cities (85 per cent) and it is not without the 'normal' developed-world problems of water quality deterioration (until recently very poorly monitored); however, 82 per cent of its water is used by rural areas. The most important river basin to consider in this light is the Murray–Darling system (Figure 4.7; Table 4.8). According to Maheshwari *et al.* (1995) the Murray–Darling river system is 'among the longest in the world' but, because once it has left the snow-fed headwaters it is an exotic stream without runoff contributions, 'its mean discharge has no global significance'. In terms of annual flow per square kilometre of catchment for the other large rivers featured in

Table 4.8 Essential data for the Murray–Darling river basin, including global indicators

Data/indicator	*Value*
Basin area	1,050,111km^2
Population density	2/km^2
Urban growth rate	0.5%
Large cities	2
Total fish species	33
fish endemics	7
Threatened fish species	5
Endemic bird areas	2
Ramsar sites	10
Protected areas	4%
Wetlands	3%
Arid	67%
Forest	8%
Cropland	9%
Irrigated cropland	0%
Developed	–
Shrub	25%
Grassland	38%
Barren	0%
Original forest lost	64%
Deforestation rate	–
Eroded area	1%
Large dams	12
Planned major dams	–

After Revenga *et al.* (1998)

this book, the Ganges has 118,000 cubic metres, the Nile and Colorado 31,000, and the Murray a mere 11,000.

Yet the basin is the key foodstore to the occupation of Australia as a developed economy: a quarter of Australia's cattle and dairy farms are in the basin, half the sheep and cropland and three-quarters of the irrigated land (occupying just 1 per cent of the basin area but using 90 per cent of its water – in fact 75 per cent of all Australia's irrigation water). The basin nicely bears out a statement by Heathcote (1969) when describing the lack of respect given to droughts by the colonisers, 'Excessive patriotism sometimes proved costly since officials occasionally promoted intensive land use in areas where it could be only marginally successful because of drought risks' (p. 191). Until recent years, government finance was always given to restoring agricultural communities after drought.

Schofield's (2004) historical analysis ascribes to the severe Victorian *droughts* of 1877–81 the beginnings of water becoming a social and political issue, leading to the Water and Conservation District Act which gave 'some security to agriculturalists in districts where rainfall is precarious'. Schofield also points to the exacerbation of hydrological problems resulting from the land use and faunal changes brought about by the settlers: in 1788 forest covered 10 per cent and woodlands 23 per cent of the continent, but by 1990 these had fallen to 5 and 15 per cent respectively. Over 120,000 kilometres of river bank was cleared of riparian vegetation, and the dominance of an engineering attitude to water and development was only halted by the protests against dam building in Tasmania in the 1980s. From then onwards there have been two major shifts in approach, and the management of the Murray–Darling basin has become symbolic of restoration, integration and public participation (see below).

Flooding has, paradoxically, been another problem of the settled regions of Australia (Smith and Finlayson, 1988). Floodplains are extensive, and dam construction (often by farmers) raises problems of safety and of providing warnings. Smith (1981, 1990) has given examples of the careful analysis of flood damage studies and the ways in which warning systems, particularly after dam failure, can reduce loss of life. There are well-established programmes of flood disaster relief and insurance in Australia but as yet no coordinated approach to planning floodplain occupancy, something detrimental to domestic occupiers and small businesses who are not covered by insurance (Smith and Handmer, 1989). In a few locations, however, drastic land-use planning in the form of floodplain acquisition and the relocation of homes is likely, and Handmer (1987) describes an objective methodology for selecting those properties affected.

The origin of settler impacts on soil and water *salinity* is described by Beresford *et al.* (2001), with an emphasis on the Western Australian wheatbelt but with archive material demonstrating the 'heroic' extent of forest and brush clearance. The slow downstream transfer of sediment released during headwater and riparian vegetation clearance and swamp drainage configures the fluvial geomorphology of the most important catchments, making many of Australia's river management problems physical as well as biochemical (Brizga and Finlayson, 2000). Brierley and Murn (1997), Fryirs and Brierley (1999) and Fryirs *et al.* (2007a, 2007b) emphasise the zonation of the sources and stores of such sediment and the subtleties of the settler impact on slopes, the drainage network and channel access to sediment sources. These impacts continue to impact on channel functions and flooding two centuries later, whilst the pressure of a growing population for urban development is the newest factor to disturb sediment release (Whitelock and Loughran, 1994), runoff and water quality (Dodds *et al.*, 1993). The fast-growing suburbs of Sydney, for example, risk damaging the very freshwater system, the Hawkesbury–Nepean catchment, upon which residents of the capital depend for water supply, waste disposal, fire fighting and recreation; as a result, planning and building regulations force adoption of minimal disturbance and maximum retention (Warner, 2000 and Plate 4.1). Sydney Water Corporation was presented with the Industry Water Award at the 2006 World Water Week in Stockholm, a reflection of its schemes to promote reductions of up to 84 per cent in water consumption-per-unit-production across a range of enterprises in the city. Meanwhile, the extreme drought conditions of 2007 are seeing supply restrictions to homes – 140 litres per head per day is a target in Queensland.

Plate 4.1 Rapid suburbanisation of Sydney, Australia has been accompanied by surface water detention ponds and protection of local stream channels.

4.4.1 The rise of planning and the use of economics

Despite (or because of) the diversity of water stress pertaining in the ten states of Australia (some using less than 20 per cent of available supply, some more than 80 per cent) the 'Water 2000' initiative of 1983 stressed the need for state water plans (Sewell *et al.*, 1985). Progress in implementing planning is variable, with some states needing to be restrained by the federal government (e.g. the case of the environmentally disastrous proposal for a dam in a world heritage forest on the Franklin River in Tasmania) and others such as the Capital Territory itself employing ambitious instruments such as public participation and coordination of land-use plans and water development. Mitchell and Pigram (1989) use New South Wales as an example to illustrate how good intentions (the state premier promised total catchment management during the 1984 election) can be frustrated by slow institutional progress. New South Wales introduced a Catchment Management Authorities Act in 2003, but its workings are frustrated by definitions (e.g. of perennial streams) inherent in other legislation: urban community groups have often had to take the initiative in, for example, river restoration (Findlay and Taylor, 2006). In the Hunter Valley of New South Wales an existing, mainly rural, Conservation Trust was authorised to make recommendations to the state regarding the 'nature, location, form and extent of any work or proposed work for the purpose of soil conservation, afforestation, reforestation, flood mitigation, water conservation, irrigation or river improvement within the Trust District'. The Trust has been successful in flood damage reduction but has been reactive and supportive rather than forceful and regulatory. 'The policy of integrated resource management has received wide endorsement at the conceptual level in Australia. Progress towards effective implementation, however, has been tentative and hesitant' (Fryirs *et al.*, 2007b, p. 210).

The harsh realities of growth in water demand, remoteness from world food markets, environmental damage and distrust of conventional politics have seen a second transition in the water institutions of Australia. The Council of Australian Governments has agreed that water should be priced to meet all the costs of supplying it to the consumer and that water rights should be traded. There is also a general implication that the Australian economy should grow sectors which do not have high water demands.

Changes from 'piecemeal accounting' to water pricing in Australia are described by MacDonald and Lamontagne (2005), with a detailed focus on the River Murray (Table 4.9). Restructuring of the economy in general was at first considered to be independent of natural resource management but, with the incorporation of public consultation as a direct means of achieving accountability, markets can be established and structured to derive, for example, a re-allocation of river water from the Murray to sustain the river

Table 4.9 Impacts of River Murray management on hydrological regime and implications for the costing of environmental externalities

Management action	*Hydrological consequences*	*Ecological outcomes*
Water extraction	Reduced median annual flows.	River salinisation; closure of mouth.
Water storage	Attenuation of floods.	Barriers to fish migration; loss of spawning cue; reduced vegetation and salinisation of floodplain.
Water distribution	Higher summer flows.	Channel erosion; cooler water impacts on fish.
Weirs and barrages	Higher floodplain surface and groundwater levels; loss of wetting/drying and tidal cycles.	Floodplain salinisation; algal blooms; drowning of red gum forests; reduced biodiversity.
Application	Groundwater mounds under irrigated areas; increased discharge of saline groundwater.	Red gum forest dieback; wetland salinisation.
Return flows	Poor-quality return flows on floodplain and as downstream flow.	River and floodplain salinisation.

Modified from MacDonald and Lamontagne (2005)

ecosystem. The process varies between states, but a general principle has been that irrigators need to recover operating costs, improve efficiency and (in South Australia) pay levies for the catchment monitoring essential to the provision of the environmental overview. Farming lobbies are keen to point up the uncertainty of success in the allocation of water to the environment and the further huge costs if irrigators are driven out of business; quite possibly severe drought will dictate the outcome of this dilemma. The biggest insoluble problem using market economics is the progressive damage to water and soils done by salinisation since the European settlers arrived. Here the federal and state governments are prepared to intervene with cash support to stem the rise in dryland salinity towards 22 per cent of all cultivated land; this damage limitation seems wise in view of the A$3.5 billion costs of land and water degradation each year.

The dimension of governance reform in water policy has received both academic and practical assessment in Australia. Tan (2006) provides a comprehensive review of the legislation supporting participation; an Institute for Public Participation has been in operation since the early 1980s and has published principles:

- People should have a say in decisions about actions which affect their lives.
- Public participation includes the promise that the public's contribution will influence the decision.
- The process communicates the interests and meets the process needs of all participants.
- The process seeks out and facilitates the involvement of those potentially affected.
- The process involves the participants in defining how they participate.
- The process communicates to participants how their input was, or was not, utilised.
- The process provides participants with the information they need to participate in a meaningful way.

Syme and Nancarrow (2006) give strong evidence that, based on their work with water resource management committees in Western Australia, these principles should evolve with experience with different communities addressing different goals (and we return to governance and participation in Chapter 9). Because of the vital role of rural communities, especially farmers, in delivering IWRM/IRBM as part of water reform and sustainable management in Australia, the voluntary work of Landcare, launched as a joint venture between farmers, conservationists and the government in 1989 ('an Australian success story'), is a vital consideration (Curtis *et al.*, 1999). As these authors put it,

> Landcare attempts to work with a broad section of the rural community and has moved extension beyond the 'expert farmer' group. There are now over 4000 Landcare type groups with around 120,000 volunteer members, involving 30 per cent of the farming community and an average of 50 per cent of households where there is a Landcare group.
>
> (Curtis *et al.*, 1999, p. 5)

A National Landcare Programme, the National Heritage Trust and regional catchment management committees underpin the approach, designed to foster a stewardship ethic to replace the exploitation of the settler culture. A compelling spin-off from the community scale of land and water management in Australia is the principle of 'catchment health', developed by scientists at the foremost Australian research institute for the natural sciences (Walker and Reuter, 1996 and Box 4.3). Catchment health is defined separately from ecological integrity – it 'implies a viable condition, a self-sustaining state or series of states, which are compatible with human use and habitation' (Walker and Reuter, 1996).

Box 4.3 Catchment health: an Australian approach to stakeholder 'catchment consciousness'

Academic arguments rage about the meaning of the word 'health' in an ecological context; however, for the purpose of inspiring non-technical land stakeholders in vulnerable dryland river basins, there can be little criticism for a goal to which they would aspire themselves. Thus, 'catchment health' has become a technical means by which social learning can promote:

- farm productivity and financial performance;
- product quality;
- soil health;
- water quality;
- landscape integrity.

(Walker and Reuter, 1996)

'The healthy catchment is more than biophysical integrity. It encompasses the possibility for change from the original state, provided the system is self-sustaining, delivers the "products" people require, and has no harmful external effects on adjacent catchments' (Walker and Reuter, 1996, p. 10). Scientists have laid out a whole suite of indicators of catchment health at three levels – to identify a problem's existence, to discover the context of the problem and to assess the causes of the problem. These are specifically aimed at groups like Landcare but in the spirit of a lasting vertical integration between government, science and pragmatic, economically viable management. There are soil, water, biology and landscape indicators, together with the essential economic productivity assessment.

Catchment health deliberately integrates its assessments and monitoring with national, regional/catchment and farm/site scales of existing environmental management. It also links assessments of biophysical condition (soil texture, tree cover, etc.) with biophysical trends (bare soil area, weed cover, stream pH) and the resultant farm productivity and financial performance. It thus creates the incentives for sound environmental management.

4.4.2 The Murray–Darling basin and its management

Little remains of the Aboriginal culture of the Murray–Darling basin – it was completely overtaken by European settlement in under a century. In the late nineteenth century the first diversion weirs were constructed on the Murray–Darling system; however, the main phase of irrigation development occurred between 1920 and 1940. The first of 26 major weirs (not dams – because of the low gradient) was completed in 1922. Hume dam, the only major storage, was completed in 1936 and augmented in 1961; the Snowy Mountains hydro-power and diversion scheme (16 dams) was finished in 1974, adding flow from the Coast Range to the Murray. The basin covers parts of four states – Queensland, New South Wales, Victoria and South Australia – together with the Australian Capital Territory (Canberra). Because of the devolved nature of water management there has been inter-jurisdictional conflict over the resources of the Murray–Darling. A River Murray Waters Agreement was signed in 1914, mainly to (fully) allocate the discharge between states, but not until the Act was amended in 1987 was the Darling catchment included in its entirety (Breckwoldt *et al.*, 2004) and a more thorough and holistic Murray–Darling Basin Commission (MDBC) began work 'to promote and co-ordinate effective planning and management for the equitable, efficient and sustainable use of the water, land and environmental resources of the Murray–Darling Basin' (Crabb, 1991). Since the second edition of this book, Queensland has at last become a signatory to the Agreement, in 1998, and the MDBC has been implementing the economic reforms discussed above.

One of the major successes of the MDBC has been its Community Advisory Council, which has used extension techniques to persuade farmers to fight environmental degradation, principally salinisation of soils and nutrient pollution of rivers. It has also had to deal with Aboriginal rights issues. It has been realised for many years that a corporate approach was required to joint land and water management in the basin (Langford-Smith and Rutherford, 1966). Much of the Australian soil cover has large stores of salt accumulated by natural processes over a long period of time; the salt may be released by poor irrigation practices (as in the Murray–Darling) or by the rise of water tables following forest clearance (common in Western Australia). Figure 4.8 separates these types of salinisation and indicates the importance of the forest cover to groundwater quality in dryland Australia. Hydrologists and land managers have combined in two prominent ways to bring about indirect 'cures' for the salinity problem. Conacher *et al.* (1983a, 1983b) describe the use of throughflow (soil water) interceptors – shallow, contoured 'scrapes' through the soil; George (1990) describes the use of *Eucalyptus* trees to deprive the groundwater recharge and thus lower the water table below the surface. Annual potential evapotranspiration for the eucalypts is 2,500–2,900 mm, whereas for the pasture with which the forest is replaced it may be as little as 360 mm. In the Murray–Darling basin a much more direct method is used, whereby groundwater is pumped to evaporation basins to avoid salinity problems in the river (Ghassemi *et al.*, 1988).

It remains to be seen whether the rhetoric of reform and restoration, particularly reallocating already-stressed water supplies to environmental flows, can be achieved by the MDBC, however closely it approaches the model

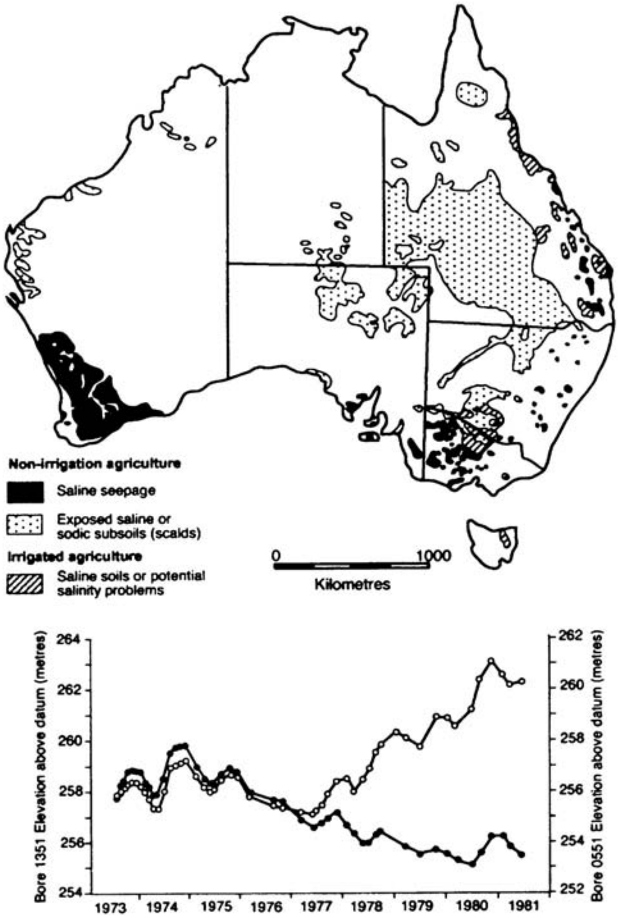


Figure 4.8 Soil salinity and its relationship with land use in Australia (after Smith and Finlayson, 1988):

(a) Distribution of human-induced soil salinity in Australia
(b) Hydrographs from two boreholes in Western Australia; both were forested until 1976 when the record marked with open circles was clear cut; the resulting groundwater rise brought saline conditions to the surface

basin institution. The research base, summarised by Young (2001), has grown impressively in the time of the MDBC, and the ecosystem approach is now feasible in terms of (albeit uncertain) knowledge and the potential for funding 'water banks' for the environment (Arthington and Pusey, 2003). There are national principles for the provision of water for ecosystems, but reintroduction of some features of a natural flow regime is not sufficient (Ladson and Finlayson, 2002) and there are grave dangers of such tokenism being ineffective and hence abandoned. Australia is rapidly developing the scientific resources for informed management of environmental flows (Gippel, 2000), and physical habitat conditions are part of state regulations for water quality (Ladson and White, 2000). Justification for an extension of legal consideration from instream flows to floodplain flows (and in the control of dryland floodplain development) comes from a study in southern Queensland (Thoms, 2003). A workshop approach to achieving a balanced allocation of dryland water resources is advocated by Kingsford *et al.* (1998), but the uncertainties of the current drought situation, of national crisis proportions in 2007, mean that purely anthropocentric considerations come to the fore, as in the construction of the desalination facility in Perth (supplying 17 per cent of the city's drinking water) and Sydney, with Melbourne not far behind in construction. The national Environment Protection and Heritage Council has initiated guidelines for widespread water recycling (use of treated sewage and 'grey' water from basins and baths); these should be used for garden watering, clothes washing and toilet flushing, irrigation, fire fighting and industrial cooling water. These dire circumstances confirm Hayman and Cox's (2003) conclusions that the longer-term strategy must include 'learning to be Australian', that drought is complex and multifaceted and that there is no single drought policy, just a series of ends and means.

We now turn to Australia's Pacific neighbour New Zealand to examine the long and apparently successful history of catchment management planning there, whilst bearing in mind that in New Zealand the European settlers found a different set of environmental hazards.

4.5 New Zealand: resource management conditioned by hazard

New Zealand is recent both geologically and as a developed economy; there is no national shortage of water, rather local and seasonal stress coupled with a fragile freshwater environment under considerable development stress. Johnston (1985) has summarised the major phases of the country's development and the environmental policy response. Development has included forest clearance and mining, both of which have combined with the hazards of a steep landscape, cloaked in weak sediments, and a wet climate to force considerable government attention to river management. Over 12 per cent of New Zealand's land area suffers from fluvial erosion (7 per cent gullied, 2 per cent tunnelled, 3 per cent bank erosion); erosion surveys are one part of a very large national effort put into land survey. It is not, therefore, surprising to find New Zealand's geomorphologists reporting some of the world's largest rates of fluvial erosion, for example in the Western Southern Alps, even without the intensive land exploitation found elsewhere in the islands (Hicks and Griffiths, 1992). Soons (1986) reports source-area rates of between 96 $m^3.km^{-2}.yr$ and 8,380 $m^3.km^{-2}.yr$ during the post-glacial period. Glade

(2003) details the chronology and impacts of settlement, stressing 'There is no simple relationship between vegetation cover and erosion process' (p. 298) and so myths focused on human blame should be avoided (see also Chapter 5 for the Himalayas).

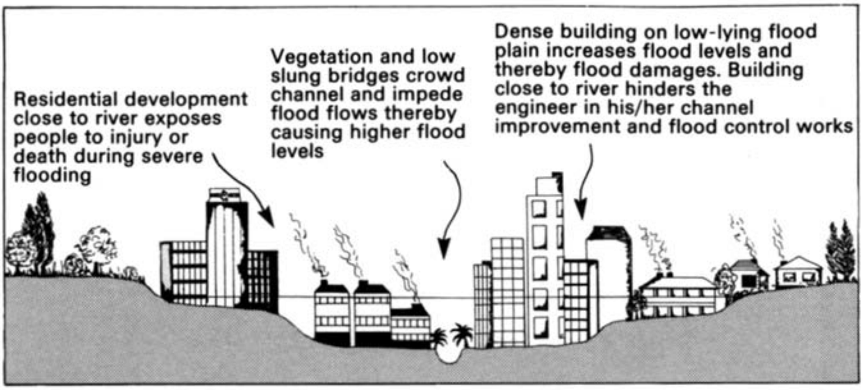
Nevertheless, catchment research at 12 locations in both islands has indicated the enhanced sediment yield after agricultural development, e.g. forest to pasture (Fahey and Rowe, 1992). Hydrological research and monitoring have been of international significance in New Zealand (Mosley, 1992), with a comprehensive flow gauging network and sediment loads officially monitored as early as 1959. Some of the impetus for these networks came from the need to construct dams in hazardous locations; Freestone (1992) suggests over 400 dams of significance and lists the capacities of the 'top 40'. Nevertheless, natural flow regimes tend to gain the upper hand in a nation subjected to extremes of natural hazard, such as Cyclone Bola (1988), and the value of the freshwater ecosystem has encouraged research of international significance in hydroecology (e.g. Jowett, 1992).

Polynesians from the South Pacific islands became the native inhabitants of New Zealand – the Maoris – around AD 1250, but there is only local evidence of an impact on sediment yields, perhaps because they chose flatter landscapes – floodplains and coasts. They did, however, cause irreversible vegetation change. With the arrival of European farmers about 1950 the steep slopes were cleared: in 1991 only 6.2 million hectares of forest (including exotics and plantations) remained from 16.2 million hectares in the pre-European period. The factor of increased sedimentation between the two eras ranges from 1.6 to 18.2 (Glade, 2003). Kasai *et al.* (2005) point to the vital difference in magnitude-frequency and subsequent routing of sediment loss by shallow landsliding and the development of gullies, the catchment system operating buffers, barriers and blankets to the subsequent released sediments (Fryirs *et al.*, 2007a). As is the case in Australia, the Anthropocene continues to enhance yields and accelerate delivery of sediments by urbanisation (Hicks, 1994).

During the period since forest clearance, landslides have cost large areas of New Zealand's hill country almost all of their original 2.5 metres of soil; the remaining 10- to 30-centimetre soils are much less able to store storm rainfall, and one result is that flooding is a further hazard to both islands: Plate 4.2 identifies the problem in the Taranaki Hill country.

The *flood hazard* in New Zealand is described in detail by Ericksen (1986). Historically, New Zealand has attempted to modify the *floods*, but continuing disasters led to a programme of modifying the *loss* burden. Because, traditionally, town and country planning and soil and water legislation have been coherent in New Zealand, concerted, catchment-wide efforts at flood preparedness are common. The use of public education programmes proved successful under the Catchment Authorities, and an example (Figure 4.9) illustrates the desirable features of regulated floodplain development.

(a) Non-regulated floodplain development



(b) Regulated floodplain development

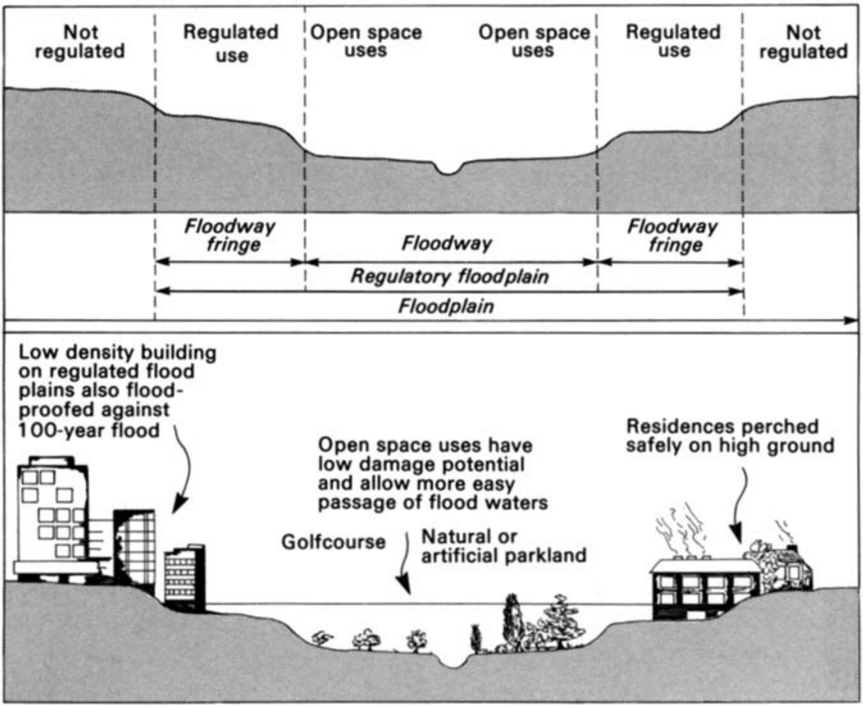


Figure 4.9 New Zealand floodplains:

(a) Non-regulated development of an urban community
(b) Means of regulation and regulated development of an urban community

(Ericksen, 1986)

Plate 4.2 Landslide resulting from Cyclone Bola, Napier, North Island, New Zealand (photo J. C. Bathurst).

4.5.1 Catchment Authorities: an early New Zealand lead in water strategy

Within a few years of the start of European settlement the folly of clearing native vegetation by fire was identified, principally because of its impact on soils (Mather, 1982); by the early twentieth century, reports referred to the fact that:

> The soil on the grass-denuded slopes, which is by no means infertile, being no longer held together by the roots of plants, is being rapidly removed by wind and rain, and pebbles and angular stones are now closely dotted over great stretches of hillside that not many years ago were covered with soil.
>
> (Mather, 1982)

The sediment from these slopes was delivered to more politically sensitive, richer flatlands by the 1930s, and New Zealand began to heed the lessons of the American Dust Bowl era; indeed an alarmist response can be seen in government regulatory activity.

New Zealand began to organise its river management along catchment lines as early as 1868 with River Boards; Acts were passed in 1884, 1893 and 1908 to strengthen these bodies. However, it was the floods and erosion problems of the 1930s which led to a truly formative piece of legislation, the Soil Conservation and Rivers Control Act 1941, subtitled as follows: ‘An act to make provision for the conservation of soil resources and for the prevention of damage by erosion, and to make better provision with respect to the protection of property from damage by floods’. The Act made New Zealand one of the first countries in the world to recognise land–water links in legislation.

By 1967 the speed of development and intensification of land use in New Zealand forced the incorporation of wider aims in the Water and Soil Conservation Act, subtitled ‘An act to promote a national policy in respect of natural water and to make better provision for the conservation, allocation, use and quality of natural water, and for promoting soil conservation and preventing damage by flood and erosion and for promoting and controlling multiple uses of natural water and drainage of land, and for ensuring that adequate account is taken of the needs of primary and secondary industry, community water supplies, all forms of water based recreation, wildlife habitats and of the preservation and protection of the wild, scenic and other natural characteristics of rivers, streams and lakes’. It set up 20 Catchment Authorities, whose functions included those of the Regional Water Boards. A vivid pictorial account of the work of the Catchment Authorities is provided by Poole (1983). They were regarded as models of a ‘new wave’ of rationally guided, democratically based institutions with widespread and comprehensive powers, including that of planning (see Newson, 1997).

There remain plenty of catchment-scale issues in New Zealand; simply the scales of government administration have been shuffled. The protection of all New Zealand’s rivers is a recurring political issue, involving pollution control, recreation and conservation interests, fisheries and *Maori rights*. To the Maori, the essence of life is water, and the river or lake of the home area is effectively the address as well as the identity of each individual (Stokes, 1992). Maori culture is threaded with quasi-religious resource management and anti-pollution concepts which are easily offended by European technocratic approaches to wealth and purity (Taylor and Patrick, 1987). Amongst the elements of a new sensitivity to Maori interests is to take on board the relevance of the *mauri* (spiritual life force) to water quality indices (Hoare and Rowe, 1992). As Paul Mosley puts it in his Preface to *Waters of New Zealand* (Mosley, 1992), ‘Hydrology is firmly founded in the western scientific method. New Zealand’s hydrologists are slowly learning to combine their own approach with those of other sections of the community’ (p. vi).

Diffuse source agricultural pollution is of particular concern in New Zealand, and there are similar movements to promote, by working with farmers, ‘best practice’ to those in Australia: Landcare is very active. A recent upsurge in horticulture as the result of difficulties in the livestock sector has led to problems with pesticides and herbicides. Of the available research on, for example, fertiliser pollution, that by McColl and Gibson (1979) concludes

Table 4.10 Best management practices relevant to dairy farms in New Zealand

Target	*Best management practice (BMP)*
Faecal pollution	Fencing of all major waterways (stock exclusion). Sediment traps on farm tracks. Deferred irrigation with dairy shed effluent. Grass filtration strips in riparian zones. Avoiding grazing of saturated soils. Reduced poaching in wet weather.
Phosphate	Deferred irrigation with shed effluent. Reducing soil phosphate to economic optimum. Avoiding soil compaction and silt loss. Open-drain vegetation to trap phosphate.
Nitrate	Optimise farm fertiliser use. Nitrification inhibitors. Feedlot hygiene and drainage detention. Natural and constructed wetlands for enhancing denitrification.

After Wilcock *et al.* (2007)

that, for hill-country improved grazing lands, very little nutrient runoff reaches streams. In certain 'source areas', particularly of surface runoff, there is, however, a clear need for management of agricultural practices. Catchment-scale research and monitoring is now leading to the adoption of best management practices in the expanding dairy industry (Wilcock *et al.*, 2007 and Table 4.10).

4.5.2 Retreat from 'catchment consciousness'? The RMA

By 1988 the New Zealand government had recognised the need for 'Resource Management Law Reform' because of the proliferation of new laws and institutions superimposed on some earlier approaches such as Soil Conservation and Rivers Control. The situation, they maintained, had become cumbersome and hard to understand by the public, had led to costly delays and did not respect Maori rights. The global market economy forced politicians into a 'leaner, harder' attitude to public expenditure.

Fenemor (1992) and Robertson (1993) outline, whilst Scott (1993) reviews, the latest piece of New Zealand legislation with relevance to catchment management, the 1991 Resource Management Act (RMA). Robertson locates the Act within a profound shake-up of central and local government, creating a separation between strategy and delivery and introducing cost recovery and accountability. The Act is designed to develop the concept of sustainable, integrated resource management – of air, water, soil and ecosystems. The concept of the life-supporting capacity of rivers and lakes is introduced, and Scott debates whether this means that there will be an 'ecological bottom line' to future land-use developments in an era when economic restructuring is the main political driving force. Planning continues: the regional councils now produce natural resources regional plans containing a water chapter, with the catchment and sub-catchment scales being handled by *inter alia* district councils, community groups and project boards for particular issues (Fenemor, 1992). Bowden *et al.* (2004) see the unitary responsibility of district councils for natural resources as beneficial to the Motueka Integrated Catchment Management Programme (South Island), which is promoting research linking scientists, managers and stakeholders. Nevertheless, there are clear deficiencies in the knowledge base for rational planning and as yet groundwater (which supplies around half New Zealand's population) is very poorly monitored and regulated (Lowry *et al.*, 2003).

By 1996 critiques of the Resource Management Act were appearing (e.g. Grundy and Gleeson, 1996), as well as defences (Robertson, 1996). Critics were describing a collision of neoliberalism and environmentalism, whilst defenders alleged that the New Zealand tradition of heavy regulation 'raises serious questions about the ability to achieve desirable aggregate results from predetermined assumptions and detailed regulation' (Robertson, 1996, p. 214). The corporate unease over previous policies is indicated by the fact that the Act replaced almost 80 earlier regulations and amended over 50 others. Less regulatory protection is given to soils by the Act; Mather (1982) suggests that this national focus was already waning: 'there has been a significant swing of mainstream scientific opinion away from the position taken up 30 years earlier, and which gave rise to soil conservation legislation and the resulting system of conservation agencies' (p. 214).

Ericksen (1990) has the last word: 'New Zealand has a reputation for throwing hastily-prepared legislation at its problems then making corrective amendments as experience highlights the shortcomings' (p. 83).

4.6 Reflections: national priorities in the developed world

To the reader in the UK, many of the aspects and approaches described above may be familiar from various stages of the evolution of UK policies (see Chapters 7 and 8). The UK may be characterised by poor distribution of water in time and space, a drastic neglect during early industrialisation of water quality, and over-simplified 'free resource' approaches to water consumption.

The lessons to be learned from this review are:

- National and regional uniqueness (climatic, hydrological and cultural/political) 'sets up' the pattern of land and water development to date.
- However, developed nations are keen to 'export' models of development for river basins which pay little attention to the growing evidence of lack

> of sustainability in, for example, dryland irrigation supported by federal handouts during a settler economy.

A recently retired head of the US Bureau of Reclamation said: ‘I think it is a serious mistake for any region in the world to use what we did on rivers as examples to be duplicated.’ Sadly, the message is too late for much of the developing world. Gangstad (1990) has another relevant message:

> Engineers and planners are at a nexus between the divergent faith in democracy and low institutional esteem. Traditionally they provide critical services for a civilisation’s ability to survive and adapt. But this tradition quickly erodes when a society’s engineering capability diverges from its changing social values.
>
> (Gangstad, 1990, p. 77)

In view of the importance attached to water-based development in drylands in both this chapter and the next, perhaps the best piece of caution comes from the conservationist sage Aldo Leopold, who wrote of the US experience:

> That what we call ‘development’ is not a uni-directional process, especially in a semi-arid country. To develop this land we have used engines that we could not control, and have started actions and reactions far different from those intended. Some of these are proving beneficial; most of them harmful. This land is too complex for the simple processes of ‘the mass mind’ armed with modern tools. To live in real harmony with such a country seems to require a degree of public regulation we will not tolerate, or a degree of private enlightenment we do not possess.
>
> (Bates *et al.*, 1993, p. 150)

Chapter 5

River basins and development

Sample trajectories

The ecosystem approach may seem a senseless luxury for water managers in the developing world who regularly 'face the facts' that 30,000 children die each year because of inadequate water supply or sanitation and half of the world's hospital beds are occupied by patients with water-related diseases. The UN's International Drinking Water Supply and Sanitation Decade (1981–90) was the first major international assault on the appalling statistics of inadequate or polluted water supplies for human use (Agarwal *et al.*, 1980). At the close of the Decade, 700 million extra people had been supplied with clean water but nearly 2 billion people remained in danger – a vanishing perspective.

5.1 New millennium, new tensions: incorporating poverty and health in the water agenda

In 1997 the words 'water supply' and 'sanitation' did not appear in the Index of *Land, Water and Development*. The second edition's international perspective had been set by the outcomes of the World Commission on Environment and Development (WCED, 1987) and the United Nations Conference on Environment and Development (1992). These two drivers had awoken the world to the *sustainability challenge*, but many considered this to be a developed-world luxury. A decade later, priorities shifted with the Millennium Development Goals (MDGs) (Cheru and Bradford, 2005) and the prescriptions emerging from the UNCED follow-up conference in Johannesburg in 2002 (Hens and Nath, 2003). At this conference, for example, the European Union created a Water Facility for development, worth $600 million. In 2005 the UK pledged to double its water and sanitation aid to Africa by 2008. The United Nations has proclaimed an International Decade for Action ('Water for Life') for 2005–15, reinforcing the MDGs; 2008 is the International Year of Sanitation, drawing attention to the fact that a clean water supply alone has little impact on sickness. The year 2008 will also see the world's population become for the first time dominantly urban (the same transition from a rural majority in the UK occurred at the end of rapid industrialisation in 1851).

5.1.1 The water and sanitation crisis

We demonstrated in Chapter 1 that the word ‘crisis’ needs careful use but its use without quotes here reflects the urgency of human needs; bad management may be to blame but, even so, a true crisis remains of how to improve conditions in the developing world. Perhaps the most direct evidence of its seriousness as a development issue is the United Nations Development Programme’s 440-page *Human Development Report 2006* (UNDP, 2006), almost entirely devoted to water and sanitation. It merits extensive quotation:

> Like hunger, deprivation in access to water is a silent crisis experienced by the poor and tolerated by those with the resources, the technology and the political power to end it. Overcoming the crisis in water and sanitation is one of the great human development challenges of the early 21st Century.
>
> (p. 1)

> Water pervades all aspects of human development. When people are denied access to clean water at home or when they lack access to water as a productive resource their choices and freedoms are constrained by ill health, poverty and vulnerability.
>
> (p. 2)

> In short, scarcity is manufactured through political processes and institutions that disadvantage the poor. When it comes to clean water, the pattern in many countries is that the poor get less, pay more and bear the brunt of the human development costs associated with scarcity.
>
> (p. 3)

> The urgency of achieving the Millennium Development Goal for water and sanitation cannot be overstated. Even if the targets are achieved, there will still be more than 800 million people without water and 1.8 billion people without sanitation in 2015.
>
> (p. 4)

> People living in rich countries today are only dimly aware of how clean water fostered social progress in their own countries. Child death rates were as high then as they are now in much of sub-Saharan Africa. Clean water became the vehicle for a leap forward in human progress.
>
> (p. 5)

Other government and independent organisations have captured the urgency of a crisis (*sensu stricto*) in water and sanitation. ‘This silent humanitarian crisis kills some 3,900 children every day and robs the poorest – particularly women and girls – of their health, time and dignity', according to a series of (undated) reports by the Swedish Water House as part of the Millennium Project of the United Nations Secretary-General (available from the Stockholm International Water Institute – SIWI). This group makes five economic justifications for improved aid to the poorest nations and communities:

- Improved water supply and sanitation boost economic growth and contribute to poverty eradication.
- Benefits greatly outweigh the costs.
- National economies become more resilient to climatic extremes.
- Investing in water contributes to increased business productivity.
- The annual costs at national level are feasible – between $4 and $7 per head.

WASH (Water–Sanitation–Hygiene), an international campaign by the Water Supply and Sanitation Collaborative Council based in Geneva, asks how IWRM can incorporate 'the new sanitation imperative', serve the needs of low-income groups and contribute to people-centred household technologies. Thus, a critical aspect of 'the way forward' from the perspective of this book is the challenge to integrate the Millennium Development Goal perspective with that of IWRM, much of which some consider to be a 'hangover' from Agenda 21.

In some professional quarters there is optimism that a merger of the ecosystem *protection* themes of Agenda 21, the ecosystem *services* themes of the Millennium Ecosystem Assessment (Alcamo *et al.*, 2003) and the *human rights* core of the MDGs can be achieved. For example, Macdonald (2001) describes a UK contribution to the World Water Vision which he describes as a 'real opportunity for balancing the human and ecological demands in an area when planning the sustainable development of future water resources' (p. 158). He also considers the likely consequences of failure to recognise the need for such a strategic process.

Newson (2004a) describes the rapid rise of the political drive behind WSS (water supply and sanitation) issues but suggests that this phenomenon need not threaten the viability of IWRM/IRBM simply because of its urgency and the involvement of private capital. He quotes the then minister with responsibilities for water in the South African government: 'without a clean supply of potable water community health is compromised as well as the health of a nation and a region. Without adequate supply to ecosystems, these will start to collapse with detrimental effects on human populations' (p. 442). There is a clear urban–rural dichotomy within the water resource–water supply–sanitation crisis; the signs are clear that an interim situation of a 'planet of slums' for a billion people (UN-Habitat, 2003; UN-FPA, 2007) may drive development aid towards cities and that water management will abandon a catchment-wide vision for these 'hot-spots' of obvious deprivation. Varis (2006) addresses the specific challenges facing nine megacities round the world (Table 5.1).

The UN-Habitat approach is to charge IWRM with the twin tasks of ensuring that urban crises are solved without downstream deterioration and that demand side management (DSM) is applied (see Chapter 7). Braga (2001) indicates that DSM may be the key to urban IWRM in environments as diverse as Denver (USA) and Sao Paulo (Brazil). Ahmad (2003) seems optimistic that enveloping the alleviation of poverty within 'normal' basin-scale IWRM will prove a successful way forward under the Bangladesh National Water Management Plan, whilst noting that 'the poor' also include smallholder farmers, nomadic pastoralists, fishermen and refugees. Ravnborg (2006) makes a demand for an enabling environment, rather than 'crafting of neatly nested water-management organizations', to halt the loss of access to water in developing rural areas. Van Koppen *et al.* (2006) point up the need in rural areas for thinking beyond domestic water and sanitation to multi-use water services; they analyse the typical characteristics of rural family water deployment, including livestock drinking, fish culture, and irrigation, and suggest that rural dwellers arrange informal redistribution if supplied only with a tap and latrine. However, others consider that there are enough special dilemmas facing fast urban growth, in terms of water supply and sanitation, to warrant a complete re-think of approaches which might promote the MDGs' ambitions for this numerically dominant, high-focus group (Lundqvist *et al.*, 2003).

Table 5.1 Important water management challenges in megacities

Drivers	*Challenges*
Poverty, squatters, informal sector	Governance: top-down v bottom-up
Food, energy, transport and water	Tensions: rural v urban
Housing, real estate and water	Bottleneck: conservation v development
Water supply, sanitation, treatment	Approach: traditional v modern
Floods and droughts	Institutions: informal v formal
Land subsidence and groundwater	Time priority: short-term v long-term
Economy and water	Responsibility: public v private
Environment, wastes and water	Management unit: jurisdictions v river basins
Ecosystems and water	Management philosophy: resource-based v human-based
Human resources and water	

After Varis (2006)

5.1.2 'Solutions' to the water and sanitation crisis?

Solutions can never be planned without a full appreciation of the causal chain relevant to the problem or of the options available for change. Langford (2005) asks 'Why are we here?' (p. 273) and lists four elements of the crisis:

- insufficient and decaying infrastructure for water delivery, particularly in deprived urban areas and rural areas;
- insufficient funding and capacity for the maintenance and expansion of water supply systems;
- pollution of traditional water sources, particularly from human and animal waste, agricultural runoff and industrial waste;
- reduced access to, and depletion of, water resources due to drought, population growth, armed conflict and the dominance of commercial agricultural and industrial activities.

There are many paradoxes, particularly cultural and social ones, in providing a clean water supply and healthy sanitation to deprived communities. Carter and Howsam (1999) ask the question 'Why are improvements not sustained?' and, in part-answer, set up a 'sustainability chain' from motivation to maintenance to cost recovery and continuing support (Tables 5.2(a) and 5.2(b)). Biswas *et al.* (2005) discuss the 'unpredictable and unanticipated' outcomes of water supply projects in Colombo. For example, 30 per cent of families surveyed continued to use water from the wells instead of that from the taps, chlorination of the latter partly explaining the counterintuitive result. Despite the assessment of many of the economic burden of constructing

Table 5.2(a) Components of water and sanitation problems in developing countries

Element	*Immediate problem*	*Consequences*
Water supply	Distant sources	Time and energy expended, especially by women and children: education impacts. Health impacts of low consumption.
	Unreliable sources	Time spent queueing or searching.
	Contaminated sources	Water-borne disease.
Disposal of excreta	Lack of safe facilities	Contamination of soil and water.
	Lack of privacy, water for cleansing	Defecation (by men) in open, near water; hardship for women.
Wastewater disposal	Treatment and disposal facilities rare	Contamination of local environment and attraction of pests, including insects.

After Carter and Howsam (1999)

Table 5.2(b) Aims and objectives for water supply and sanitation programmes in developing countries

Component	*Comment*
Overall aims	To bring about health improvement, privacy in defecation, reductions in time and effort spent water-hauling for the whole community. Soil, surface water and groundwater to be protected from faecal contamination. Hygiene practices to be improved by appropriate components of such projects. These goals to be achieved at acceptable capital and recurrent costs and should be realised for the foreseeable future.
Objectives in relation to *impact*	Achieve a daily consumption of at least 20 l/h. Reduce time spent water-carrying to one person-hour per day. Improve water-carrying technology. Achieve bacterial quality of supplies. Achieve supply 'downtime' of 2 per cent. Pit latrines or better for use by whole community. Soakpit or better for wastewater disposal. Effect full adult adoption of good hygiene. Reduce contamination of environment by excreta. Supply these services at per capita capital cost <£20. Supply these services at <£2 per year.
Objectives in relation to *sustainability*	Caretakers for the system, in post and fulfilling duties. Effective community committees. Revenue collection regular and effective. Government or NGO should be in regular, supportive contact with community. Use of facilities should continue at high levels. Physical infrastructure should remain fully functional.

Proposed by Carter and Howsam (1999)

urban water and sanitation services (e.g. Giles and Brown, 1997), the Colombo study and several others confirm a *willingness to pay* by those benefiting. A prominent campaigning organisation, the International Rivers Network (IRN), has driven the alleviation agenda away from supply and sanitation projects requiring large capital investments towards small-scale, alternative technology solutions (IRN, 2006) such as solar water disinfection; the reduced environmental damage is also beneficial.

In 1972 a geographical, epidemiological and sociological study of domestic water use in Kenya, Tanzania and Uganda was published (White *et al.*, 1972) which permits replication after 30 years (Mujwahuzi, 2002) (at least for Tanzania). The repeat, participatory, research asked five questions based on our deep ignorance of the processes surrounding the problem of water and health in the developing world:

- How has people’s use of water changed over this period?
- How have their sources of water and service levels changed?
- What effect have these changes had on people’s water use and well-being?
- What internal and external factors contributed to these changes?
- What implications does an understanding of these trends and changes raise for future policies and programmes in the water and health sectors?

The new study shows some surprising contrasts – per capita water use *down* in piped settlements (*c.*142 to *c.*80 litres), owing mainly to poor infrastructure maintenance and increased population, but *up* in unpiped sites (*c.*14 litres to *c.*19 litres). After 30 years the drawers of water themselves are very dominantly women (almost 90 per cent). For unpiped areas the transition from 20-litre *tin* jerry cans to plastic has slightly eased the burden of labour. In terms of lessons for policy, the 2002 survey stresses the importance of community initiatives, within which the private sector can operate but regulated, mobilised and financially supported by the state. Charging users the ‘real cost’ of water will not, in itself, bring about adequate and continued improvements.

‘Privatisation’ appears to be a glib remedy for the frustratingly bad record of developing nations and their municipal authorities in getting clean water to the poor and their excrement away. There are in reality many forms for the involvement of private resources (McDonald and Ruiters, 2005). These authors consider at least seven models but also suggest that the most politically sensitive thread through all of them is ‘commodification’ of water: ‘any act, practice or policy that promotes or treats a good or service as an article of commerce to be bought, sold or traded through market transactions’ (p. 20). Chenoweth (2004) emphasises the great variety of service provision, including unregulated independent agents in the developing world: there is not one situation of crisis but many variants.

Pressure for ‘privatisation’ comes partly from the grandiose private water utilities created by commodification in, for example, Europe (notably France and the UK) but partly from funders of international development – banks. Rodriguez (2004), writing from a bank perspective, suggests that the real aim is for successful public–private partnerships (PPP), ‘creating long-term, sustainable creditworthiness, as well as promoting the right market conditions, the right instruments, the right allocation of risks and responsibilities, and the necessary credit culture and enhancements essential to bringing projects, utilities and markets into the same equation’ (p. 111). Nevertheless, the basic logical chasm remains: alleviate poverty via water supply because it is a human right *but* expedite the process via its becoming a private good!

5.2 Characteristics of water development projects in the twentieth century: 'gigantism'

There are many characteristics of developing world water projects which are reminiscent of the distribution philosophies of the early hydraulic civilisations. Adams (1992) writes of 'bureaucratic gigantism' in African water management projects and institutions. The strong social structures which upheld prehistoric irrigation economies are imitated by forced resettlement schemes and innovative, but rarely successful, land tenure arrangements. 'In the area of water development, it has to be realised that "one size does not fit all" ' (Tortajada, 2005, p. 226); however, this realisation has been very late in attaching to the conventional water development route. In addition, the ecosystem concept of sustainable river basin development has little political kudos when intensive exploitation of basin resources appears to be the most rapid route to a national trade surplus, wealth and political success. Mega-projects have a fatal fascination for political elites. The spontaneous regulatory functions of the basin remain understated without a proper investigation, which the urgency of development precludes for the elites. The indigenous peoples of the developing world have practised extensive exploitation for centuries, largely leaving the spontaneous regulators intact.

5.2.1 Pre-empting damaging development: the dilemma of rapid urbanisation

Is there a rationale with which the technology of water development could have a more acceptable social focus when viewed both from the centre and from the periphery of a developing nation? Marchand and Toornstra's (1986) ecosystem model has been translated by its authors into a highly practical policy formulation which could easily be used to filter projects heading for 'gigantism' (Box 5.1).

Despite the urgency of providing basic human facilities, the internal and external demands of burgeoning *developing-world cities* pose special problems for protecting basin ecosystems. Their water environment exhibits many signs of stress, particularly to the important water and sediment transfer systems (problems of pollution may, in the longer term, be surmountable). In the *humid tropics*, for example, urbanisation around Harare, Zimbabwe, has destroyed the water storage capacity of the dambos (African valley wetlands), channelised the natural watercourses and created downstream channel erosion problems (Whitlow and Gregory, 1989). Within city limits, as was the case with rapidly urbanising cities in Britain in the Victorian period, open channels are used as sewers and refuse dumps. In south-western Nigeria, Ebisemiju (1989) points to a decrease in channel capacity brought about by this depositional activity, with an increased flood hazard resulting. Elsewhere in

Box 5.1 Precautionary guidelines on development whilst protecting and conserving ecosystem goods and services

One of the major characteristics of land and water development in the twentieth century was 'gigantism'; under it and the accompanying project cycle, development followed the ethos and principles of construction: 'new build' was the slogan. Marchand and Toornstra (1986) can be credited with the first agenda for land and water development which seeks to retain as many of the spontaneous regulatory functions of the ecosystem as possible. Their list has in many ways 'arrived too late' but, equally, it has led to adoption by influential bodies such as the World Bank of a series of precautionary principles and assessments without which gigantism fails to get funded.

The principles (in summary) are shown in Table 5.3 overleaf.

Nigeria, Odemerho and Sada (1984) describe the erosional gullies which result from the 'increase in impervious land uses, the discontinuous urban sewerage and generally unplanned layout of buildings'. Urban wastewater management is particularly problematic in the humid tropics because of the very intense rainfall (Gladwell, 1993); five-minute intensities of 160–250mm.h^{-1} are common, overwhelming runoff collection systems and spreading the copious surface wastes into the nearest watercourse.

In rapidly urbanising areas of the world's *drylands* a major hazard is that of extreme floods in what, otherwise, is a semi-arid climate. Schick (1995) records the case of Eilat, on the Red Sea coast of Israel, a city undergoing rapid tourism development (see Plate 5.1) but situated on an area of coalesced alluvial fans. Forty per cent of the rainfall falls in storms reaching an intensity of 20mm.h^{-1} and although the streets of the town are designed to carry flood waters there is considerable disruption, damage and deposition as the result of choosing such a hazardous site. Eilat has many a badly sited urban example to follow, e.g. Las Vegas in the USA.

Urbanisation around dryland rivers inevitably leads to problems of river and groundwater pollution; in fact there are strong potential linkages between environmental degradation in urban and rural areas of the developing world. A study of a region in south-east India where the leather tanning industry is a notorious polluter (Bowonder and Ramana, 1987) has demonstrated how a combination of rural land pressures and urban/industrial developments leads to health problems, community stress and environmental decline.

Table 5.3 Guidelines for river basin management during rapid development

1. Preservation or improvement of the *spontaneous functions* fulfilled by the river, by:
   - (a) restoring erosion/sedimentation processes;
   - (b) preserving genetic diversity, through conserving natural areas and threatened species;
   - (c) reserving the self-purifying capacity of the river, through combating pollution.
2. Conservation of the *natural values* of the river basin, by:
   - (a) legally preventing deterioration/destruction of natural resources;
   - (b) establishing reserves in the most vulnerable ecosystems, with surrounding buffer areas;
   - (c) establishing environmental education programmes;
   - (d) initiating programmes to promote sound, durable exploitation of ecosystems.
3. Conservation of the river basin's *extensive exploitation functions*, by:
   - (a) allocating appropriate quantities of water;
   - (b) implementing sound watershed management.
4. Development of *sustainable intensive exploitation functions*, by:
   - (a) drawing up a water allocation plan for the entire river basin, to achieve balanced water demand and supply, giving due consideration to the water requirements of the spontaneous functions (para. 1), natural values (para. 2) and extensive exploitation functions (para. 3);
   - (b) developing small-scale projects, e.g. irrigation, fishponds, forestry;
   - (c) improving traditional product processing, sales and marketing;
   - (d) ensuring that detailed plans for the above objectives are considered within the framework of an environmental impact assessment.
5. Improvement of the overall *health* situation in the river basin, by:
   - (a) combating water-borne diseases;
   - (b) improving the food situation, both quantitatively and qualitatively;
   - (c) establishing a drinking-water programme for rural areas;
   - (d) ensuring an environmental impact assessment procedure.
6. Guiding principles for *regional planning*:
   - (a) Work with, not against, the environment.
   - (b) Start work from the existing situation: infrastructure, knowledge.
   - (c) Protect the authentic evolution of local culture and institutions.
   - (d) When undertaking action or introducing social change, ensure decision making at the lowest possible level.
   - (e) Assess the carrying capacity of extensive agricultural and water-use systems, as well as their present value.
   - (f) Assess the required inputs for intensive systems of land and water use.
   - (g) Intensify land- and water-use systems only at optimum locations.
   - (h) Preserve, develop and utilise nature's spontaneous functions.
   - (i) Reserves for species or ecosystems should be as large, as varied and as interconnected as possible.
   - (j) Preserve rare species and ecosystems in their authentic ecological setting, giving due consideration to the long-term effects of isolation.
   - (k) Avoid land- and water-use systems exhibiting irreversible dependence on a single crop or market (especially narrow or foreign markets).

Source: Marchand and Toornstra (1986)

Plate 5.1 Encroachment by dryland development on to hazardous alluvial fan environments, Eilat, Israel.

5.3 A development focus: food, power and trade in drylands

Griffith (2001) provides an important background to those cradles of civilisation, religion and science: drylands. His perspective derives from personal experience of ‘desertification’ as a development worker in India and Kenya; his analysis is of the tense human–environment relationship under aridity, one of communal discipline whilst battling the unpredictable elements. Brooks and Tayaa (2003) write that ‘Nowhere is there a greater need for comprehensive watershed management than in drylands’, justifying this view by emphasising the risks of damaging a range of natural resources by poor land use and management and the vital role of vegetation in switching between ‘blue’ and ‘green’ water.

The 42 LDCs (least developed countries) on earth show a high correlation with the tropical arid and semi-arid lands; half a billion people live in these countries (Figure 5.1). Many of the major river basins of the world impinge on the arid and semi-arid lands, and the exploitation of their basins has a disproportionately vital effect on indigenous peoples. Most of the important basins are also international – they cross the boundaries of sovereign nations. Whilst the population of most of the LDCs is rising fast, much of the land within their boundaries is limited by drought and it is very difficult to increase food production for the home population as well as creating exportable surpluses of cash crops. The ‘answer’ has conventionally been to promote large-scale irrigation as a vital component of development (Table 5.4 and see

Figure 5.1 Major river basins, least developed countries and the world's arid and semi-arid lands.

Table 5.4 Irrigated area (thousand hectares) by region

Region	*1965*	*1975*	*1985*	*1995*	*2003*
Africa	7,770	8,943	10,073	12,463	13,370
Asia	96,713	121,151	141,780	181,767	193,890
Europe	9,401	12,704	16,018	26,150	25,208
North/Central Americas	19,526	22,822	27,454	30,465	31,264
Oceania	1,370	1,622	1,959	2,695	2,844
South America	5,070	6,403	8,269	10,155	10,522
Former Soviet Union	9,900	14,500	19,689		
TOTAL	149,750	188,145	225,242	263,695	277,098

Data from Gleick (2006)

Chapter 6). Africa has the most formidable problem of all continents; drought years place an unmanageable burden upon food production systems by both delaying the crop cycle and curtailing the period of growth (Figure 5.2). Drought is a multidimensional phenomenon, in need of more appropriate definitions (Box 5.2).

Before moving on from the general characteristics of water in drylands, there are also clear links here to climate change (Chapter 6); most scenarios point to a spatial spread of aridity and also a temporal intensification of drought. Socio-political factors also exaggerate the stress cause by aridity;

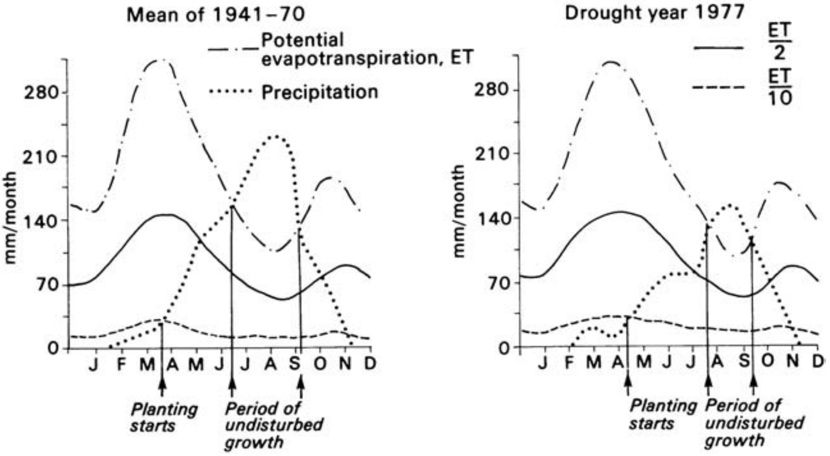


Figure 5.2 Problems of the developing semi-arid world: the sensitivity of the growing season to the water balance, both depths and timings, normal and drought (Falkenmark, 1986).

Box 5.2 Towards more meaningful definitions of 'drought' which will empower those dealing with it to work sustainably

Rural or urban, water stress in drylands is most commonly caused by periodic drought (as we have already shown in the American West and Australia: high levels of economic development are only a partial coping strategy). Hydrologists have been suggesting the need for an improved understanding of drought and its ancillary conditions of desertification and desiccation (Agnew, 2002). Only with this understanding and with a precise understanding of the environmental context for drought (see Figure 5.3) can strategies be debated and selected. Paulo and Pereira (2006) elaborate on available drought indices, since the data needs for these and their differing weightings can yield uncertainty in what is essentially emergency planning. Policy and preparedness are receiving lots of attention as the international scientific community becomes aware of shared information for drought forecasting and governments realise the disasters caused by simply providing emergency relief to people and enterprises in unsustainable dryland locations (Wilhite, 2003).

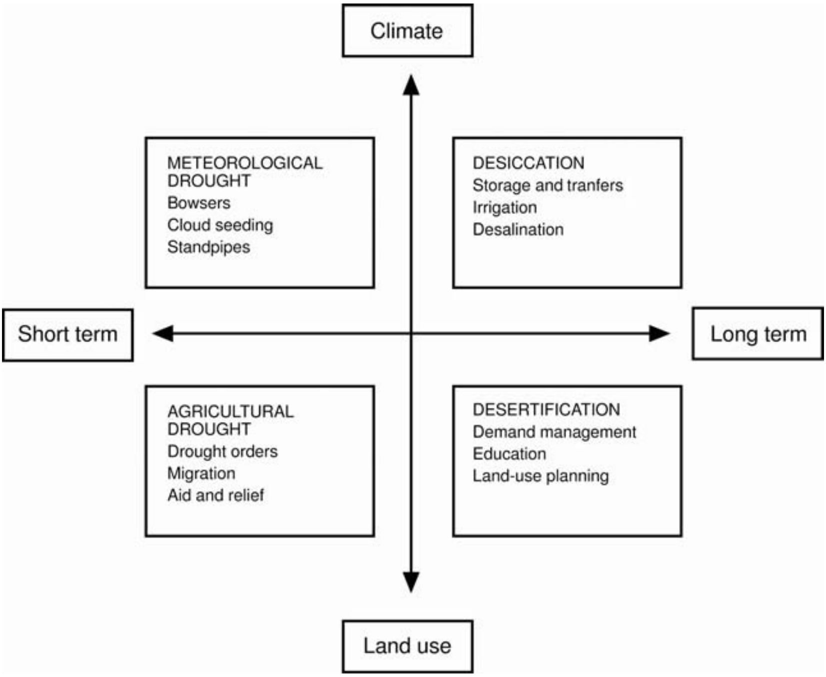


Figure 5.3 A broader understanding of drought relating to climate, land use and duration of dry conditions (after Agnew, 2002).

this stress becomes multidimensional through ignorance, inefficiency, rural–urban rivalries, disputes, 'theft' of water, and pollution, particularly of the shallow aquifers vital to 'wadi' society. The complex is explored in a detailed study of a city and its surroundings in Yemen by Handley (2001).

5.3.1 Desertification: dryland degradation

> Drought and desertification threaten the livelihood of over 1 billion people in more than 110 countries around the world.
>
> (Kofi Annan, whilst Secretary-General of the United Nations)

Paradoxically, despite their acknowledged vulnerability, the drylands of the world are mismanaged to the extent that annually, in the Sahel zone of Africa, as much land is lost to food production by the processes known as desertification as is gained by new irrigation schemes. Obviously, thresholds of ecosystem damage are precariously close to the intensive demands made on them in dryland development, and when exceeded the landscape becomes desertified. The term *desertification* and the extent of the problem are both hotly debated by hydrologists, agriculturalists and development specialists.

Promoted vigorously by the 1977 UN Commission on Desertification meeting in Nairobi, the phenomenon was said to affect 21 m ha yr^{-1} at a cost of \$26 bn yr^{-1}. Desertification was originally defined as: the diminution or destruction of the biological potential of land that can lead ultimately to desert-like conditions (UNCOD, 1977). Despite such specificity, Thomas and Middleton (1995) examine the hypothesis that desertification is a myth and claim that 'desertification is a shorthand term rather than a specific process with a specific cure' (p. 9). They examine four dimensions of the myth – the size and progress of the problem, the fragility of dryland ecosystems, the physical effect on human communities, and the role of the United Nations; in each case they find that we are guilty of applying a spatial definition to a general problem of human occupation – that of degradation.

Most authorities now see desertification as an issue complicated by climate change. Mensching (1986) emphasises the need, therefore, for the population of the Sahel to have a flexible response and for exploitation potentials to be reviewed downwards to reflect the inherent variability of environmental controls. Indigenous participation is supported by Thomas and Middleton (1995) who stress that desertification has been conceptualised mainly by Western minds with little or no cultural experience of adaptation to dryland conditions:

> The life cycles of plant and animal populations in drylands are characterized by 'boom and bust' cycles in tune with a variable environment, and human populations may have adjusted in a similar manner under environmental stress in the past. When this occurs today, it is viewed from the West as unacceptable.
>
> (Thomas and Middleton, 1995, p. 154)

However, the fact remains that desertification represents ecosystems pushed beyond limits (Williams, 2000), with such outcomes as:

- accelerated soil erosion by wind and water;
- salt accumulation in the surface horizons of dryland soils;
- a decline in soil structural stability, with crusting, reduced infiltration and reduced soil moisture storage;
- replacement of forest or woodland with savannah grassland or scrub;
- an increase in the flow variability of dryland rivers;
- an increase in the salt content of freshwater lakes, rivers and wetlands;
- a reduction in species biodiversity and plant biomass in dryland ecosystems.

The International Geosphere-Biosphere Programme has initiated the Dahlem Desertification Paradigm (DDP, named after the host city in Germany), which makes nine assertions, with relevant translations into both biophysical and socio-economic policy recommendations (Table 5.5 and Reynolds *et al.*, 2003).

Table 5.5 The nine assertions of the Dahlem Desertification Paradigm and some of their implications

Assertions	*Implications*
1 Desertification always involves human and environmental drivers.	Always expect to include both socio-economic and biophysical variables in any monitoring or intervention scheme.
2 'Slow' variables are critical determinants of system dynamics.	Identify and manage for the small set of 'slow' variables that drive the 'fast' ecological goods and services that matter at any given scale.
3 Thresholds are crucial and may change over time.	Identify thresholds in the change variables at which there are significant increases in the costs of recovery; quantify these costs, seeking ways to manage the thresholds to increase resilience.
4 The costs of intervention rise non-linearly with increasing degradation.	Intervene early where possible, and invest to reduce the transaction costs of increasing scales of intervention.
5 Desertification is a regionally emergent property of local degradation.	Take care to define precisely the spatial and temporal extent of processes resulting in any given measure of local degradation but do not try to probe desertification beyond a measure of generalised impact at higher scales.
6 Coupled human–environment systems change over time.	Understand and manage the circumstances in which the human and environmental systems become decoupled.
7 The development of appropriate local environmental knowledge must be accelerated.	Create better partnerships between local environmental knowledge development and conventional scientific research, employing good experimental design, effective adaptive feedback and monitoring.
8 Systems are hierarchically nested.	Recognise and manage the fact that changes at one level affect others; create flexible but linked institutions across the hierarchical levels, and ensure processes are managed through scale-matched institutions.
9 A limited suite of processes and variables at any scale makes the problem tractable.	Analyse the types of syndromes at different scales, and seek the investment levers that will best control their effects – awareness and regulation where the drivers are natural, changed policy and institutions where the drivers are social.

Bearing in mind the dangers of myth and cultural prejudice it is important that we now look at the problem of dryland river basins, the management of which is complicated by the international nature of many of the world's most prominent dryland rivers; we therefore begin with the experience of Iran in managing a basin entirely within its national boundaries.

5.4 River basin management in Iran: the Zayandeh Rud

Integrated management of land and water resources should be an overriding preoccupation for drylands if sustainable development is a realistic ideal – such is the sensitivity of the relationship under existing climate stresses and population pressures. However, the two major elements integral to IWRM/IRBM are managed antagonistically (often in a direct sense) in many dryland nations: ‘land’ makes unreasonable water demands via irrigation (returning it polluted) and ‘water’ grabs land for reservoirs whilst being blind to the dangers of siltation from high catchment sediment yields. Dams have been a pivotal element in this ‘stand-off’, as Manouchehri and Mahmoodian (2002) describe for Iran, where the first dam was built 2,500 years ago (the Darius dam on the Kor river). Iran now has 85 dams, with 65 more planned or under construction, some of them attracting rare political protests in this Islamic state. They write that ‘no single dam exists in the country without its own special environmental problems’ and that, ‘Should the ecological issues continue to be ignored, the other dams, planned for construction, will be nothing more than reservoirs filled with putrid water’ (pp. 180, 181). They quote the example of the Minab dam, for which design engineers predicted only half the actual rate of sedimentation.

The Zayandeh Rud (River) basin in Iran offers a suitable case study without the complication of international boundaries. It covers 41,503 square kilometres, approximately half lying within the mountain (snowmelt) source of most of the flow and half in a semi-arid environment (Figure 5.4). There is rapid urbanisation in and around Isfahan (population now 1.3 million), an ancient Persian capital city in the centre of the basin. Most of the eastern half of the basin relies on irrigated farming in what Beaumont (1989) calls the Isfahan Oasis. Only 20 per cent of the natural flow of the river remains in-channel at the Gavkhuni marsh – the ‘end’ of the river, which does not reach the sea. Thus the physiography, climate and layout of the Zayandeh basin are typical of the dryland basin, but there are two extra reasons for a special study: the very long (*c.*2,000-year) history of irrigation, its links to the Islamic culture of resource management and the impacts of the post-revolutionary Islamic state since 1979.

The flow of the Zayandeh to Isfahan and its ‘oasis’ has long been augmented by engineering schemes to store spring snowmelt from the Zagros Mountains (there being virtually no summer runoff and little in the lower basin) and also to transfer runoff from neighbouring basins with headwaters in the Zagros. The modern ‘hinge’ of the basin is the Zayandeh Rud dam (Figure 5.4; Plate 5.2(a)). Adding to the inflow to the dam is water transferred from a neighbouring catchment to the south through artificial tunnels with a total flow capacity of 95 cumecs. The transfer system also requires minor dams,

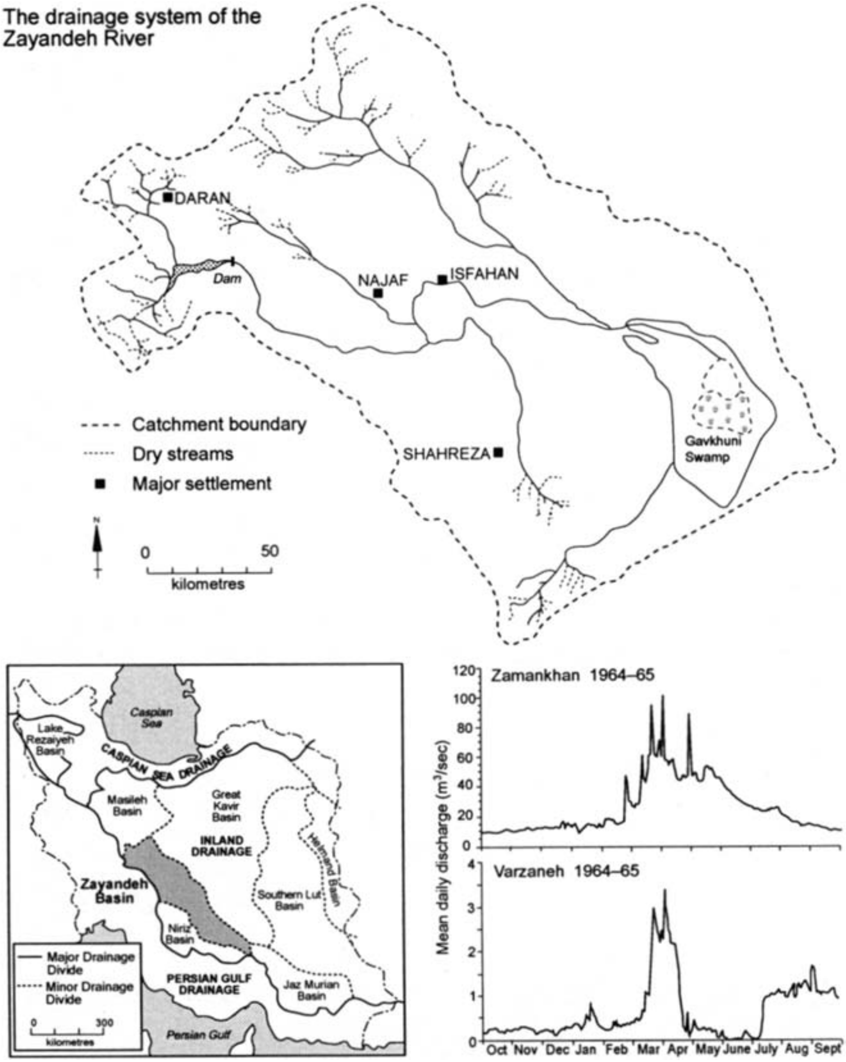


Figure 5.4 The Zayandeh Rud basin, Iran: the basin, its setting and two annual hydrographs, one from upstream and one downstream of Isfahan, the major population centre (note the snowmelt-fed spring runoff and the heavy use of the water in summer).

and the least sustainable aspect of the entire scheme is the lack of compensation water allowed down the Karun to sustain that river on its path to the Persian Gulf (Newson and Ghazi, 1995). There is also 'clear-water erosion' of the Zayandeh's upper tributaries where the transfer flows enter; 22 check weirs are required to control erosion on the 35-kilometre reach to the Zayandeh Rud reservoir (which took four years to fill after completion in 1970).

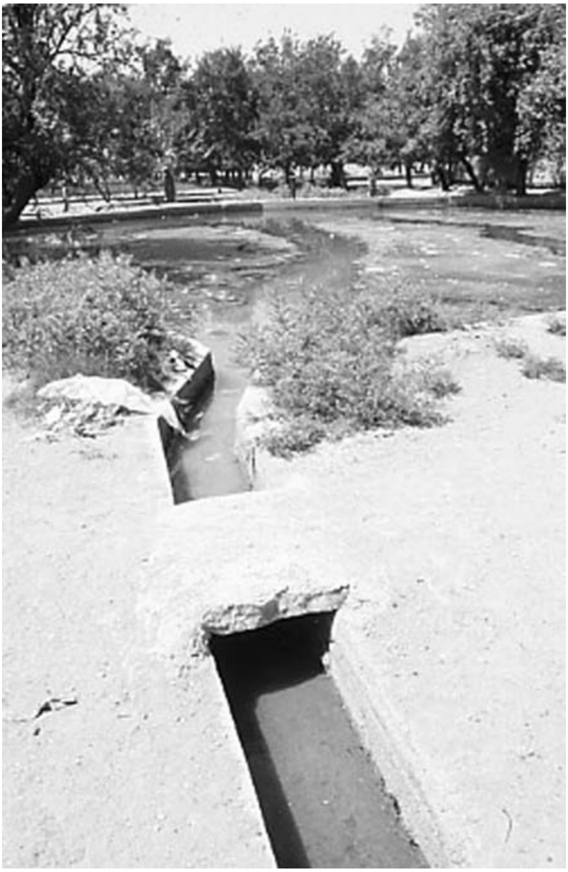


Plate 5.2a The old: qanat and dam water management system in the Zayandeh Rud, Iran

Other aspects of the management of the basin demonstrate, however, the importance of a blend of good engineering, environmental concerns and a strong cultural inheritance in terms of equity and flexibility. The origin of Isfahan as a settlement is an irrigation system based on canals (‘Madi’) from the river and subterranean ‘qanats’ from the alluvial fan aquifers of the mountains to the north. Qanats are known in 34 countries and there are *c.*33,000 of them in Iran (Motiee *et al.*, 2006). The use of these supplies has, according to Islamic law and tradition, been based upon multiple use (e.g. a sequence through villages of drinking water, washing water, water to bathe the dead, animal water and irrigation water: Plate 5.2(b)) and common, community property rights (see Chapter 1). Molle *et al.* (2004) create a vivid picture of these traditional rights and the other forces, including

Plate 5.2b The new: dam water management system in the Zayandeh Rud, Iran.

nationalisation of water in 1968 and dam construction, which have eroded both the attitude and the infrastructure of traditional systems. Irrigation water has traditionally been used four times in rotation in the villages; nitrogenous fertiliser is collected from traditional pigeon roosts. The qanats have now fallen into disrepair in places or have been ruined by deep groundwater pumping (Motiee *et al.*, 2006). In the modern irrigation economy east of the city there has been regular attention to the problems of salinisation and other soil degradation; new, concrete-lined canals reduce leakage waste, and other drainage canals remove polluted seepage.

Overall management of the water resources of the Zayandeh basin is now in the hands of the Isfahan Water Company, which regulates water usage by a new pricing system. Pollution control legislation is, however, slow to keep pace with the rapid industrialisation of towns like Zarrinshahr, and there are fears that continued growth will place stress on Zayandeh before the river passes the holy sites along the Isfahan river front, already a growing focus for the tourist ambitions of the city.

The other problem facing the Zayandeh, in common with all dryland rivers, is that of climate change, and the future is being modelled by university researchers in Iran (Morid and Massah, 2004). They use the Hadley Global Climate Model (GCM) with appropriate downscaling to set up scenarios for the Zayandeh for the periods 2010–39 and 2070–99. The present population of 2 million will grow to 9 million; crop yields could increase by 25 per cent but will be likely to suffer from reduced water quantity and quality, as will

Gavkhuny marshes, unless more water transfer tunnels are constructed to neighbouring headwater catchments (in turn reducing their hydro-power capacity). The advice is that cropping patterns can make a large contribution, as can ‘population control’ and reduced water demand, but ‘Transfer of water from neighbouring basins to the Zayandeh Rud basin is an essential adaptation measure’ (p. 56).

Within a single culture, tradition and management institution and with the focus of one major city, the Zayandeh has advantages of one national, regional and civic management not enjoyed by the next dryland river we feature – the Nile.

5.5 The Nile: a definitive case of hydropolitics

The Nile (Figure 5.5) is the world’s longest river (6,825 kilometres); its catchment area (3M km^2) covers one-tenth of Africa, and its annual flow is measured in cubic kilometres (Table 5.6). However, the scale of the Nile basin

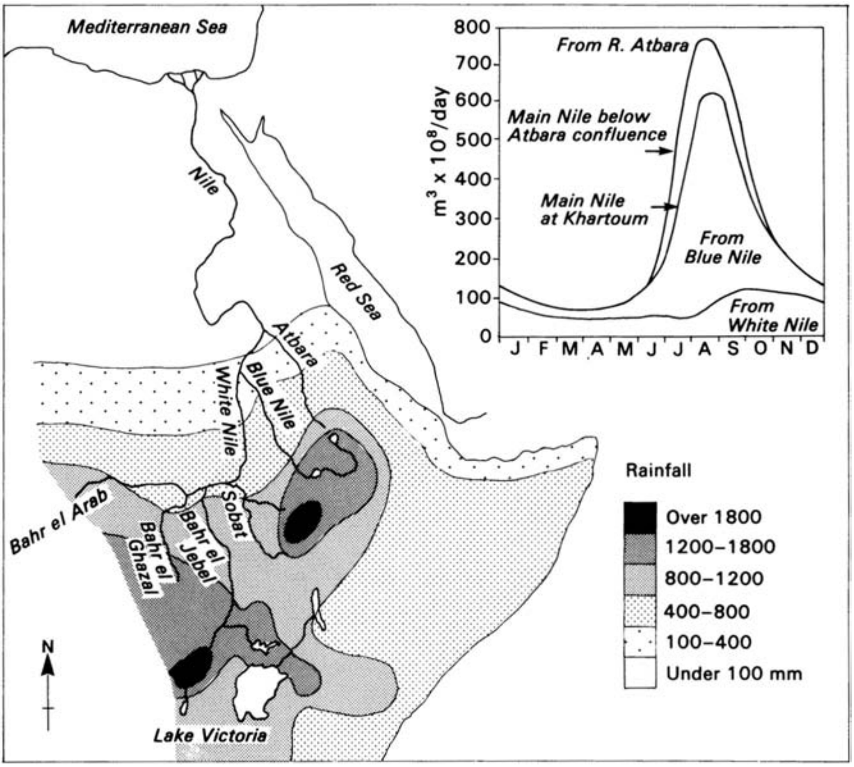


Figure 5.5 Nile basin annual rainfall and the Nile flood hydrograph, subdivided by contributing catchment.

Table 5.6 Essential data for the Nile river basin, including global indicators

Data/indicator	*Value*
Basin area	3,254,555 km^2
Population density	44/km^2
Urban growth rate	4.0%
Large cities	30
Total fish species	129 (Nile only)
Fish endemics	26 (Nile only)
Threatened fish species	0
Endemic bird areas	5
Ramsar sites	2
Protected areas	5%
Wetlands	6%
Arid	67%
Forest	2%
Cropland	10%
Irrigated cropland	5%
Developed	1%
Shrub	4%
Grassland	52%
Barren	30%
Original forest lost	91%
Deforestation rate	6
Eroded area	5%
Large dams	7
Planned major dams	–

From Revenga *et al.* (1998)

is not the sole cause of its river management problems, except in so far as its scale stretches its boundaries across several climatic zones, nine sovereign states and a number of racial and religious boundaries.

Moorehead (1973, 1983) has given us a very graphic insight into the physiography and exploration of this river's two main branches – the Blue Nile, which carries the majority of the flow, and the White Nile, whose source proved so elusive to men like Burton and Speke.

5.5.1 Egypt: product of the river

Modern Egypt has a severe population problem; *c.*80 million people live there (an increase of 20 per cent in the last decade); 95 per cent of its agricultural production is irrigated, sustained only by the waters of the Nile. Unlike some Middle Eastern states, Egypt's oil resource is small by comparison with its size. Egypt's water resource situation is dire, as Table 5.7 indicates. Most of its adaptive capacity in terms of water conservation lies in the 84 per cent of its

Table 5.7 Water use in Egypt, historical and projected (km^3)

	1960	*1970*	*1980*	*1990*	*1995*	*2000**	*2010*	*2025*
Irrigated area (thousand hectares)	2,568	2,843	2,445	2,648	3,265			
Water withdrawal	49.7	55.5	50.5	53.1	53.7	54.3	61.6	67.7
Water consumption	35.2	39.0	34.5	36.7	37.5	38.0	39.2	40.4

* Total water withdrawal in 2000	68.3
Allocated from Nile, 1959 Agreement	55.5
Groundwater withdrawal	7.043
Treated wastewater for irrigation	1.5
If Upper Nile projects proceed: extra	9.0
Virtual water in imports	13.13
Agricultural use	59.0
Domestic use	5.3
Industrial use	4.0

water use for agriculture; irrigation efficiency could be increased by a third, and in reality this would be the only way to extend agriculture to the Western Desert – hence the recent national Irrigation Improvement Project (Hvidt, 1998). Biswas (1993) points out that Egypt needs very careful land-use planning in connection with its joint needs for food and water to produce that food; urbanisation has a double impact, covering much-needed agricultural land and raising the water demand. However, Egypt has long been quoted as a prime example of utilising 'virtual water' to boost its resources; Hoekstra and Chapagain (2008) put the dependency through wheat imports alone as equivalent to 7 per cent of the volume available from the Nile under the 1959 Agreement.

Egypt's need for water has had violent political repercussions already in modern times; in 1956 when the USA refused finance for the construction of the Aswan High dam, Egypt nationalised the Suez Canal to raise the capital itself but then accepted Soviet backing for the venture. The Egyptian leader at the time, President Nasser, described the dam as follows: 'Here are joined the political, social, national and military battles of the Egyptian people, welded together like the gigantic mass of rock that has blocked the course of the ancient Nile.' Nasser also remarked that 'In antiquity we built pyramids for the dead. Now we will build pyramids for the living.'

Aswan has both saved Egypt from famine and constantly posed the problem of providing guaranteed inflows from upstream.

Another historian with a fascination about the Nile is Robert Collins, who uses the word *hydropolitics* to connote the sequence by which the basin has reached its present level of development. Collins (1990) traces history through the lives of those who harnessed the river's water in both Egypt and Sudan. The size of this task is demonstrated by the river's markedly seasonal regime (Figure 5.5). Collins (2006) brings the drama up to date by focusing on the urgent need for international agreement on utilising the waters of the Nile (see below).

5.5.2 'Hydrosovereignty': control of the river

A new phase of development on the basis of dam building began with the first Aswan dam in 1902. Collins (1990) records the history of the long British engineering/hydrological involvement with the river; Garstin's hydrological surveys between 1899 and 1903 heralded the modern phase, although flow records at the ancient 'nilometers' date back to AD 672 (Chapter 1). Sutcliffe and Parks (1999) have recently brought the hydrological analysis up to date but are not recent enough to include the remarkable upturn in Nile discharges which have contributed to Egypt's optimism about diverting more Nile water to Sinai and to the Western Desert (Collins, 2006).

Throughout the centuries, Egypt had established its claim to Nile waters by historic use. However, by 1929 it proved essential to reconcile the Egyptian needs with the growing use of irrigation in Sudan. The Nile Waters Agreement of 1929 merely partitioned the annual flow between the two countries; it did nothing to develop the basin's resources as a whole. H. E. Hurst was the first hydrologist to use data to create a strategy which he labelled 'century storage', a proposal to smooth out the regular variability in Nile flow by increasing storage (principally on the White Nile) to the point where 100-year mean discharges could be guaranteed. Figure 5.6 compares Hurst's design with the existing management and utilisation pattern in the Nile Basin. One major obstruction has, however, always thwarted the notion of century storage – the Sudd, a huge area of floating vegetation and wetlands which physically blocks the river in southern Sudan, detaining and evaporating half of the inflow. The area of the Sudd fluctuates according to climatic conditions in the headwaters of the White Nile, as Table 5.8 shows. In 1925 the Egyptian government approved a scheme to cut through the Sudd in order to reduce detention and evaporation.

Table 5.8 Losses in the Sudd

	Precipitation 7.5 km^3	
Inflow 21 km^3	*Area (average) = 8,300km^3	Outflow 14.3 km^3
	so loss = 21 + 7.5 – 14.3	
Areas of floodplain	*pre-1960*	*post-1960*
Permanent swamp	2,700 km^2	16,100 km^2
Temporary swamp	10,400 km^2	13,600 km^2

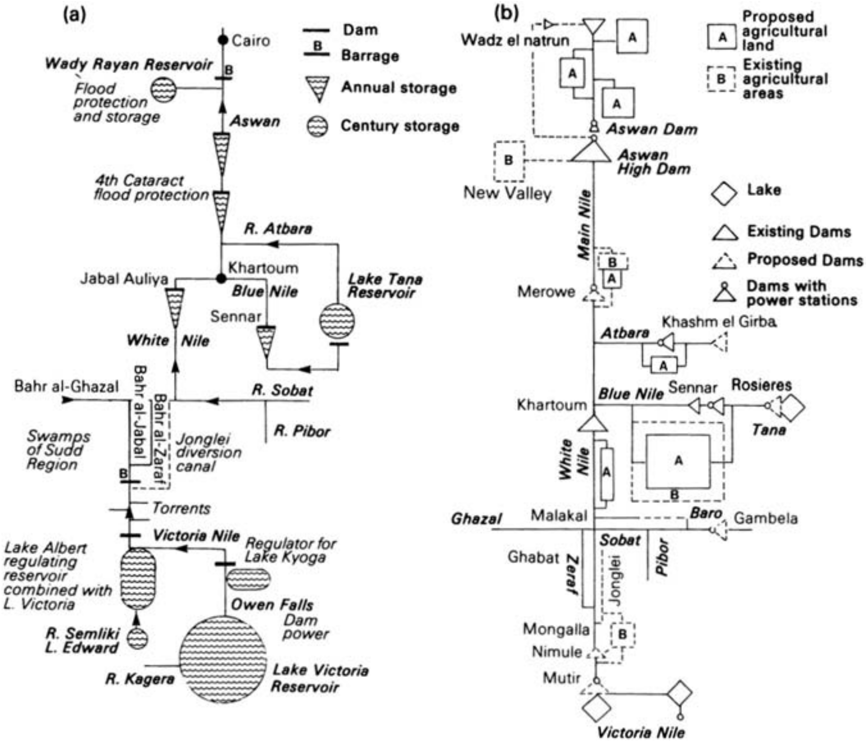


Figure 5.6 Nile water resources – dreams and reality:
(a) Hurst's plan for 'century storage', indicating the value of the upper White Nile (Collins, 1990)
(b) Actual developments in resources, showing the concentration on Egypt/Sudan (Fahim, 1981)

5.5.3 Jonglei: long promised, incomplete through war, failed mega-project?

After the Second World War, British officials in Khartoum assembled a Jonglei Investigation Team which was to survey the desirability of reducing evaporative loss with minimum impact on the living and economy of the people of the Upper Nile, an early example of environmental impact assessment. The canal was planned to be 360 kilometres long, 28 to 50 metres wide and 4 to 7 metres deep. The Jonglei Investigation Team's four-volume report was published in 1954 but its findings have been refined and updated (Howell *et al.*, 1988). As part of the work undertaken by the Jonglei Investigation Team, Sutcliffe (1974) surveyed the floodplain regions of the Sudd in relation to inundation patterns and the resulting spatial distribution of vegetation, the basis of the existing rural ecology. Later Sutcliffe and Parks (1987) used a simple mathematical model to predict the areas of inundation under various natural and modified flow regimes. Howell *et al.* (1988), in their volume devoted to the Jonglei Investigation Team's work, conclude:

> The fact of the matter is that water evaporated in the Sudd region is not a total loss; it has its vital local value in the subsistence economy and has done from time immemorial (Laki, 1994). It also has potential for future development in the Jonglei area. In this context there are fundamentally different perceptions of riparian rights. For downstream users, water saved from evaporation by major drainage or diversion works financed by them is 'new' or 'additional' water; it is water saved and theirs by right (conveniently forgetting that the 2m of water lost annually from the surface of Lake Nasser represents twice the losses from the Sudd – Pearce, 1994). For those who live in the Jonglei area . . . in the process of seasonal inundation of the floodplain valuable economic assets in pasture and fisheries are created.
>
> (Howell *et al.*, 1988, p. 468)

As a result of civil war in Sudan and continuing unrest, all work on the Jonglei Canal, begun in 1978, has ceased, probably around 1984; however, the Sudanese government vowed in 1994 to complete the project.

5.5.4 Aswan and Lake Nasser: plus and minus

For the foreseeable future Egypt and Sudan will need to maximise the benefits of the Aswan High dam. In order to carry through this project a second Nile Waters Agreement was signed in 1959, dividing 'the spoils'. The Aswan scheme has been documented (e.g. by Fahim, 1981) in terms of construction and early impacts, both positive and negative. Fahim writes:

> As the controversy over the Aswan High Dam began to intensify during the early years of the 1970s and was especially aggravated by increasing conflicts between facts and fiction, science and politics, in both domestic and international circles, it became essential to tackle the dam's dilemma on a scientific basis and in a way that would realistically account for the technical and human issues combined.
>
> (Fahim, 1981, p. xiii)

Four major problems with Aswan are generally agreed:

(a) water loss from Lake Nasser by seepage and evaporation;
(b) sedimentation in the lake and degradation below the dam and in the delta;

(c) waterlogging and soil salinity from year-round irrigation;
(d) increase in disease, especially schistosomiasis.

There is no sign of an end to controversy, rival sets of views and 'facts' offered freely on every topic. Egyptians are sure of the impact of the dam in preventing famine in 1972 and 1984/1988 – for this they are prepared to accept some costs. As Collins (2006) puts it, 'While the Nile waters stored behind the high dam enabled the Egyptians to survive without loss of life, one million Ethiopians perished from famine when the rains did not arrive' (p. 116).

5.5.5 Nile basin planning – sharing data but not opportunities

Efforts continue to bring about political consensus on the planning of the Nile as a basin resource. During negotiations over the Nile Waters Agreement of 1959, Ethiopia launched a major study which proposed four major dams on the Blue Nile, producing three times more electricity than the Aswan High dam, virtually eliminating the seasonal fluctuations of flow into Sudan and reducing the total flow by 8.5 per cent. The losses are accountable to evaporation, but this is much reduced, compared to Aswan, in the mountains of the Blue Nile headwaters. Ethiopia's democratic federal government has other calls on its finances and, despite food demand increasing at 6 per cent per year, its Ministry of Water Resources has yet to bring forward proposals for either consumptive (irrigation) or hydro-power development on the Blue Nile (Collins, 2006).

Bewket (2002) suggests a dynamic land cover picture in the Blue Nile headwaters during the latter twentieth century. Hurni *et al.* (2005), using conventional plot studies of runoff and erosion, suggest a positive correlation between population growth, cultivation at the expense of tree cover and sediment yield to the Nile over the longer term, with soil and water conservation measures being most successful in the semi-arid test areas. In the White Nile basin, with the demise of the Jonglei Canal, attention switched in 2006 to the problem of Lake Victoria's water level; the Ugandan government was accused in the media of using 3 per cent of the lake's water to generate hydroelectric power, reducing its level by half a metre compared to an internationally agreed water line.

As for multinational forums in which use of the Nile can be discussed, the Nile Basin Commission (set up by the 1959 Agreement) was mainly a technical and hydrometric organisation but it spawned a grouping of riparian nations (Egypt, Sudan, Uganda, Zaire and the Central African Republic) as the UNDUGU ('Brotherhood') group. Rwanda and Burundi also joined and the aim was to encourage Kenya, Tanzania and Ethiopia to join, moving towards a Nile Basin Economic Community (Samir, 1990). TECCONILE

(Technical Cooperation Committee for the Promotion of the Development and Environmental Protection of the Nile) presented UNDUGU with the Nile River Action Plan in 1994. This 'innocuous' proposal (Collins, 2006) – largely concerned with data collection and capacity building – was not disputed, but the Ethiopian Minister for Water Resources demanded ominously that 'Ethiopia has a right to have an equitable share of the Nile waters and reserves its rights to make use of its waters'.

A small-scale action research programme called ECONILE is described by Mason (2005); it set up dialogue workshops over a three-year period to move the main players (Egypt, Sudan and Ethiopia) from their entrenched positions (described as 'scorpion' or 'ostrich') to exploratory, knowledge-based communication.

Most recently, as described by Metawie (2004), the Nile Basin Initiative, a transitional institutional mechanism, was launched with these objectives:

- to develop the water resources of the Nile basin in a sustainable and equitable way to ensure prosperity, security and peace for all its peoples;
- to ensure efficient water management and the optimal use of the resources;
- to ensure cooperation and joint action between the riparian countries, seeking win–win gains;
- to target poverty eradication and promote economic integration;
- to ensure that the programme results in a move from planning to action.

5.6 River basin development authorities: experience elsewhere in sub-Saharan Africa

As told us by politicians and pop stars alike, Africa is different. Ashton (2002) draws attention to the problems of climatic variability and contested, international basins or aquifers in a context of dramatic population growth and attendant diminishing per capita availability and quality degradation. Vorosmarty *et al.* (2005) use an earth systems science approach on global databases to gain the overview of water stress so often missing from treatments of the world's second-largest and poorest continent. Africa is, they conclude, 'more than simply dry'; chronic water stress is high for 25 per cent of the population, and 40 per cent experience drought stress once each generation, but poor water delivery structure is also a major factor. Douglas *et al.* (2007) examine water stress in the Lake Victoria basin to forge the socio-economic links to biophysical constraints from *existing databases*: delays in strategic guidance cannot be afforded in Africa.

5.6.1 The Awash Valley Authority, Ethiopia

The Awash Valley Authority was established in the pre-revolutionary Ethiopia of Emperor Haile Selassie in 1954. Ninety per cent of Ethiopia's estimated 52 million people live in the central highland area where rainfed agriculture is feasible most years but where population pressure (growth of 2 million per year) has led to significant soil erosion losses (Plate 6.1). This loss is often generalised as being due to deforestation, but, as Williams (2000) points out, the abandonment of fallow periods in the cropping cycle may be to blame for the enhanced erosion rates. As Williams puts it, 'The concept of recent, progressive and linear deforestation in the Ethiopian highlands is therefore open to question' (p. 241). We return to this question in Chapter 6.

Whilst 6 million hectares are currently cultivated, half as much again could yield food and cash crops with irrigation. Rivers radiate from the highlands ('the water tower of Africa'), many sourced in erosional gullies. Situated in convenient proximity to the nation's capital, Addis Ababa, the Awash valley stretches 700 kilometres towards the Djibouti border across the Rift Valley, its flow sustained by 14 tributaries but its course succumbing to aridity in the shallow Lake Abe (Figure 5.7). The highland rainfall of 1,000 mm/yr decreases to 200 mm/yr in the Rift, and rainfall is very unreliable; nevertheless irrigable soils constitute 24 per cent of the valley area. The indigenous agriculture consists of livestock, with cattle, sheep, goats and camels migrating in search of grass and water.

The Awash Valley Authority was set up to coordinate the activities of government ministries in the valley, to charge for the use of water, to conduct surveys and to administer water rights. The development plan followed by the authority was highly ambitious prior to the Marxist revolution of 1974, itself a result of Sahelian drought. Winid (1981) describes the plan's objectives as including policy change to promote development, social and health surveys, feasibility studies for irrigation, flood control and hydro-power, establishment of agro-industries and infrastructure improvements to permit tourism. Winid describes seven run-of-river irrigation sites in the upper and middle Awash, together with some smaller areas of the lower Awash (Figure 5.7); however, dam sites to increase the scope of irrigation and to generate power for industry are continually prospected.

The calculation of benefit–cost ratios for developments in the Awash is, according to Winid, markedly influenced by the balance between the cultivation of food and cash/industrial crops. The latter have dominated; this in turn determines the fate, in development, of native nomadic pastoralists (cover picture), who must be settled to form a labour force, joined by other migrants from troubled regions of Ethiopia. However, the Awash schemes for resettlement have been failures, with the true costs of resettlement soaring. No attempt was made to integrate an improved traditional livestock sector with the plantation irrigated agriculture. The Awash Valley Authority was wound

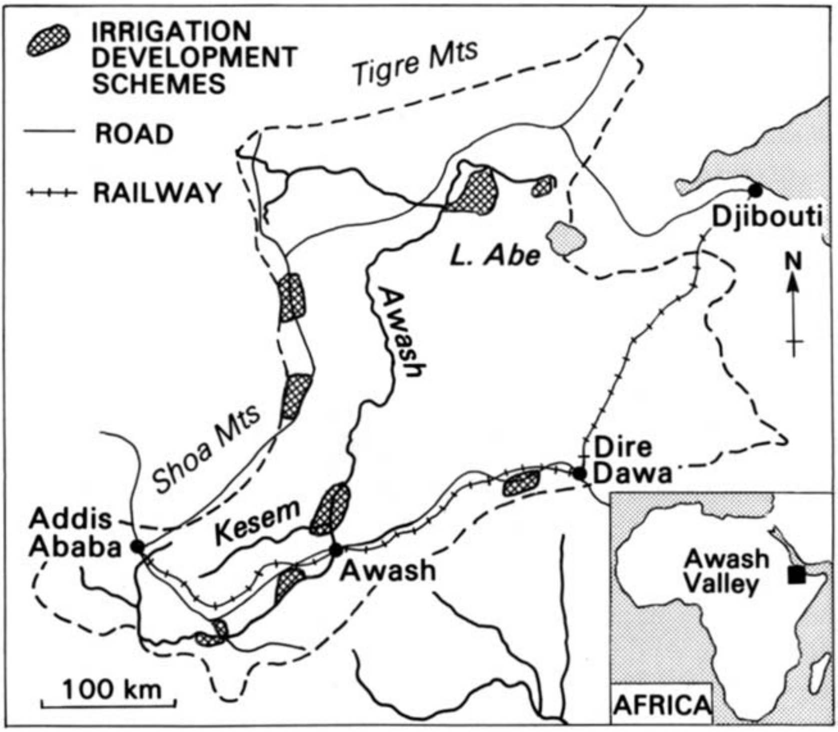


Figure 5.7 The Awash valley, Ethiopia and schemes developed by the former Awash Valley Authority (after Winid, 1981).

up by Ethiopia's centralist Marxist government in 1981 in favour of stronger ministerial roles in water developments.

Administrative change had little impact on the 'mega-project' philosophy to Ethiopian land and water development. In the midst of drought-induced famine in 1986, the author was a member of the British team which investigated the feasibility of a dam on the Kesem tributary of the Awash, one of four dam sites suggested by the Awash Valley Authority in the 1960s. It was found to be unfeasible through the high predicted rates of siltation and the world market for its proposed irrigated cash crops. Plate 5.3 shows the dominant traditional small-scale irrigation of crops on the Kesem floodplain: an example of appropriate technology.

Abate (1994) has recently updated the water resource development picture for Ethiopia. He is critical of the fact that 'there is no thorough attempt to base organisational structure on the requirements of development programmes. What should have been considered is the functional compatibility of the organisation [the new Ethiopian Valleys Development Studies Authority: EVDSA] with the requirements of the development programme' (one

Plate 5.3 Small-scale irrigation in the Kesem valley, Awash Basin, Ethiopia.

which Abate considers should have been more 'bottom up' and much less based, by the former Communist government, on social settlement models). The present government of Ethiopia is encouraging regional resource development and, as yet, the implications of this decentralisation for water resources have not become firm.

In 1994 a national Ministry of Water Resources (MWR) was set up as a single unified public agency. It promotes small-scale and traditional irrigation schemes. The need is dire; given the annual population growth rate of 2.9 per cent, the annual growth rate of per capita food demand of 6.3 per cent and the proclivity of the region to severe drought, MWR faces every temptation to act unsustainably. A recent survey of agricultural water management practices under drought conditions in the Upper Awash (Desalegn *et al.*, 2006) suggests that there exists a whole suite of coping mechanisms, both agricultural and for conflict resolution, in such communities; information such as this was not available to those working on the Kesem dam scheme.

5.6.2 The Tana and Athi Rivers Development Authority, Kenya

Like Ethiopia, Kenya has a burgeoning population highly concentrated in its humid zones with an acute problem of peripheral aridity. However, it has a more pronounced and more recent colonial European past and had, until recently, fewer problems of war, drought or famine than has Ethiopia. Severe drought in recent years, punctuated by equally damaging floods and exacerbated by the pressure of thousands of Somali refugees, has begun to impact on agriculture. Tribal and border clashes over access to water by herders have also been a feature of the drier conditions.

Mogaka *et al.* (2006) estimate that floods and droughts cost Kenya 2.4 per cent of gross domestic product each year on average (up to 14 per cent in extreme runs) and 0.5 per cent GDP for general water resource degradation (Table 5.9). A particular problem, one faced by many dryland nations, is that 72 per cent of Kenya's power is hydro-electric. Kenya's president has pronounced that 'improvement in the management of water resources is a top

Table 5.9 Impacts of floods and droughts on the Kenyan economy

Extreme event	*Sector*	*Physical impact*
Floods	Water supply	Extensive damage to water supply and sanitation infrastructure.
	Transportation	Roads and railways damaged/disrupted.
	Agriculture	Silting or destruction of small dams; losses of crops and stock.
	Health	Food losses affecting especially children's health. Increased incidence of water-borne disease after flooding. Some damage to health facilities.
	Education	Schooling disrupted – transportation damage, children required to seek clean water.
	Tourism	Infrastructure disruption, especially roads. Damage to ecosystems (e.g. coral reefs).
Droughts	Agriculture	Reduced crop harvest. Loss of livestock. Additional veterinary costs and feed supplements.
	Fisheries	Additional overfishing. Reduced aquaculture production.
	Forestry	Increased illegal felling, fires, grazing.
	Energy	Reduced hydro-power production. Costs of generators and power imports.
	Industry	Reduced production through power shortages. Loss of jobs in relocated industries.
	Tourism	Coastal problems of saline intrusion to water supply. Reduction in wildlife viewing – Rift Valley.
	Water supply	Increased charges in urban areas, queueing. Increased time spent seeking water – rural areas. Increased pumping in urban areas.

After Mogaka *et al.* (2006)

priority in our country', but it is as yet too early to judge the effectiveness of the Water Act passed in 2002 (Mogaka *et al.*, 2006).

The Tana and Athi basins, whose joint authority, TARDA, has been reviewed by Rowntree (1990), total 132,700 square kilometres, containing a significant proportion of Kenya's population (62 per cent), including the capital, Nairobi (Figure 5.8). The principal water yield for both basins comes from the slopes of Mount Kenya and the Aberdares, which receive 2,000 mm of precipitation each year; out on the plains a potential evaporation of 1,200

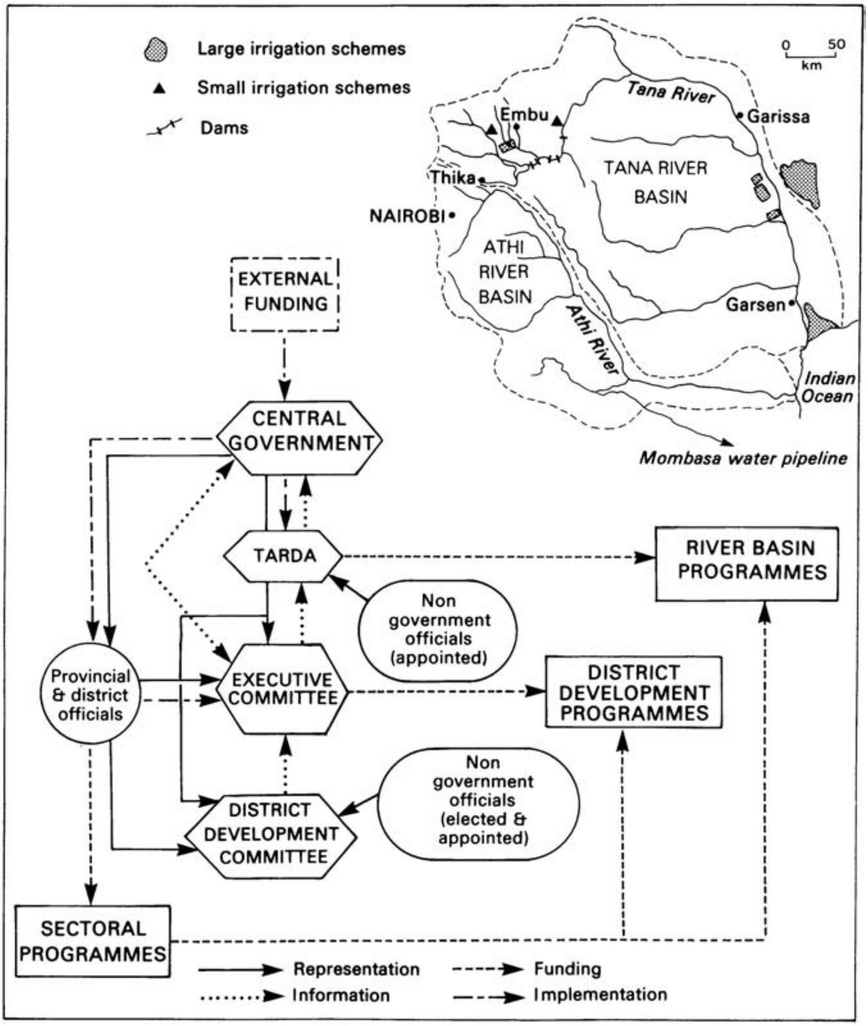


Figure 5.8 The area of the Tana and Athi Rivers Authority and its decision network diagram (after Rowntree, 1990).

mm exceeds rainfall, and *irrigation* forms the basis of most agriculture. An immediate problem of this twofold hydrological division is that, as in the case of the Kesem, the desire to exploit *rainfed agriculture* in the uplands has led to deforestation and soil erosion. Sediment yields of between 109 t $km^{-2}.yr^{-1}$ and 433 t $km^{-2}.yr^{-1}$ are quoted by Rowntree. (Kenya is fortunate at least to have had hydrometric surveys which include measurement of sediment yields.) As well as threatening irrigation schemes downstream by excessive sedimentation, the populous uplands also have a high demand for hydro-electric power (coal and oil must be imported, and exploitation of wood fuel leads to further erosion) and for domestic water supply/sanitation.

TARDA, like that of the Awash in Ethiopia, was designed to coordinate the work of ministries and to balance the competing demands of domestic water supply, hydro-power and irrigation in the basin. The first major project of the authority was the commissioning of the Masinga dam in 1979. It was designed to generate power: Nairobi is continuing to expand and to require power and water; its City Commission appears to Rowntree to act independently of TARDA. Rowntree's sad conclusion about TARDA is as follows:

> We are left with the conclusion that TARDA does not represent an effective framework for regional planning, neither on its own nor through integration with the district focus policy. Both are controlled by top-down planning, by political allegiance to the power elite and by the interests of foreign aid agencies. It may represent a forum through which technocratic solutions to resource development can be promulgated but it is unlikely to achieve the type of grass-roots development that is so essential to effective and lasting development programmes.
>
> (Rowntree, 1990, p. 39)

5.6.3 Nigeria's river basin development authorities

As Toro (1998), an official of the Benue River Basin Development Authority in Nigeria, observed, 'like most third-world countries, Nigeria embarked upon large-scale construction of dams and irrigation-infrastructure facilities without proper planning and coordination' (p. 212). River basin development authorities (RBDAs) in Nigeria date from 1960; in 1976 an extraordinarily wide brief was laid down by government to include water resource development and flood protection but also watershed management (including afforestation), control of pollution, resettlement, land clearance, agricultural research, crop processing and rural water supply. Adams (1985), discussing the performance of RDBAs (he cites 11), reveals the following shortcomings:

(a) over-reliance on large projects: dam construction and irrigation development;

(b) inadequate economic, environmental and social appraisal;
(c) ineffective population resettlement;
(d) almost total lack of attention to watershed management and pollution control.

A worrying paradox is that strengthening the role of the authorities would seem to require the collapse of the river basin unit into a state or regional bureaucratic unit, merely to improve the chances of collaboration and adequate financial resources. Another set of shortcomings, in the implementation of IWRM by the RBDAs, is identified by Akpabio *et al.* (2007). Using the Cross River Basin as an example of the 11 authorities in Nigeria, these authors detect a number of legal, political, administrative and financial obstacles. The abundant water resources of the basin make it difficult to make a powerful point for careful management in the face of considerable corruption and of inherent weakness in dealing with other parts of the Nigerian bureaucracy.

Toro (1998) concludes that, in the face of increasing drought, especially in the rainfed agricultural regions of northern Nigeria, the government should take a central lead on:

- gathering vital hydrological data;
- promoting small earth-dam programmes, less expensive, with faster returns on investment;
- developing small-scale, farmer-operated irrigation schemes;
- involving communities;
- implementing water transfer schemes, notably to protect Lake Chad.

Lake Chad depicts, like the Aral Sea, the consequences of unsustainable land and water development, exacerbated in this case by climate change. The Lake Chad basin is almost a million square kilometres and home to 20 million people, 12 million of whom live in Nigeria – so Nigeria has a leading role in the Lake Chad Basin Commission formed in 1964 (Cameroon, Niger, Chad and the Central African Republic are also members). Lake Chad's volume has fallen by 60 per cent in 40 years, whilst its area has declined from 25,000 square kilometres to 2,000 square kilometres. A canal is planned to bring water from the Zaire to augment the supply to Lake Chad but also to generate hydro-power at two dams and to irrigate a further 5 million to 7 million hectares of land.

5.7 South Africa: a unique water management experiment

In view of these problems with IWRM/IRBM in Africa, a particularly interesting challenge is that now faced by the people of South Africa; their colonial past, engineering skills and relative wealth have led to a highly structural set of solutions to massive water shortage – highly dependent on dams (Figure 5.9). The ending of apartheid in 1993 and the election of a government committed to the rights of the black population in 1994 effectively meant a fresh start on all issues of water resources, rights, distribution systems and planning. In an atmosphere of political release, democratisation and popular empowerment it is extremely interesting to see how the previously technocratic management of rivers is 'opening up' and how the needs of non-human biota can be incorporated against a background of huge human needs. At the outset, however, we need to consider the advantages held by South Africa in the continent: Binns (1998) quotes the UN's Human Development Index (HDI) as indicating South Africa's elevation above the 14 African nations at the bottom of the world league in this respect; only Botswana in sub-Saharan Africa scores a higher HDI. However, 45 per cent of South Africans do not have a water supply inside their home, and the HIV/AIDS epidemic is currently driving down its HDI; HIV/AIDS is also a factor in predicting future population and per capita water requirements.

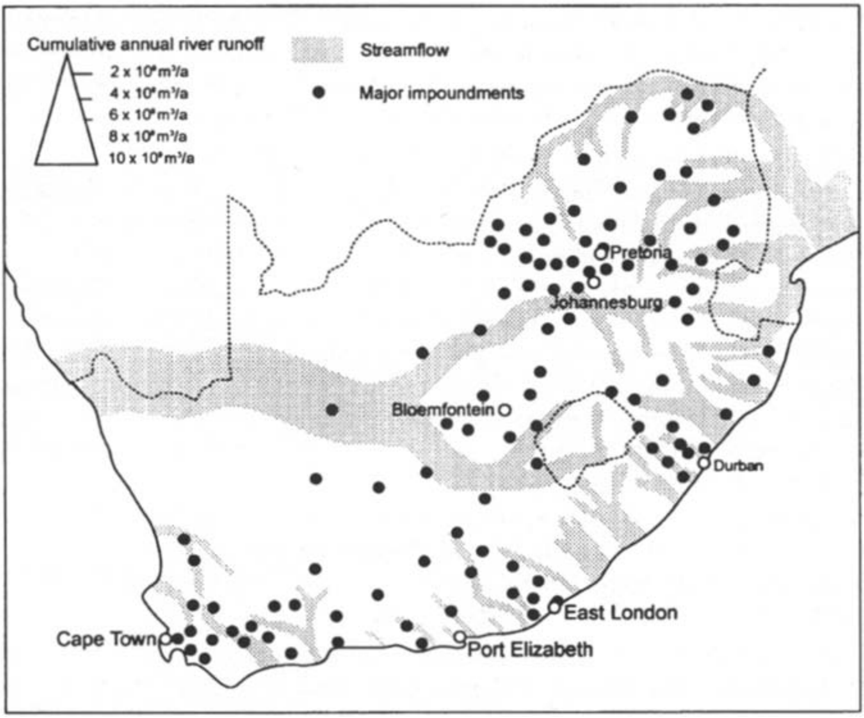


Figure 5.9 River flow and major dam impoundments in South Africa (note how the major centres of demand are remote from the major surface water resources) (after Department of Water Affairs, 1986).

Schulze *et al.* (2004) demonstrate how policy, science and management require urgently to jointly focus on the ambitious IWRM programme initiated by the new government's Water Services Act (1997) and the internationally respected National Water Act of 1998 (Tewari, 2005).

5.7.1 Starting afresh: the 1998 National Water Act (NWA)

The White Paper laying out the Mandela programme for water (DWAF, 1994) puts the South African problem succinctly: 'In a country with nuclear power, cellular telephones and vast inter-catchment water transfer schemes, more than 12 million people do not have access to an adequate supply of potable water; nearly 21 million lack basic sanitation' (p. 1). The urban water situation is typified by Johannesburg, sited not on a river or other reasonable water supply but because of gold mining and therefore both short of water and in danger of excessive pollution (Turton *et al.*, 2006). There are other problems:

> The mean annual rainfall of 500mm is only 60 per cent of the world average. It is poorly distributed relative to areas of need. On average only 9 per cent of rainfall reaches the rivers. The country is vulnerable to droughts and floods. The groundwater is sparse and often saline. South Africa's abundant natural riches are scattered across the country, while most of the rain falls near the south-eastern seaboard.
>
> (Conley, 1989)

Schulze (2000) takes the variability and sensitivity of South African water resources a stage further by stressing the degree to which the spatial and temporal variability and unpredictability of the resource is heightened by climate change and, especially, by land-use change. Salient features of the NWA are presented in Box 5.3.

Information and decision support systems are seen as vital to the programme (Schulze *et al.*, 2004); the sophistication of the water management system operating before the birth of the new South Africa helped create a large database of both hydrometric and land-use statistics, together with modelling and decision-support capabilities. The former Department of Water Affairs published in 1986 the 'Red Book', a comprehensive compilation of information about the national and provincial water situation. The small but flourishing freshwater science community in South Africa has been vital to supporting institutional progress; vital stimulation was provided by the impressive hydrological atlas of Schulze (1997) and the book *Vanishing Waters* (Davies and Day, 1998). Conley (1989) had earlier emphasised the role of high-technology solutions to sustainable river basin development – not as *construction* technology, but *information* technology to plan, interact with communities and resolve conflicts.

Box 5.3 The National Water Act for South Africa (1998)

Policy principles of the 1998 National Water Act include:

- Development should be demand driven and community based.
- Basic services are a human right.
- ‘Some for all’, rather than ‘all for some’.
- Equitable regional allocation of development resources.
- Water has economic value.
- The user pays.
- Integrated development.
- Environmental integrity.

(See also Newson, 1997, Table 9.8.)

The National Water Act (DWAF, 2002a, 2002b) has behind it the strength of the 1996 Constitution, which states:

- Everyone has the right to have access to sufficient food and water.
- Everyone has the right to an environment that is not harmful to their health or well-being.
- The environment must be protected for the benefit of all people living now and in the future.
- National government is the custodian of the sources of water, such as rivers, groundwater and dams.
- Local government is in charge of municipal water services.

The Act re-establishes water as a public good in South Africa, with the state holding the burdensome responsibility of allocation, this after 300 years of water rights following the riparian (ownership) principle (Tewari, 2005). The Act divides South Africa into 19 water management areas (WMAs) based on major watersheds, within which the management scale is the catchment, a job carried out by catchment management agencies (CMAs). Since the principal political drive of the Act is allocation of scarce resources (both to humans and through an ‘ecological reserve’), the ‘nuts and bolts’ of management are labelled ‘resource-directed measures’ and include classifying the present status of the resource before defining ‘the reserve’ for both humans and ecosystems. The basic human needs reserve includes water for drinking, for food preparation and for personal hygiene. The concept of the reserve is shown in Figure 5.10 and is considered a major contribution to the way forward in sustainability policies. Within the larger areas managed by CMAs the local interest is served by water user associations (WUAs), principally irrigators but including the municipal water supply organisations. The irrigators come principally from the former whites-only irrigation boards, but now that water rights and land ownership are

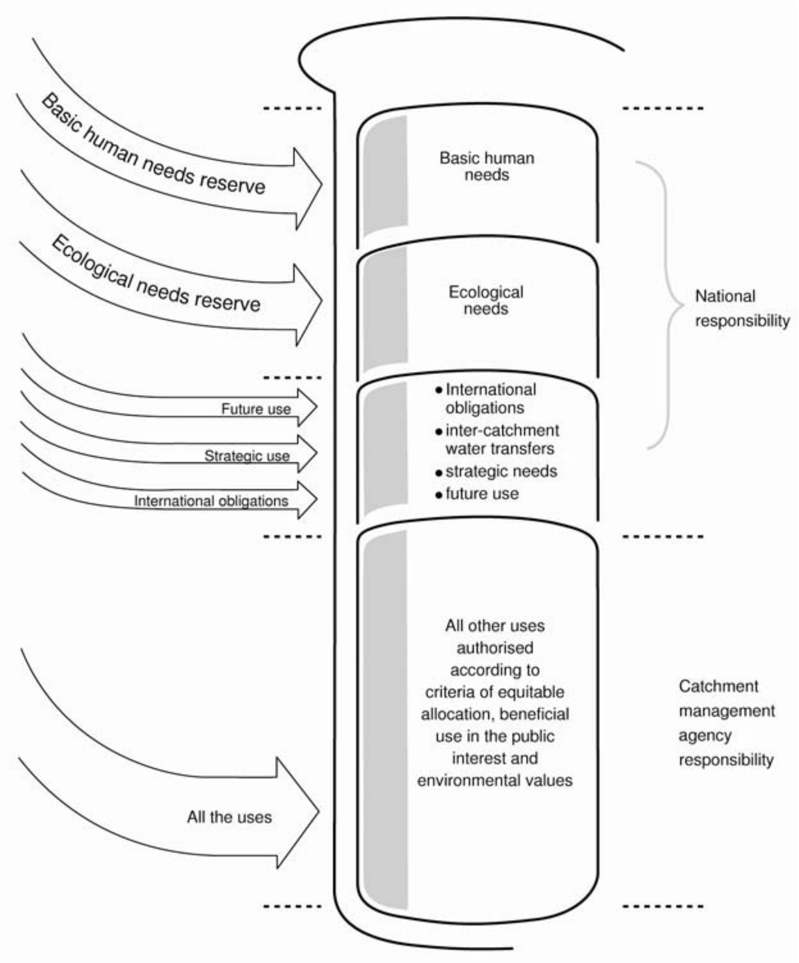


Figure 5.10 Water allocation under the National Water Act in South Africa (from graphics widely used by the Department of Water Affairs and Forestry, Pretoria).

being disconnected there is considerable pressure to make the WUAs open to historically disadvantaged individuals (HDIs). This will occur most easily in the former homelands where smallholders dominate, but the transformation of the irrigation boards is making slow progress (Faysse, 2004).

The Act has also encouraged substantial moves towards public participation – a vital communications core to a successful 'Rainbow Nation' and one that disciplines and channels the undoubted technocratic potential and legacy of river science in South Africa towards simple explanation and the inclusion of indigenous knowledge. The use of economic instruments has become widespread as a mechanism of domestic demand management: Greater Hermanus and Durban have block tariffs by which they can make essential volumes available at low price but gradually create prohibitive prices as water use enters the luxury category. The allocation of water rights is in the power of the state, but the Act does not impede the development of water markets (Döckel, 2006) which might be effective in shifting surpluses from profligate traditional users to newly enfranchised ones. Another, heavily debated, impact of water allocation has been the privatisation of water supplies, which many judge to be in danger of flouting or at best compromising the Constitution (Flynn and Chirwa, 2005). However, the involvement of global capital and technical expertise in brand new infrastructure development is hard to ignore, and it was no accident that the WCED which acknowledged this was in Johannesburg.

5.7.2 Catchment management under the National Water Act

Amongst the land-use conflicts facing the new South Africa in relation to water management are:

- afforestation (partly the reason for the new joint department);
- thermal power generation and use of cooling water;
- irrigation – the biggest water user;
- construction of farm dams on headwaters;
- informal settlements (‘townships’) peripheral to cities;
- the needs of biodiversity, both in high-profile sites (e.g. Kruger National Park: Rogers and Biggs, 1999) and of endemic species generally in a global biodiversity ‘hot-spot’.

There are rapid moves towards integrated catchment management in South Africa (Stoffberg *et al.*, 1994). Clearly, as in the UK, catchment plans become activated only in a context of national and local strategic and development control planning. In a strongly sectorised administration like South Africa, the new government challenge to local government to implement Integrated Development Plans (Sowman and Brown, 2006) may well, if successful, provide the right medium for catchment plans. At present, however, in the hands of the fledgling catchment management agencies, there are inevitably distractions caused by the politics of forging collaborations, within water, with relevant stakeholders in other resource management agencies and with the basin polity in general. Waalewijn *et al.* (2005) detect too great a concentration on structures and authority in their Lower Komati case study.

In terms of rural land-use problems, land degradation has become the focus of a South African contribution to the United Nations Convention to Combat Desertification (UNCCD) (Meadows and Hoffman, 2002). This used remote sensing and mapping, grounded via 34 workshops in each of the country's agricultural regions, to gather the experience of agricultural extension officers and soil conservation technicians. It was found essential to divide the assessments of both soil and vegetation damage into those on commercially farmed lands and in communal areas, the latter being characterised by higher levels of poverty on physically marginal land. The results are not startling on a world scale but become so when they exacerbate the water management problem (for example, the Hazelmere dam in KwaZulu-Natal lost more than a quarter of its capacity through sedimentation in 30 years). Both arable cultivation and intensive grazing are causes of degradation; reduced livestock pressure has been found to bring improvements in badlands extension in the Karoo region (Keay-Bright and Boardman, 2006). Dollar and Rowntree (1995) point to the need for cautious geomorphological interpretation of the rival explanations of climate change, poor agricultural practices and intrinsic channel processes in explaining the sediment dynamics of South African rivers.

The use of land in South Africa for commercial forestry dates back to the 1870s. It mainly employs exotic tree species which thrive largely through making a large transpiration demand to promote rapid growth. A permit system was introduced in 1972 but despite the importance of the timber and timber products sector of the economy its environmental impacts, especially on river flows, have become the focus of more recent strictures (van der Walt *et al.*, 2004). It is not surprising that a nation with a government Department of Water Affairs *and Forestry* labels forestry as a 'streamflow reduction activity' and allows no further tree cover if mean annual runoff is reduced by certain threshold values. The research base for this restrictive approach is amongst the best in the world and follows long-term catchment experiments under different crops (e.g. *Pinus radiata* and *Eucalyptus grandis*) in different climatic conditions and different parts of the crop cycle (see Scott and Lesch, 1997; Lesch and Scott, 1997): impacted streams dry up in areas where the available runoff is naturally low.

Another land-use problem with direct impacts on runoff is that of invasive alien plants. Around 161 plants are regarded as invasive, and they cover 8 per cent of the land, utilising around 7 per cent of the country's total runoff. The costs and benefits of controlling alien plants have been compared and justify a control programme – far beyond the economic value of runoff sacrificed (van Wilgen *et al.*, 2001). In an inspired scheme entitled 'Working for Water', begun in 1995, the Reconstruction and Development Programme employs 23,000 people, the majority of them women, to cut, clear and burn invasive plants (McQueen *et al.*, 2001). In parallel there is now a 'Working for

Wetlands' programme, employing 2,230 previously disadvantaged people, including those with HIV/AIDS.

Eco-tourism has the potential to become a major employer and earner of foreign exchange in South Africa and so protection of biodiversity is crucial, both of terrestrial species against loss of habitat to irrigated lands or the reservoirs which feed them and of freshwater species needing ecologically acceptable flows in rivers beneath abstraction points. Issues such as the development of irrigation, forestry and public water supply upstream of the Kruger National Park (Gore *et al.*, 1992; van Niekerk and Heritage, 1994) indicate that conflicts will be enormous. Dam construction (both on a large scale and at the farm level) has been the widespread solution to supply problems; demand management has hitherto been politically unthinkable. However, progress is being made on the assessment of the environmental resources and sensitivities of South African freshwater ecosystems (see Chapter 6).

5.7.3 Sharing or stealing: facing basin closure in South Africa

Finally, given the gloomy resource projections and the threats of climate change, South Africa is necessarily concerned with inward water transfers across international boundaries. This strategy, born of engineering optimism and resource desperation, is at odds with the geomorphological, ecological, social and political sensitivities of the basins concerned (Snaddon *et al.*, 1998). The Lesotho Highlands Water Project, on the drawing board since the mid-1950s, was financed by the World Bank following the end of economic sanctions against South Africa. Lesotho occupies only 3 per cent of the Orange River catchment but contributes 47 per cent of its flow (Makhoalibe, 1999; Keketso, 2003). The scheme seeks to dam the headwaters of South Africa's major surface water source (see Figure 5.9) and to divert the regulated flows northwards towards Johannesburg and Pretoria. In return, Lesotho (which is landlocked by and totally dependent on South Africa) gains finance, perhaps 40 per cent of its export budget, infrastructure and hydro-electric power generation (Nel and Illgner, 2001). Local people who have lost land have been compensated with corn or with jobs on the project but protests and bribery have been rife (according to Horta, 1995), and the prediction of 'no major environmental obstacles to the project', made in 1986, is being reconsidered as biologists carry out surveys of the biota impacted. The Katse dam, the Project's first, was completed in 1996 and filled by 1997.

There is no doubt that South Africa will need a further development of water storage: more dams or more transfers from its neighbours. However, in future the water needs of all the southern African nations need to be considered jointly as part of a trade grouping in which 'virtual water' is moved, rather than the raw material itself (Conley, 1996; Ashton, 2004). Beukman

(2002) revisits the role of the Southern African Development Community (SADC), where all 14 nations share at least one river with a neighbour (Mozambique shares nine!), with 11 of them facing water stress, scarcity or seasonal drought. She concentrates on the IWRM progress in the region rather than configuring possible regional trade-offs; these are the responsibility of the SADC Water Sector, which now operates a coordination unit and a protocol for developments affecting the shared watercourses. Equally (and perhaps opposite) NGOs are beginning to use the regional framework to point out development threats (Pottinger, 1999).

5.8 Land use writ large? Himalayan headwaters and the GBM

Like the Nile, the Ganges (Table 5.10) is a truly remarkable international river basin, with a dominant exploiting nation in the form of India, for which the river contributes a quarter of the available water resources. The basin constitutes 26 per cent of the nation's land, housing 43 per cent of its irrigated land.

Table 5.10 Essential data for the Ganges river basin, including global indicators

Data/indicator	*Value*
Basin area	1,016,104 km^2
Population density	375/km^2
Urban growth rate	3.3%
Large cities	14
Total fish species	–
Fish endemics	–
Threatened fish species	0
Endemic bird areas	0
Ramsar sites	0
Protected areas	4
Wetlands	1
Arid	43
Forest	7
Cropland	63
Irrigated cropland	27
Developed	7
Shrub	2
Grassland	20%
Barren	0%
Original forest lost	77%
Deforestation rate	11%
Eroded area	1%
Large dams	3
Planned major dams	–

From Revenga *et al.* (1998)

Additionally 'Ganga' has constituted a basis for successive dynasties in India's history and a firm religious theme of life-giving significance; the Hindu god Shiva collected Ganga's waters from heaven in his matted hair that the ashes of human dead might be purified for their return to heaven (Darian, 1978). Vignettes of the significance accorded to the river in everyday life and in frequent festivals are painted by its many author-travellers (e.g. Pavan, 2005; Trojanow, 2005). The river is most often considered together with its prominent tributaries – the Brahmaputra and Meghna – hence 'GBM'.

Indians bathe, water cattle, wash clothes and utensils, defecate, cremate their dead and conduct the other waste activities of 27 cities of over 100,000 people in the River Ganges; it is sacred in what we might call a 'pre-hygienic' way. A Ganga Action Plan targets sewerage improvements for the 27 cities larger than 100,000 population along its banks, notably Varanasi, where Hindus believe they will achieve liberation for the soul by the river (Ahmed, 1990). The ecosystems of the Ganges are but little understood; conservation focus falls on the Ganga river dolphin *Platanista gangetica*, which is now the subject of international action. However, the major system concern for decades has been the degree to which 'upstream' and 'downstream' phenomena are causally connected; simple answers have been proposed and myths perpetuated but the truth remains elusive and a severe challenge for hydrology and geomorphology.

5.8.1 Nepal: a rush to judgement under a myth of Himalayan degradation

In a book devoted entirely to the Ganges and the development of the mountain zone in Nepal (Ives and Pitt, 1988) Ives considers the elements of '*the perceived crisis*' in the Himalaya–Ganges region. They include population growth, poverty, land deprivation, deforestation, soil erosion, downstream flooding, sedimentation, climate change and reduced rainfall.

Whilst true that Nepal's population, now 29 million, is increasing at 2.1 per cent a year, there are other, more fundamental causes for these problems. The Himalaya–Ganges region is one of huge natural instability and of active mountain-building (rising at approximately 6 mm per year in the Everest area); the result is an extremely vigorous background of natural geomorphological evolution (Figure 5.11).

Ives and his colleagues demanded a scaled, geographical approach to the search for solutions in which the people, the village, the region and international policies are reconciled through the flow of viewpoints and information; this has in fact become a model scale-based approach – see Chapter 9 and Figure 5.12. A local argument for a scaled, downstream approach has been put by Bandyopadhyay and Gyawali (1994), who list 22 large dams proposed for the Himalayan region in an environment which has no basin

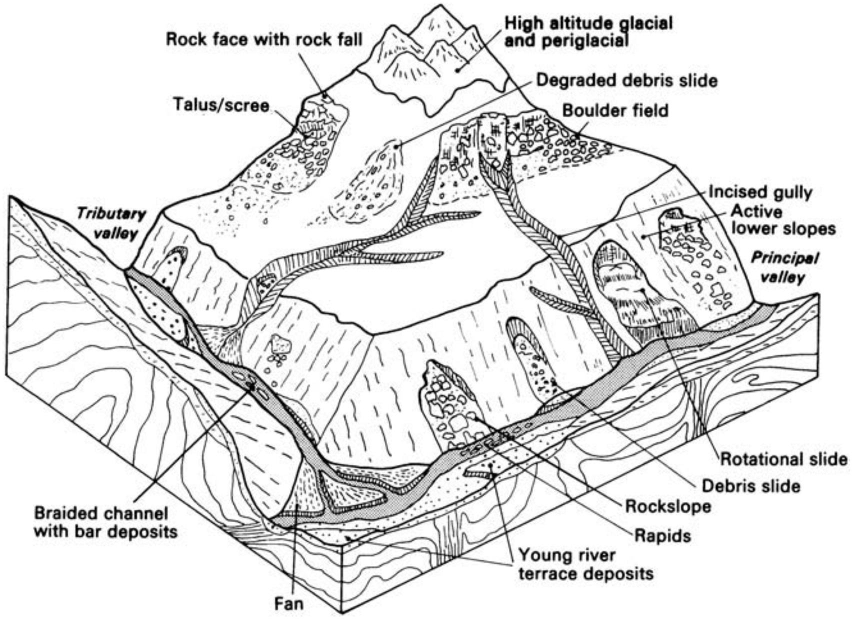


Figure 5.11 The physiographic instability problem of the Himalaya–Ganges region: montane geomorphology and hazard (modified from Fookes and Vaughan, 1986).

organisations and, as a result, no integrated information base from which to make the projects sustainable.

Gilmour *et al.* (1987), undertaking the all-too-rare factual field investigation in Nepal, point out that, whilst soil does become compacted after deforestation and grazing, only 17 per cent of rainfall exceeds the infiltration capacity of such soils to become flood-producing, erosive surface runoff; they also point to the fact that deep-seated landslides are promoted by efficient infiltration, not surface flows (though undercutting of slopes by stream incision must also be a factor). Hamilton (1988) stresses the importance of maintaining a litter layer in forests. Hydrological analysis of trends in Himalayan rainfalls and river flows finds no significant increase in flood flows (Hofer, 1993). Wasson *et al.* (in press) use a rare earth tracer from various geomorphic source zones in the Himalayas to suggest that relatively rare events, such as the flood of 1970 in the Patal Ganga catchment, mobilise landslides preferentially in deforested areas; elsewhere, sedimentation problems in reservoirs, for example, derive from sources in grassland and forest areas.

UK researchers have been part of a major effort to push harder towards an understanding of the complex biophysical and socio-economic problems of the ‘upstream–downstream’ arguments in the Ganges basin. An interdisciplinary study of the Likhu Khola basin of the Middle Hills of Nepal

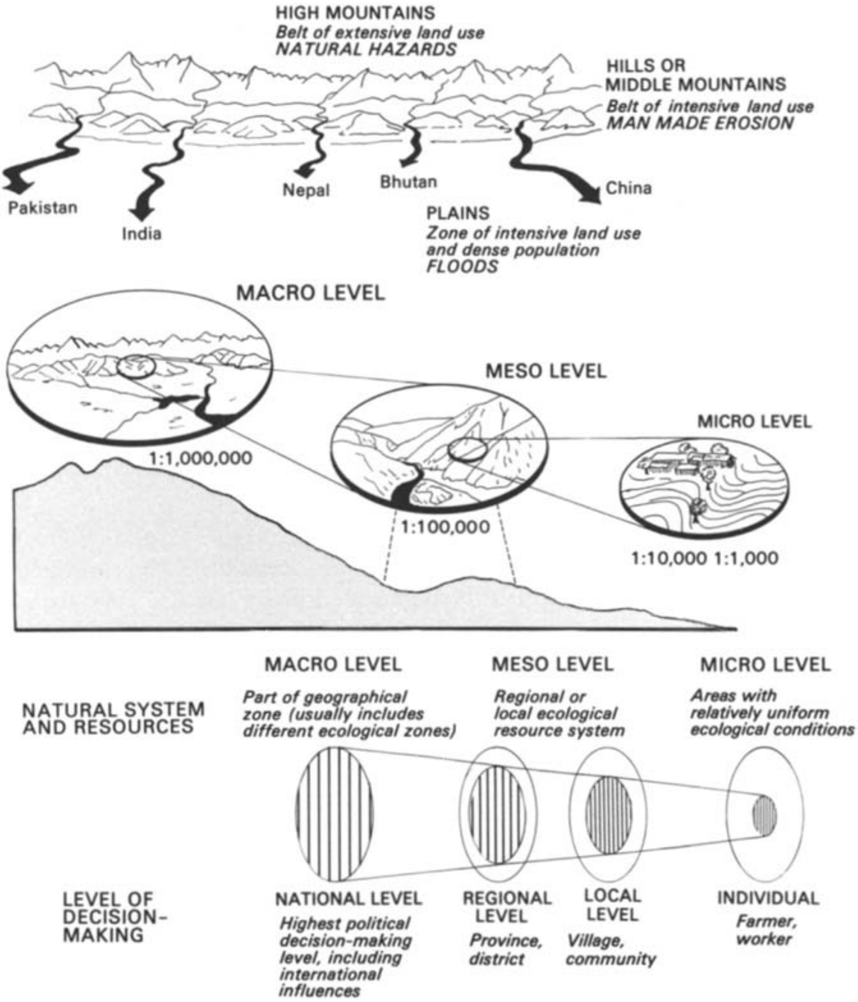


Figure 5.12 Himalayan research: appropriate scales for implementation (after Ives *et al.*, 1987).

(Gardner and Gerrard, 2002) confirmed that the *nature of forestry* is more important than *canopy cover* (the variable often used in estimates of deforestation rates); ground cover, especially leaf litter, is more important in retaining runoff than canopy cover. Rates of deforestation in the area were less than 1 per cent by area in the preceding 24 years, but forest degradation (partial canopy loss, increased bare areas) was rife, leading to increased runoff and sheet and gully erosion. In another part of the UK-funded study, Gerrard and Gardner (2000) noted the impacts on runoff and erosion of the mainstay method of food production in Nepal: irrigated terraces. Cultivation of irrigated rice weakens the ‘risers’ on the terrace systems and, whilst not producing significant land degradation, is part of the potentially unsustainable management of land in an expanding economy.

Elsewhere in the Himalayas, successful land-management schemes in India (Dhruva Narayana, 1987) have reduced the river impacts of deforestation, and the Chipko movement has popularised the environmental and local political benefits of forest covers. However, Negi and Joshi (1997) report on the initial failings of a World Bank-sponsored Land and Water Resource Management (LWRM) project in Garhwal Himalaya, where land degradation is becoming common; it failed because it was not participatory, and the authors describe its renaissance, from the ‘bottom up’. The participatory approach has been shown to have big impacts on management of fragile landscapes in the Central Himalaya (Rawat *et al.*, 1997) and also worked well in the Lesser Himalaya (Datta and Virgo, 1998). Achet and Fleming (2006) review the long history (dating from the late 1960s) of integrated watershed management efforts in Nepal. The government’s successive five-year plans have boosted the programme towards 100 sites; Achet and Fleming summarise the lessons learned about scale and participation.

5.8.2 GBM as an international basin: India’s drought stress, Bangladesh’s flood hazards

The Ganges as a problem of international water resource management is best considered along with its neighbours and tributaries, the Brahmaputra and Meghna, of whose joint catchment area India forms 62 per cent, China 18 per cent, Nepal and Bangladesh 8 per cent each and Bhutan 4 per cent. International diplomacy tends to focus, not on the whole basin, but on India’s demands for water from the barrages erected across the river at Farakka and Gandak. Following the Farakka diversion of water to benefit navigation to Calcutta, India and Bangladesh set up a Joint Rivers Commission to study flows (Robinson, 1987); a treaty, resembling the Nile Waters Agreement, on ‘Sharing of the Ganga waters at Farakka and on augmenting its flows’ was signed in 1977. Crow (1995) points out that the navigation (siltation) problems at Calcutta may have originated when India’s Damodar Valley Corporation (modelled on the Tennessee Valley Authority) closed its dams in 1955.

The barrage has had a number of interconnected and unforeseen impacts on the Ganges downstream, including saline intrusion, but, as might be expected, India and Bangladesh disagree on the areas impacted; Nishat (1996) charts the history of six phases of arguments from the perspective of Bangladesh. Adel (2002) goes so far as to blame the diversion of Ganges water from its natural delta for summer warming and winter cooling at climate stations in Bangladesh, owing to the different thermal properties resulting.

It is hard to envisage a set of management rules for the waters of the GBM, given the highly contrasting opportunities and constraints facing the co-riparians and their geographical distribution. For example, whilst India has a vital proportion of its total irrigated farmland on the Gangetic plain, Nepal and Bhutan do not have this potential. Verghese (1996) puts the economic position of all the co-riparians into a picture that requires reciprocating solutions rather than competing ones. Shrestha and Singh (1996) offer an eight-point agenda of 'development through cooperation', and we return to this when dealing with the overall problem of international basins.

Yet another bilateral treaty, signed in 1996, between India and Bangladesh, establishes the volume of flow at Farakka to be divided, the overall proportions of this flow, seasonal guarantees for flows to India, but principles for negotiating during extreme low flows. Water quality is not included and neither is the increasing consumptive use of the river upstream which is thought likely to drive down low flows regularly to the negotiating levels set by the 1996 treaty.

India has seen rapid development since independence in 1947 but in its first 50 years the corollary has been a two-thirds reduction in per capita water availability, compounded by drought crises and a poor record of success in dam building (Chakraborty, 2004); 16 per cent of the world's population is trying to get by on 4 per cent of its water resources, 71 per cent of which come from the GBM basin. Thus, aside from its rivalry with Bangladesh across the river, India is in potential conflict with the upstream nations too (and with Pakistan in the Indus basin on its western borders). The treaty with Nepal has little to do with that country's environmental and population problems, though it may come to have: the Gandak Barrage Treaty allows Nepal rights to withdraw water upstream until India's irrigation schemes downstream are threatened by shortage; the shortage is then shared!

The situation is undoubtedly complicated by India's apparent unwillingness to confront the shortcomings in its water policy, particularly its approach to irrigation and to drought. As put by the South Asia Network on Dams, Rivers and People (1999), in their submission to the World Commission on Dams, 'What is clear from the origin, functions and constitution of River Basins Organizations in India is that they are all structured for planning, design and implementation of large projects.' The submission also reveals the complex institutional structure including a Ministry of Water Resources, a Central Water Commission, a Central Groundwater Board, a National Water Development Agency, a National Committee for Irrigation and Drainage and a plethora of research institutes.

India has more than 1,500 large dams (Bandyopadhyay, 1987); very little pre-scheme monitoring was carried out and, for example, silt loads were 'fixed' at 1/5,000 of the inflow stream discharge. Chettri and Bowonder (1983) itemise the sorry state of the Nizamsagar reservoir, which has lost 60 per cent of its gross water storage capacity in 43 years and will be filled by sediment after 72 years! The Indian government appears to the authors to be unconcerned about remedial action or monitoring, instead coping with drought emergencies in a way which makes Mathur and Jayal (1993) detect political cunning: the provision of relief measures shows the government to be the true guardian of public welfare.

The government of India has also been criticised for its mismanagement of floods and its failure to consider groundwater recharge as a much more cost-beneficial way to store water for droughts (Thakkar, 2007). Management of groundwater resources in India faces a crisis of long neglect, with groundwater tables declining by up to 2 metres a year under intensive irrigation projects (Singh and Singh, 2002); a general lack of awareness and hence of political will has rendered measures to protect and enhance the groundwater resource largely ineffective.

5.8.3 Watershed protection and development in India

Despite widespread criticism of the water bureaucracy at national and state level, India takes pride in local activism. The Indian government initiated a National Watershed Development Programme for Rainfed Agriculture in 1986 (Mathur and Jayal, 1993). Sivanappan (1995) illustrates the good sense of soil and water management strategies based upon the catchment outline. Management of resources has been devolved in India generally, and micro-watershed development is currently supported to the tune of £300 million per year. The emphasis is on agricultural development and water supply rather than river basin management: Joint forest management projects are also involved, with their grassroots hill resource management societies (Kurian and Dietz, 2005). One of the benefits of such small-scale efforts has been erosion protection, notably in the Himalayan foothills of India where community-based schemes involve earth dams, water conveyance, forest management and improved agricultural productivity (Grewal *et al.*, 1990; Arya *et al.*, 1994). Watershed committees have charge of the community-level actions to improve rainfall harvesting and control erosion but there remains competition with local bureaucrats. The benefits are not evenly distributed and there may be downstream hydrological disadvantages of headwater controls; Batchelor *et al.* (2003) even suggest that watershed development may be ‘part of the problem’ of taking a holistic, integrated approach focused on benefits to deprived rural groups and the wider catchment ecosystem. Kurian and Dietz (2005) reveal that poor design and technology transfer render almost a third of earth dams useless through siltation or other forms of damage. Kumar *et al.* (2006) ask further questions about the validity of rainwater harvesting techniques, lacking as they do the hydrological planning and sound economic analysis of large water resource systems. The second criticism is made to sound unfair by an earlier analysis (Ninan and Lakshmikanthamma, 2001) which carried out a social cost–benefit analysis on the Mittemari Watershed Development Project in semi-arid Karnataka state. This showed benefits could be expected but that the good land-use practices encouraged by the project could build up the costs of, for example, grazing foregone. The authors, nevertheless, conclude that the projects in dry regions are 'economically viable and socially desirable'.

Part of the watershed management debate in 'dry India' will inevitably centre on forests (they are important to the culture and economy of rural India) and in particular on the hydrological and erosional impacts of *Eucalyptus* plantations. Recent intensive research in Karnataka, southern India, suggests that the prodigious rates of evaporation reported for eucalypts in Australia (see Chapter 4) are unlikely in dry regions where soil moisture is limiting (Calder, 1994). Euclaypts use similar amounts of water to indigenous trees, but twice as much as most traditional agricultural crops; in fact, in a later paper Calder *et al.* (1997) reveal how *Eucalyptus* can use more water than falls as rainfall input. In the interests of conserving natural forests, says Calder, the productivity of eucalypts should be modelled so that irrigated patches or rotation cropping could be used to integrate their production with agriculture and other water users.

As Figure 5.13(a) shows, and despite the watershed initiatives (Figure 5.13(b)), there are plans for a 'water grid' in India, a scheme which will need yet more abstraction from the Ganges, supported perhaps by dams built in Nepal. This project, like NAWAPA in North America (Chapter 4), seldom leaves the drawing boards of India's engineers but fails to progress beyond them into construction, despite having fairly universal support from politicians. A combination of the country's water specialists and the long tradition of local activism point elsewhere, towards better rainfall harvesting and smaller-scale initiatives; small individual components of the water grid are acceptable to this lobby.

5.8.4 The GMB and Bangladesh

Bangladesh is regularly flooded by the coincidence of synchronous monsoon flood peaks arriving from the Ganges and Brahmaputra (Jakobsen *et al.*, 2005). The country is still constructing engineered protection against disastrous flooding of the scale of 1987 and 1988 (Brammer, 1990a). Floods, both coastal and river, are an integral part of Bangladeshi life (22 per cent of the country is flooded, on average, each year), but these were the worst on record, killing 1,200 people and inundating 60 per cent of the nation's land. Up to 15 per cent of the grain production was lost, but certain flood-loving rice varieties (Bangladesh has 10,000 varieties, each requiring a unique water regime – Custers, 1992) performed better. Custers points out that flood management does not mean flood prevention. However, as one journalist put it, 'the world

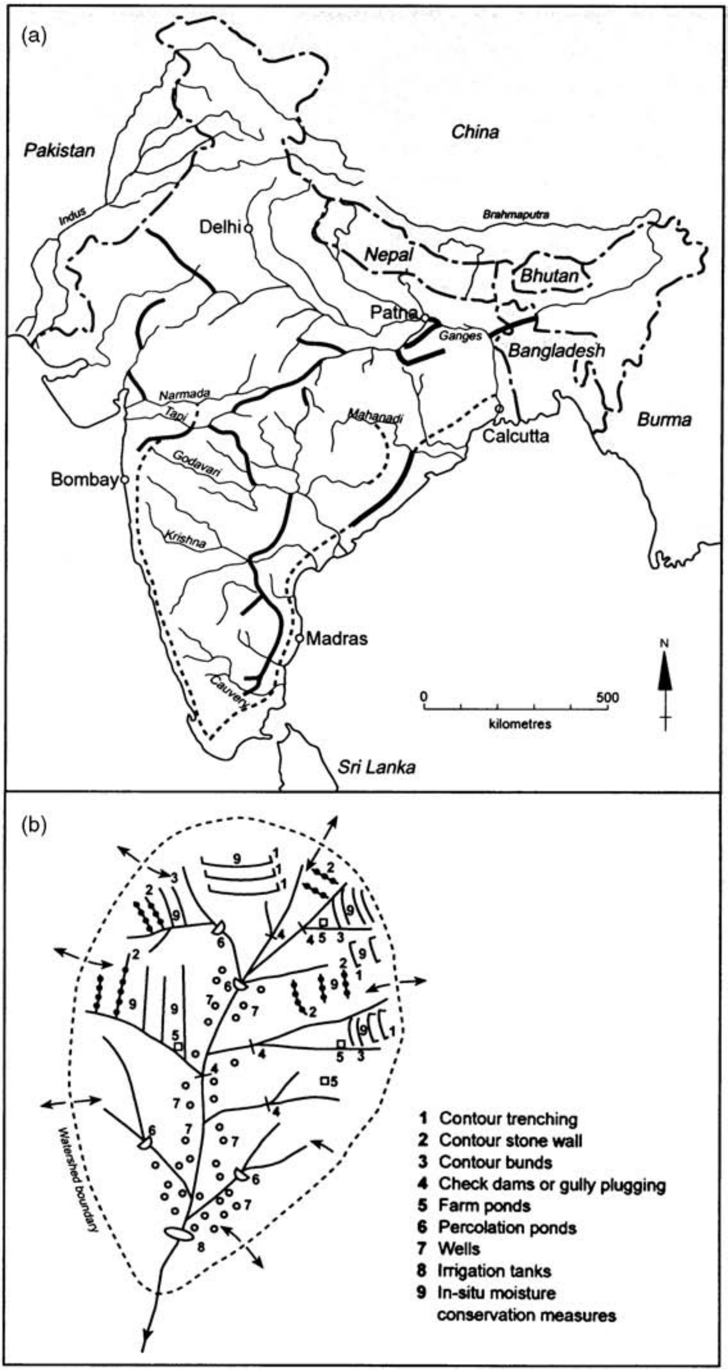


Figure 5.13 Indian water resource development at different scales:

(a) The proposed water grid

(b) Catchment scale soil and water management (after Sivanappan, 1995) rallied round. It was open season for hydrologists and technologists and what emerged was a dog's breakfast of massive flood defence proposals.' The World Bank has now selected a coordinated scheme of the best proposals, avoiding large dams, but nevertheless having a large impact on people adapted to riparian or island livelihoods. This is clearly important in the light of early conclusions from socially based investigations (e.g. Thompson and Sultana, 1996) which reveal that flood losses can be greater within the flood embankments, that there is no stabilisation of livelihoods, and that fishermen and boatmen are disadvantaged by the schemes; only nine of 63 flood projects justified themselves economically. The UNDP has stipulated that the flood control strategies adopted should research river morphology (a challenge taken up by Thorne *et al.*, 1993) and justifies a 'small is beautiful' approach to irrigated food production in Bangladesh (Brammer, 1990b). The Lower Atrai basin, a tributary of the Ganges, represents a much less structural approach to flood control and has involved a broader approach to the needs of local farmers (Franks, 1994). Younus *et al.* (2005) have demonstrated the 'autonomous adjustments' made by Bangladeshi farmers to flooding, an indigenous human–environment reaction developed over centuries: 'The autonomous adjustment process ensures cropping patterns are in a sympathetic relationship with flooding characteristics. Different land types accommodate different flood depths and for different durations every year' (p. 117).

Bangladesh is now implementing IWRM through its Ministry of Water Resources and National Water Resources Council (Das Gupta *et al.*, 2005). It has many water resource challenges besides flooding, including saline intrusion to and arsenic contamination of its essential aquifers. Das Gupta *et al.* point to inherent problems of public participation and lack of cohesion among development sectors, as well as the dependency on outside forces of inward investment and outside factors in water supply from the Ganges, Brahmaputra and Meghna.

5.9 Is the dam-based development mega-project a thing of the past?

Dams have played a major role in development project 'gigantism', such is the almost monotonous linearity of the river basin development model evolved in the Western world and exported, like soft drinks and burger bars, across all cultures, economies and stages of development. Do we need dams? Part of the answer may lie in a phrase from an Indian newspaper: 'Promise a dam, win an election'! But the question is also rhetorical, because so many large dams are already there, must be maintained for safety reasons and have very little operational flexibility, but also because many would claim (as do the builders of the Aswan High dam in Egypt) that they prevent the starvation of millions of humans.

5.9.1 The case against large dams and associated developments

Goldsmith and Hildyard (1984, 1986) were amongst the first authors to make an extensive critique of dams in the development process; their work was featured heavily in Newson (1997). The International Rivers Network (now International Rivers), an NGO which took on the mantle of exposing the inadequacies of dam-based river management, has divided the history of modern dams into ‘the boom years’ (1902: the Low Aswan dam, to 1976: collapse of Wyoming’s Teton dam) and ‘the rise of the People’s Movement’ (1981: Chico dam, Philippines, abandoned, to the present).

Goldsmith and Hildyard identified several prime target plans for new dam projects, amongst which was the Narmada Valley Project (Kalpavriksh and the Hindu College Nature Club, 1986), involving two major reservoirs and up to 3,000 smaller structures, which has now been the subject of an individual book of criticism (Alvares and Billorey, 1988). The key to the Narmada controversy, according to Alvares and Billorey, was that a ‘majestic and sacred’ river would be equipped with a plethora of dams which ‘would, in addition to generating irreversible environmental changes, also uproot over a million people, including a large number of tribals, and submerge a total of 350,000 hectares of forest lands and 200,000 hectares of cultivated land’ (Alvares and Billorey, 1988, p. 10).

In March 1993 the World Bank announced that it was withdrawing its funding from the Sardar Sarovar dam, centrepiece of the scheme, but the Indian government immediately said that it would proceed alone or find other funding agencies after another review of options. This followed a threat by villagers to drown in the rising waters behind the dam and a hunger strike by two members of the Save the Narmada Movement. Figure 5.14 points up the huge scale of the Narmada, a project in the tradition of the Tennessee Valley Authority but seemingly justified only by supply-side issues and India’s agrarian crisis (Vyas, 2001). Further justifications followed from Indian water specialists (Gupta, 2001a, 2001b), and the Indian government obtained a Supreme Court decision to proceed with the project in spite of international disapproval (Verghese, 2001). Dislocations of traditional societies on such a scale have been relatively common in development schemes involving dam construction; the Narmada project(s) have been the focus for open and strident debate concerning displacement and resettlement (Drèze *et al.*, 1997). Barrow (1987) tabulates more than 20 such schemes with resettlement costs ranging from $3.6 million to $100.2 million. The Narmada project looks set to put the international community in conflict with official water management in India for many years to come; even the widely acclaimed report of the World Commission on Dams (see Chapter 6) is disputed (Thatte, 2001).

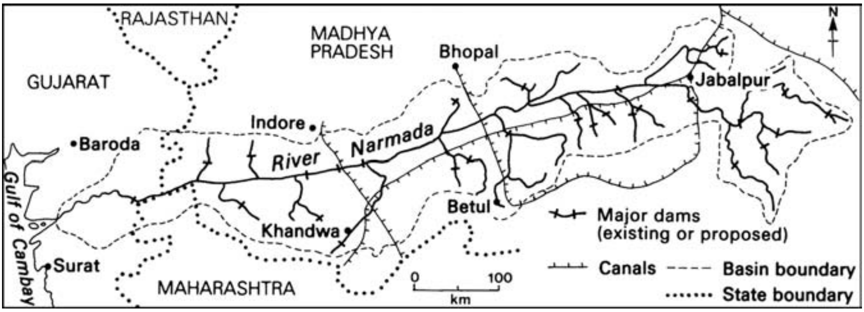


Figure 5.14 The Narmada scheme, western India, indicating the heavy reliance on dam construction (after Kalpavriksh, 1986).

The signs are that large dam construction will continue to accompany rapid economic development: the other world 'giant' in growth rates, China, faces international isolation over its Three Gorges dam on the River Yangtze. Accurate information is difficult to obtain from technical sources because of language difficulties and confidentiality by the Chinese authorities. However, even the authorities have recently admitted to problems with landslides caused by rising water levels behind the 2.25-kilometre-long, 185-metre-high dam, and the slowing (ageing) of the impounded waters is already creating water quality problems. Hundreds of smaller dams are planned for the catchment behind Three Gorges, because the huge energy demands of economic growth are currently supplied mainly by coal, and a switch to 'green' power is vital. The history and construction of the Three Gorges dam is described by Sutton (2004); the rising water will oust over a million people and 'drown' 13 cities, 140 towns, 326 townships, 1,352 villages, 650 factories and 139 existing power plants. At the time of completing this book (early 2008) China has announced cancellation of the Tiger Leaping Gorge dam on the Upper Yangtze; however, its energy needs and the need to trap some of the sediment load which may pose a threat to Three Gorges mean that the upper catchment is unlikely to escape further dam building.

Aware of the dam dilemma, Macdonald (2001) concludes that, in the light of the findings of the World Commission on Dams, the assumed efficiency of large dams must submit to the less controversial, less capital-intensive, more easily maintained advantages of smaller, locally acceptable schemes. It would be 'unfortunate', he writes, if the debate over mega-projects such as Three Gorges and Narmada was to obscure the creation of more water storage to grow food, alleviate poverty and sustain ecological processes. Biswas (2005) is also concerned about a reduction in World Bank and regional development bank support for water projects; he also attributes this partly to pressures from 'social and environmental activists'.

5.9.2 Respect for tradition: 'bottom-up' water development in drylands

Much of the fascination for dam-building programmes in the developing world derives from the need for irrigated agriculture and power generation as part of general national development. Are there alternatives which combine traditional virtues with modern capacity?

Gilbertson (1986) provides a general introduction to 'floodwater farming'; traditional forms of 'dry farming' cultivation are also worthy of encouragement by NGO aid or government extension services. The 'Khadin' system of cultivation in India uses basins of internal drainage in undulating semi-arid land to focus both surface and groundwater supplies; the ratio of catchment to the 'plain of accumulation' (Figure 5.15) is 11:1 (Tewari, 1988). Wheat and chickpeas are grown without irrigation after the summer rains have infiltrated the basin (also recharging wells for domestic supply and for livestock which manure the basin). Khadin farming may date back to 3000 BC, but currently the Indian government has revived 500 Khadin farms under the Drought Prone Areas Programme.

Tucson, Arizona, is experimenting with 'retiring' groundwater-irrigated agriculture and replacing it with *water harvesting* via catchment basins (Karpiscak *et al.*, 1984). Runoff from the non-agricultural area is increased by removing weeds, compacting soil and adding salt to decrease infiltration. The resulting 'agrisystem' is at its most efficient in small units of 0.2 hectares. Runoff from catchment strips is concentrated in channels and flows into a sump. Annual average rainfall does not exceed 250 mm, but evaporation reaches 2,860 mm; consequently losses from storage are potentially ruinous

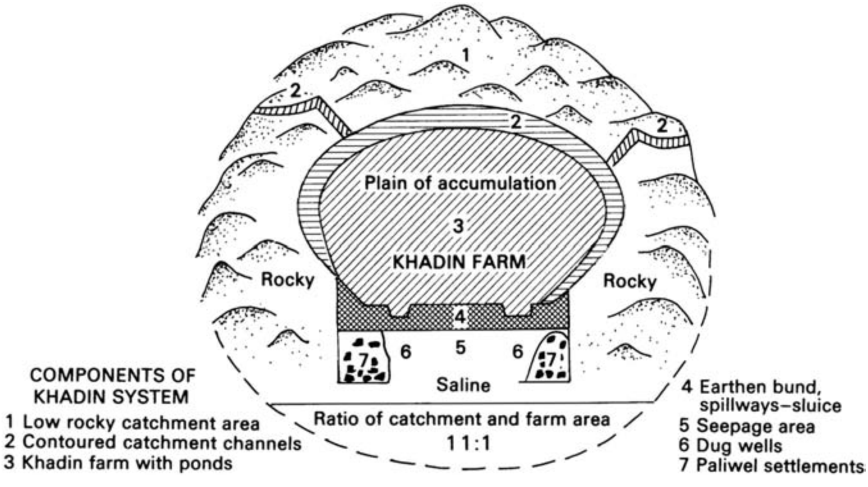


Figure 5.15 Traditional Indian dryland farming strategy: the Khadin irrigation system (after Tewari, 1988).

but are curtailed by ingenious techniques such as the use of black film canisters which float on the reservoirs. High-yield, high-value and drought-tolerant crops such as grapes, jojoba, olives and pines are grown.

5.9.3 'Water wars' or 'hydrosolidarity'? International river basin development

At several points in the review of river management in developing nations we encounter the obstructions to water security (therefore obstructions to resource planning and allocation) posed by the international scale of the basin. As revealed by Table 5.14 in Newson (1997), river basin *treaties outnumber water wars*. Uitto and Wolf (2002) urge us to beware of including incidents and events where water is the tool, target or victim of war, not the cause; they identify only one example of the latter – 4,500 years ago! There exists, at Oregon State University, a Transboundary Freshwater Dispute Database, covering 263 international river basins (and also 45 per cent of the global land surface as well as 40 per cent of its population). Giordano *et al.* (2002) and Stahl (2005) have statistically tested the database entries to detect patterns between hydroclimatology and socio-economic variables as they impact on water-related international relations (WIR), in this case degrees of stress between co-riparians. The results are surprisingly successful in relating hydroclimatic and population density factors to stress in drier climates, whilst economics and political regimes dominate in humid basins.

Nevertheless, there are often signs that political positioning can include the *threat* of 'water wars', particularly in the Middle East. During 1990, for example, Turkey closed the Ataturk dam across the Euphrates, a culmination of the 'Pride of Turkey' project on both the Tigris and Euphrates designed to boost electricity supplies by 70 per cent and to irrigate 1.6 million hectares of land; it is self-funded because of its political sensitivity (Hellier, 1990). Syria, next in line for the river's waters, suffers flow reductions of 40–70 per cent volume; Iraq, next in line for the waters, suffers from increased salt contents of inputs to its irrigation schemes.

Rowley (1990) describes how, within the general problems posed by Middle East aridity, competition occurs for groundwater resources on the West Bank (of the Jordan). Since Israeli settlers entered the region in 1967, much of the water pumped from the region has been destined for Israel proper, and there are signs of over-exploitation. The shallower wells and tunnel systems of the Arab population are being depleted by the superior Israeli technology. Abu-Maila (1991) reports on similar problems caused by population growth and the establishment of Israeli settlements in the Gaza Strip; over-exploitation of fossil groundwater is essential because of the negative water balance (306 mm precipitation, 1,800 mm evaporation). Water quality is also declining rapidly, and with a continuing resource deficit the only options appear to be desalination, recycled sewage effluent or import of supplies from elsewhere in Israel, a prospect which must be considered in the context of Israel's relationship with the Palestinians and with its neighbours. The construction of a security barrier between Israel and the Palestinian West Bank is rumoured to have skirted traditional springs and wells so as to put them on the Israeli side. Conflicts of interest between Jewish and Arab rural settlements within Israel reduce the effectiveness of the Israeli drainage districts – the nearest approximation to river basin authorities.

Despite these case studies of political stress over water (one must bear in mind the opportunism rooted in practical politics!) we can end on two optimistic notes. One is that the Middle East, even in places and at times of greatest political stress, is negotiating water into peace agreements rather than out of them (Haddadin, 2002). The other is that the UN Global Environment Facility actively promotes practical forms of cooperation for international basins – Uitto and Duda (2002) provide case studies of the kinds of advice offered.

5.10 Development and rivers: broad trends

At the beginning of Chapter 4 we addressed two almost rhetorical questions about the size of large water-based development schemes, particularly those involving dams, and about the need to respect local variations in 'appropriate technology'. The two chapters (4 and 5) can be viewed as a series of disparate national and regional case studies, hardly helping to answer these big questions. However, there seem to be certain threads in the material which indicate scenarios for better management of river basins, even if only to point up contextual differences in the two sets of situations (Table 5.11 – compare with Table 4.1).

It is a fair comment that developed nations made the sorts of gross environmental errors about which they now criticise the least developed countries! In an environment of rapidly increasing population and urbanisation, the developed nations felled their forests and let generations die from cholera; under the same conditions of growth, but under the additional stress of dryland conditions, it is likely to remain normal for large water development schemes to dominate if encouraged by the political management of international finance.

However, a 'second front', mainly operated by non-government organisations, deliberately exploits a knowledge of, and sympathy for, the local talents of indigenous peoples for environmental management – even when that environment is changing. These organisations can combine physical and social improvements much more efficiently at the local level. Under the title *Social Aspects of Sustainable Dryland Management*, Stiles (1995) has brought together those elements which are essential to the social development of those communities upon whom we depend to protect the environment. Evers (1995) lists the guiding principles as 'support, empower and enable', whilst

Table 5.11 Water contexts: developed and developing countries

Developed countries	*Developing countries*
Temperate climate, humid, perennial streamflow.	Drylands, climate extremes and other hazards, water scarcity an emerging constraint.
Population densest in valleys, downstream.	Population high in mountains and other headwaters, also upstream as well as downstream of dams.
Water rights based on riparian doctrine or prior appropriation.	Water rights often based on rights to rainfall or groundwater.
Focus on 'blue' water.	Focus on 'green' water.
Users supplied by 'service providers'; prevalence of formal sector makes governance easier.	Little mediation by public agencies or organised service providers; informal sector dominant.
Small number of large-scale stakeholders.	Vast numbers of small-scale stakeholders.
Low transaction costs for monitoring use and collecting charges.	High transaction costs for monitoring use and collecting charges.

Modified from Shah *et al.* (2004)

Hausler (1995) criticises the entire Western model of development, the backdrop to large dam schemes and their universal, if inappropriate, application:

> At the core of this process lies a universalist economistic framework of the human/nature relation. . . . The universal introduction of the Western industrial, export-led, economic growth model of development, despite some positive changes, has caused considerable damage to local life styles, cultures and – very visibly – to the environment.
>
> (Hausler, 1995, p. 181)

Chapter 6

Technical issues in river basin management

Despite the power of holistic science to open up issues to interdisciplinary analysis, and despite an impression created in this book of a waning role for traditional engineering, it is likely that *technocentric* solutions will remain influential, if not dominant, for water management in a world of teeming population and wide-spread famine and disease. The same world constitutes a globalised Risk Society (Beck, 1992), representing a stage reached in relationships within the uneasy triangle linking capitalism, technology and communities. If technocentric solutions remain dominant there will need to be changes in our evaluation and use of the knowledge they bring to bear (Chapters 8 and 9).

Improving the *strategic application* of technology has become a central part of the research agenda whose results are outlined here; we also need to improve the *operational techniques* used in river basin management, the pivotal example being the construction and operation of large dams. The scientific challenge is enormous, for a traditionally reductionist 'hydrocentric' research approach, to address the need amongst politicians, and the managers they appoint, for attention to the larger-scale and longer-term environmental elements. Inevitably such improvements are brought about by 'normal science' – the conventional, experimental route championed by Francis Bacon and oriented to 'the relief of man's estate'. It is also inevitable, for the foreseeable future, that research results will be applied by engineers – agricultural, civil and environmental. Nevertheless, the social, economic and political sciences are equally committed to turning knowledge into 'tools' in the form of procedures to deal effectively with poverty, deprivation, equality, efficiency and institutionalised governance.

If a thread were needed to discipline issues of inclusion and exclusion of material one might select the key issues of manipulating 'blue' water as distinct from those of allocating 'green' water; alternatively, one might select the key issues of 'disconnected rivers', because reconnecting them is a central element of sustainability in its 'strong' form. Following the 'green' water/ 'blue' water framework leads to an order of issues where soil erosion is retained in pole position as a major threat to the physical structure of whole basins, taking eons of time to repair. Closely entwined are issues of irrigation and rainfed agriculture, crucially embraced in the water–food dilemma of a populous planet; these have been promoted forward in this edition because they relate closely to the soil resource, as does the world food 'crisis' to the world water 'crisis'. We can then address a major 'blue' water issue, that of water storage in reservoirs: the dams and development conundrum, before taking on their main system-wide impact on environmental flows. This leaves as last in order, but not importance, the technology of ecosystem restoration applied to rivers (and their flows) and evidence of a phenomenon that may alter everything on preceding pages: climate change.

Once again, as in Chapter 3, we make relatively limited reference to water pollution as a technical problem in basin management. Restoration of unpolluted conditions is a challenge to law and to economics as much as it is to science; restoration of a physically degraded river system is a daunting task, and the requirement to do so should be avoided by anticipation, good science and public support. Throughout the chapter the research material is blissfully guilty of being 'hydrocentric'. Later in the book we need to debate those scales and management functions for which the basin framework is undoubtedly the best and those for which lawyers and economists have advocated moves away from the fascination of 'hydrocentricity'.

6.1 Soil erosion

The erosion of soils by running water (we do not here deal with wind erosion or other forms) is not in itself a problem; soils are produced from a bedrock or drift mineral base by weathering (and the incorporation of organic material) and are then eroded as part of the long-term evolution of landscapes. Soil erosion only becomes a problem when its rate is accelerated above weathering, partly because it becomes visible. It is clearly linked to farming systems, especially their use of water (hence the initials SWC: soil and water conservation), and it becomes a river management problem when it constrains agricultural production and leads to river and reservoir sedimentation. Erosion is not the only way in which exploitation of river basins can damage soil. Mismanagement of this thin, interface system between lithosphere, biosphere and atmosphere takes many forms, as Figure 6.1 illustrates. The interface location partly explains the significance of the world's soils as global carbon stores and regulators.

Soil erosion is often quoted as one of the clearest symptoms of global environmental abuse by humans, representing the reckless disposal of a storehouse of biophysical and chemical assets to the long-term detriment of communities on-site and off-site. As with 'desertification', there are many opportunities for even the well-intended to misunderstand the extent and significance of erosion. Lal (1993) lists some of the key statistics – erosion affects 24 per cent of the planet's inhabited land area; 1,094 Mha of land are

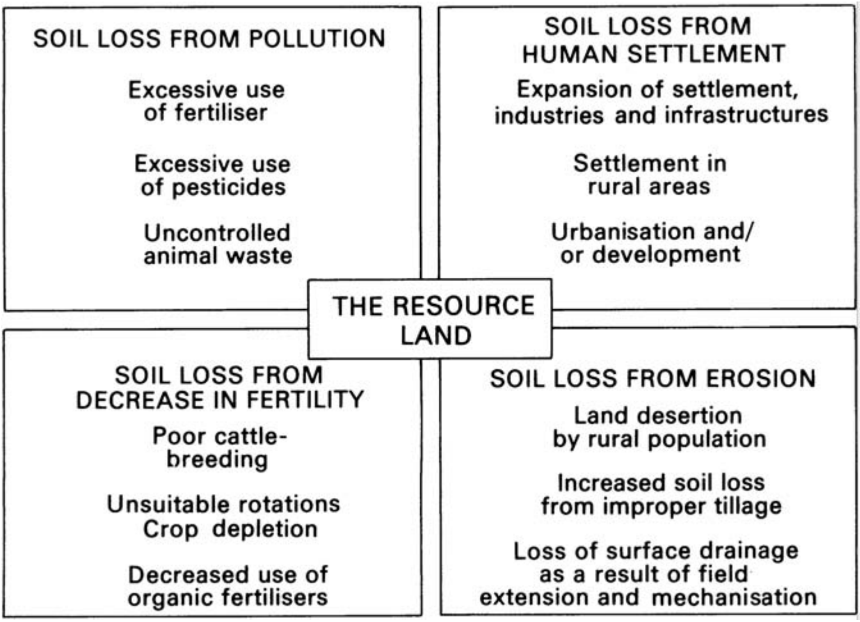


Figure 6.1 Mismanagement of land resources: soil erosion in context (modified after Guerrieri and Vianello, 1990).

impacted by water erosion and 548 Mha by wind erosion. Morgan (2005) also quotes these figures, but requires 11 sources of reference to compile erosion rates in nine countries, indicating the difficulty of gaining a reliable overview. Because soil erosion rates are accelerated most commonly by human intervention in the soil formation/denudation process, its identification and control involves the social as well as the physical sciences; Hallsworth (1987) describes the 'anatomy, physiology and psychology' of erosion, whilst a book by Blaikie (1985) explores the 'political economy' of soil erosion in developing countries. Boardman (1990) writes of the 'costs, attitudes and policies' in soil erosion control.

6.1.1 The physical processes of erosion: identifying controls in order to protect

Morgan (2005) stoutly defends the biophysical scientist's position on soil erosion: 'A thorough understanding of the processes of erosion and their controlling factors is a prerequisite for designing erosion control measures on a sound scientific basis wherever they are needed' (p. ix). However, Boardman (2006) writes of the long-standing limitations of soil erosion science, and some of these will become apparent as this section proceeds.

Montgomery (2007), in his aptly titled *Dirt: The Erosion of Civilizations*, suggests that empires decline with their topsoil. Seymour and Girardet (1986) and Hillel (1992) also stress the core significance of the soil resource in stimulating historical reviews. Hillel points out that terracing of sloping fields began in the second millennium BC, but erosion was still a major problem at the time the *Iliad* included the observation, 'Many a hillside do the torrents furrow deeply, and down to the dark sea they rush headlong from the mountains with a mighty roar and the tilled fields of men are wasted.'

The need to control soil loss by scientifically framed interventionist measures, both agricultural and hydrological, was first perceived in terms of national crisis by the USA in the early 1930s following extremes which had created dust bowls and badlands from essential pioneer farmland. The measures adopted in the USA during the modern era have, however, been exported across the globe, rightly or wrongly coming to dominate over the local, traditional measures practised by traditional agrarian communities. Equations to predict soil loss were developed during the 1930s and 1940s. However, these tended to be of only local or regional relevance, and in the 1950s field research at the plot scale was combined to produce the universal soil loss equation (USLE: see Box 6.1), originally described by Wischmeier and Smith (1965).

Box 6.1 The universal soil loss equation (USLE): Western science for the world?

The USLE is phrased as a simple multiplicative expression predicting a mass of soil removed from a unit area per annum, based on causative factors (see Figure 6.2) identified and measured at 36 locations in 21 states in the USA (totalling over 10,000 plot-years of data).

The equation is phrased as:

$A = RKLSCP$
where A = soil loss, kg.m^{-2}
R = rainfall erosivity
K = soil erodibility
L = slope length
S = slope gradient
C = cropping management factor
P = erosion control practice

The USLE is codified in a simple fashion, with nomographs to ease calculation of the basic factors from minimal data collection in the field. Clearly, care and experience in applications are essential and, as shortcomings have been identified in aspects of its operation, further research has 'filled in the gaps'. The USLE has become much more 'universal' in a geographical sense than originally intended and is now applied well beyond its original range but has the great advantage of rationality and simplicity. Boardman (2006) is very critical: 'Continued use of the unmodified USLE ignores fundamental problems . . . the USLE is not satisfactory' (p. 77), but his comments derive from his European perspective.

The USLE has been used to:

(a) predict annual soil loss under specific land uses;
(b) guide the selection of cropping and management options;
(c) predict the effects of changing land use or management;
(d) determine conservation practice;
(e) estimate losses from non-agricultural developments (e.g. mine spoil).

Numerous authors have reviewed the refinements produced by the considerable research support that the USLE has achieved (e.g. Mitchell and Bubenzer, 1980). Even within the USA, the need was perceived for a revised universal soil loss equation, largely to better reflect conditions west of the Mississippi (Renard *et al.*, 1991 – and see below). Two main components of research improvements have been made:

(a) improvements to the rationality of the process mechanisms of the equation or to the way that it agglomerates processes;
(b) improvements to the applicability of the equation in specific (often tropical) environments.

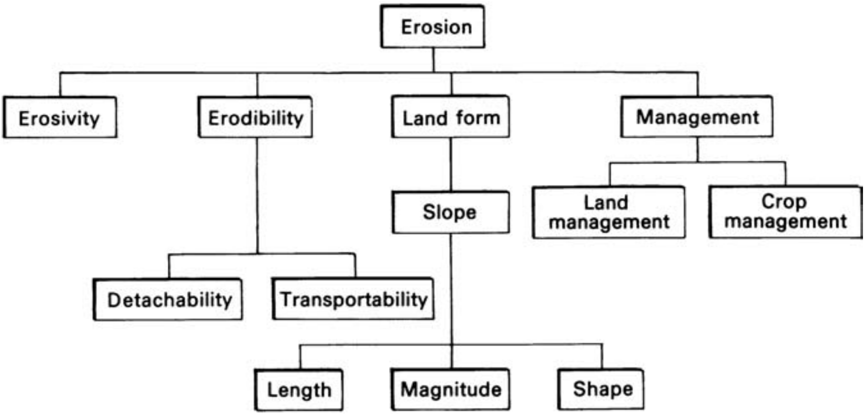


Figure 6.2 Controlling factors built into the calculations of the universal soil loss equation (USLE).

As it stands, the equation performs best for medium-textured soils on 3–18 per cent slopes less than 122 metres in length. Renard *et al.* (1994) describe the revised universal soil loss equation (RUSLE). It retains the same nomenclature and format of the original but has incorporated the following broad improvements. The 'R' term now incorporates more climatic information, making the equation more 'transportable' to other regions of the world. The 'K' term can be varied seasonally and includes soils containing rock fragments (common in drylands). Renard *et al.* note that, whilst 'L' has attracted controversy, its effect on outcomes is far less significant than 'S', which has been improved to incorporate complex slope profiles and plans. The conservation term 'C' has been extended to include surface soil roughness and ground cover plants as well as crop cover. 'P' is still the least reliable term because of the difficulty of incorporating farmer variability in practice. The US Department of Agriculture has also developed the Water Erosion Prediction Project (WEPP) – a model which incorporates the small-scale geometry of eroding fields, i.e. rills and inter-rill areas; it also extends from the plot and field scale to the watershed via hillslope, channel, impoundment (terraces, stock tanks) and irrigation modules. A further problem has been to address *gully erosion* rather than *sheet erosion*. Rational equations, similar to the USLE, are available but tend to predict the rate of growth of gullying rather than initiation of this damaging process.

As examples of the often dire need to extend and apply the USLE to new conditions, we may select the work described by Hurni (1983), who improved the rainfall erosivity and slope components in Ethiopia, and Harper (1988), who additionally improved the 'C', 'K' and 'P' components for North Thailand. Hurni's studies (Figure 6.3) contribute a basic statement of erosion as a long-term resource problem facing rainfed agriculture in the Ethiopian Highlands. Figure 6.3 compares the timescales of soil formation with those of its erosional loss; rates of loss should not exceed those of production – a key test of sustainable development. His project led to the production of a simple field manual, using cartoons to select appropriate estimates of erosion rates for different agroclimatic zones and to design simple protection strategies. Such advice in the hands of capable extension workers touring the farms achieves very rapid conservation results (see Section 6.1.3). The statistics of Ethiopian soil erosion and attempts to control it are impressive. Losses of soil from the Ethiopian Highlands (Plate 6.1) exceed 20 tonnes per hectare; since this region constitutes 40 per cent of the country but receives 90 per cent of the rainfall and is home to 88 per cent of the population, remedial action is urgent.

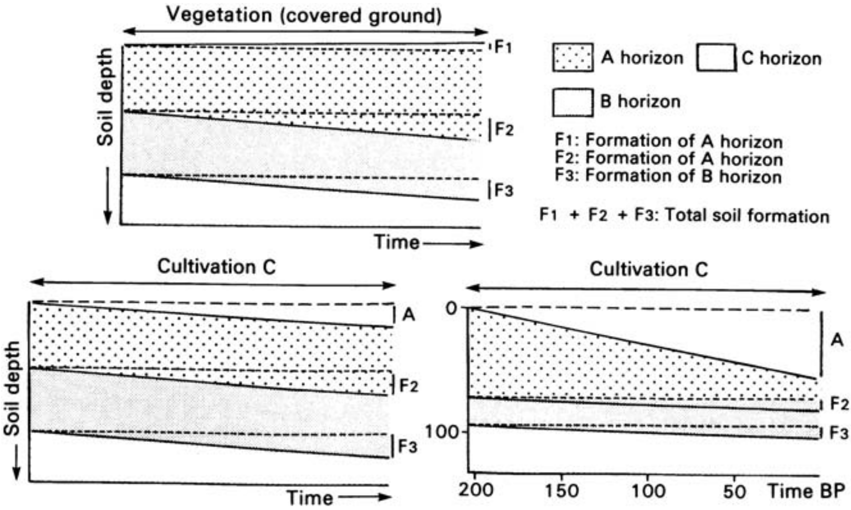


Figure 6.3 Soil erosion and sustainability: comparing the rate of soil production by weathering and loss by careless cultivations (Hurni, 1983).

Plate 6.1 Sheet (mid-foreground) and gully erosion, Ethiopian Plateau (photo M. D. Newson).

6.1.2 Sophistication inappropriate: a realistic role for research

Experience such as that of Hurni and his collaborators, together with that slowly emerging from other problem regions such as the Himalayas (Chapter 5), points to some interesting but daunting problems of effective erosion control. In Ethiopia (and Eritrea), for example, subsequent analysis of the big 'push' for bunds and terraces during the 1970s and 1980s reveals that increases in crop yields and biomass production did not repay the investment in time and money (Herweg and Ludi, 1999). A major problem concerns the 'one size fits all' techniques employed, with insufficient consideration of micro-scale impacts on farm systems, such as reduced yields on the spoil thrown up to produce bunds and waterlogging caused by the detained runoff. The structures harbour rodent pests, they take up cropping area and their maintenance takes up precious labour. The influence of livestock movements (stock farming is more important on the core areas of the Ethiopian Highlands) has not been included in design (Mwendera *et al.*, 1997).

We have already identified a further 'surprise' with the widespread adoption of soil and water conservation (SWC): the use of 'green' water high up in a watershed means that it is lost (evaporated) to users further down the system. Such has been the improvement of rainwater harvesting and management (RHM) for irrigation in parts of the Kenyan Highlands (notably through population pressures in the Upper Ewaso Ng'iro basin (Aeschbacher *et al.*, 2005) that comprehensive basin-wide modelling is now required to develop strategies to manage land use (Ngigi *et al.*, 2007).

In terms of erosion research, the paradox becomes one of a need for increasing sophistication yet the virtual impossibility of applying it. For example, multi-parameter hydrological erosion models (Morgan, 2005), either for sheet or for gully erosion, require expensive instrumentation in the field. Whilst this is not impossible, it is likely that such instrumentation can only be provided by foreign aid and only run by foreign experts, immediately breaking an important bond with local land users (Blaikie, 1985). Boardman *et al.* (1990) reveal two fundamental elements of mismatch in research support for soil conservation. One is that research is often best supported in regions where there are few erosion problems: technology transfer has significant restrictions in land-use and land-management fields. Another is that 'problems in erosion studies' are not equivalent to 'erosion problems'; a mismatch can therefore occur between the intellectual satisfaction of process studies and the practical needs of application. Once again the USLE, or techniques with a similarly practical but validated orientation (e.g. Harris and Boardman's simple expert system, 1990), is seen to occupy an essential niche.

Boardman (2006) goes on to list the following 'big questions', often ignored or poorly answered by soil erosion science:

- Where is erosion happening?
- Why is it happening?
- When is it happening?
- Who is to blame?
- How serious is it?
- Who does it affect?
- What does it cost?
- Over what timescale is degradation occurring?
- Can we do anything about it?
- Who should take action?
- Is action worthwhile?
- What is the risk of erosion in future?
- Where is that risk?

In answer to the first of these, clearly technology has a contribution to make via remote sensing and GIS. For example, Mambo and Archer (2007) describe a mix of time-referenced satellite imagery, overlaid with both biophysical maps and social data, which can set up a strategic approach to degradation 'hot-spots'. Boardman also attempts to answer his own question by listing the global erosion hot-spots as the loess plateau of China, Ethiopia, Swaziland, Lesotho, the Andes, South and East Asia, the Mediterranean basin, Iceland, Madagascar, the Himalayas, the West African Sahel and the Caribbean/Central America.

6.1.3 Social science and erosion

Napier (1990), reviewing the successes and failures of erosion control in the USA since the inception of the Soil Conservation Service in the 1930s, stresses the very high levels of financial and infrastructural support needed to achieve the initial, voluntary thrust by farmers. He produces a list of 12 conditions to be satisfied by effective soil conservation programmes (Table 6.1).

In the developing world the translation of soil conservation goals into practical agricultural action must bear Napier's assessment and the USA's experiences in mind but with the additional elements of local sensitivities. As Eckholm (1976) put it, 'Land-use patterns are an expression of deep political, economic and cultural structures; they do not change overnight when an ecologist or forester sounds the alarm that a country is losing its resource base' (p. 54). It is not surprising, therefore, that land degradation problems are seen as a perfect test-bed for participatory approaches, particularly because they value the intimate association and 'vernacular science' of local people (Stringer *et al.*, 2007). It is to the farmer that 'experts' should logically turn for field indications of the existence and severity of excess soil erosion and, if left to become advocates of farming change, they are naturally self-motivated (Okoba and Sterk, 2006). These authors utilised a list of erosion

Table 6.1 The elements of a successful soil conservation programme

1 The development of a political constituency which supports action to reduce the social, economic and environmental costs of soil erosion.
2 The allocation of extensive human and economic resources on a long-term basis by national governments to finance soil conservation programmes.
3 The creation of government agencies commissioned to address soil erosion problems with sufficient autonomy to be immune from short-term political influences.
4 The development of well-trained professionals to staff soil conservation agencies.
5 The development of an informed farm population which is aware of the causes and remedies of soil erosion.
6 The development of a stewardship orientation among land operators to protect soil and water resources.
7 The creation of national policies which place high priority on the protection of soil and water resources.
8 The creation of national development, agricultural and soil conservation policies and programmes which are consistent and complementary.
9 The creation of national environmental policies which are consistent and complementary.
10 The development of physical and social scientists who are committed to the generation of scientific information which will contribute to the creation, implementation and continual modification of soil and water conservation policies and programmes.
11 The creation of an interdisciplinary professional society committed to the maintenance of environmental integrity of soil and water resources.
12 The emergence of political leadership which will be willing to implement policies and programmes which some segments of the agricultural population will find oppressive.

Source: Napier (1990)

indicators couched in the local language of the Kenyan Central Highlands, such as rills, sheetwash, root exposure, gullies, stoniness (and, of course, broken SWC structures). If supporting motivation is necessary it should come from a genuine interaction of equals in the field of extension work (e.g. between agricultural colleges and land users), a conclusion that is also relevant to developed countries such as the UK (Evans, 2006; Ingram and Morris, 2007). Kessler (2007) suggests six fundamentals for working with farmers in SWC:

- Focus on the most progressive farmers.
- Achieve short-term impact and success in SWC.
- Enhance the profitability of agriculture.
- Invest in satisfying households' basic needs.
- Stimulate collaboration within a village.
- Promote income diversification.

We are now closer to Hallsworth's 'psychology' and Blaikie's 'political economy' of erosion. Whilst we might advocate coordination of soil protection efforts at the watershed scale it may be that management units based on village communities are more appropriate if that is the identification of local people. Tiffen *et al.* (1994) are optimistic that the success of quite large community units in soil conservation (and productivity increases to cope with a 3 per cent population growth rate) can be achieved given social and economic cohesion; the Machakos district of Kenya (in the Athi catchment) is home to 1.4 million people and has recovered from abject land degradation in the 1930s. Van Dyke (1995) describes, from a very detailed study, how the Beja nomads of the Sudan adapted and improved their traditional *teras* for collecting runoff and curtailing erosion; profitability was raised at the household level.

Investigations of farming systems in and around *tropical forests* have indicated a very complicated social, political and economic background to soil degradation (Renaud *et al.*, 1998). In northern Thailand 'national security' issues in border areas with Burma and Laos, and legislation to protect tropical forests from traditional swidden agriculture ('slash and burn') have produced a rural community structure in which soil conservation measures are widely ignored in the face of, for example, other employment opportunities, shortages of labour (for the same reason) and, as in Ethiopia, a lack of positive benefit–cost ratios to the family unit. It is vital that a more enlightened strategy is adopted at farm level – the study region is part of the headwaters of the Mekong and provides the source of water supply for Bangkok.

It is of considerable significance to sustainable river basin development that the soil cover of catchments is now likely to gain the significance suggested for it in history (Montgomery, 2007) and that SWC attains the landscape scale, within which the community of land users can play their significant role.

6.2 A stressed global food supply – 'Water for Food, Water for Life'

> We need a blue revolution in agriculture that focuses on increasing productivity per unit water – more crop per drop.
>
> (Kofi Annan, Secretary-General of the United Nations, Millennium Assembly, 2000)

Without doubt, the biggest single conceptual shift since the second edition of this book has been the globalisation of water through its links to both anthropogenic productivity (hence food, health and poverty) and ecological goods and services (hence global biodiversity and environmental stability). Thus, the emergent concept of 'virtual water' (Allan, 1992, 1995) became linked with the hydrodemographic and hydropolitical global frameworks of Falkenmark (see Figure 9.1) to make trade, especially in food, of core concern to IWRM. The 'technical issues' in this chapter have thus been dragged one by one into the global socio-political focus, notably large dams (Shady, 2005).

The Stockholm International Water Institute (SIWI), under guidance from Malin Falkenmark, has continued to render the global framework persuasive to the vital international communities, e.g. via the Millennium Development Goals and the Commission on Sustainable Development. In growing evidence-based confidence they have published a series of outspoken reports, from *Water: More Nutrition per Drop* (SIWI and IWMI, 2004) to *Let It Reign: The New Water Paradigm for Global Food Security* (SIWI *et al.*, 2005). Of vital support to the new paradigm are the refinements made to the separation between 'blue' water and 'green' water (e.g. Rockström and Gordon, 2001) and the careful methodological improvements to and compilations of 'virtual water' in world trade (e.g. Hoekstra, 2003).

6.2.1 The water we eat . . . and don't

The introductory words to the SIWI and IWMI 2004 report (p. 3) are worthy of quotation as a simple, stark truth:

> Production of food is a highly water-consuming activity. Huge volumes of water are transformed into vapour during the production process. . . . With prevailing land and water management practices, a balanced diet represents a depleting water use per capita of 1,300m^3 per year, which is 70 times more than the 50 litres per day used to indicate the basic household needs of water. Despite laudable efforts and accomplishments in global food production, 840 million people remain undernourished.

Table 6.2 indicates average water consumption by (not contained in) essential food categories. However, a large component of the water-for-food 'story' relates to variability around this average, determined by, for example, climatic conditions, water-use efficiency and crop choice – these constitute true 'technical issues' and we will return to them below. Numerical assessment of the

Table 6.2 Water consumption by key diet elements

Food item	*Average water requirement (m^3/kg)*
Beef (fed on grain)	>15
Fresh lamb	10
Fresh poultry	3.5–6
Cereals	0.6–2
Soya beans	1–2
Palm oil	2
Pulses, roots, tubers	1

Data from SIWI *et al.* (2005)

inbuilt international variability is important to the methodological refinement of world trade in 'virtual' water: it is important to decide whether one works with the consumptive use of water in the country of production or what it would have been during production in the country where it is consumed (Hoekstra, 2003; Hoekstra and Chapagain, 2008). Table 6.3 suggests that there are arguments against trade in virtual water as strong as those in favour. A further conceptual development in virtual water analysis is the national-scale 'water footprint' (SIWI *et al.*, 2005; Hoekstra and Chapagain, 2008). It follows the persuasive arguments deriving from 'ecological footprints' (Wackernagel and Rees, 1996) and takes the total volume of fresh water (both 'blue' and 'green') required to produce food – the major component – and other goods and services; the volume is a total of water used within the nation and that imported.

Clearly, another important contribution by the 'new water paradigm', 'blue revolution', etc. is in forward projections of risks in food supply. SIWI *et al.* (2005) give the bleak warning that, based on a desirable diet of 3,000 kcal/day, an additional 5,600 km^3/year of water needs to be appropriated by 2050 – almost three times the current consumptive use in irrigation. Their other stark statistic is that current groundwater *overdrafts* (see Chapter 3) are equivalent to the water needed for 10 per cent of the world's grain supply. Falkenmark and Lannerstad (2005) lay out a more technical, hydrological treatise on the linkages between the demographic assessments of 'water crowding' produced in the 1990s, a division between 'green' and 'blue' water and future food requirements to reduce world poverty. There is little wonder, therefore, at the high level of international interest now being shown in

Table 6.3 Pros and cons of 'virtual water' trade in food

Pros	*Cons*
Water saved by importing from a country with higher productivity.	High risk of environmental impact in exporting regions.
Reducing agricultural use of water in the importing country frees up supplies for industry and home consumption.	Political resistance to imports instead of food security from home sources.
Export substitution becomes feasible to increase GNP.	Adds to urban migration by reduced agricultural employment in importing countries.
Trade can reduce the land take of agriculture and again benefit other sectors of the economy.	Can impact the access poor people have to food via price mechanism.
Structural changes facilitated by trade can provide a bridge whilst agricultural productivity (nutrition per drop) is improved at home.	Can reduce agricultural export earnings from the importing country.

After SIWI *et al.* (2005)

addressing the ‘greatest water problem: the inability to link environmental security, water security and food security’ (Falkenmark, 2001). Food and environmental concerns are geographically linked: in the words of Johan Rockström (2003), the ‘food challenge now faces societies hosted in environmentally vulnerable landscapes’ – he selects the world’s savannahs as the global hot-spot for such problems.

The broader environmental contribution of the work of Falkenmark and colleagues at SIWI is that a ‘green’ water separation from ‘blue’ water allows us intellectual access to water allocations to ‘nature’, or rather natural goods and services (see this topic in Chapter 9). Rockström and Gordon (2001) put the case clearly:

> Global freshwater assessments tend to focus primarily on water flow in perennial rivers, lakes and groundwater, so called blue water in the hydrological cycle. Little attention is paid to the role of green water, or vapour flows, in sustaining the generation of terrestrial ecosystem services, including biomass production.

Perhaps the most important initial role of the separation is to illustrate the danger of basing world water assessments for the future solely on ‘blue’ water, or ‘economically useable water supply’, whilst simultaneously the need to secure water allocations to the environment is high on the international agenda. The authors estimate mean ‘green’ water flow volumes in the world’s biomes as (Gm^3 yr^{-1}):

- cropland 6,700;
- forests/woodland 40,000;
- grassland 15,100;
- wetlands 1,400.

Grossing up these figures they calculate that our anthropogenic appropriation of available water *vapour* flows is 88 per cent – a much tighter limit than that suggested by ‘blue’ water budgets in terms of head room: we have underestimated our dependence. Two conclusions follow:

- ‘A land use decision is always a water decision’ (p. 849).
- ‘There is a need to develop methodologies that internalize integrated water resources management within the context of *ecological landscape management*’ (p. 850).

Another implication of incorporating ‘green’ water uses is that we can include rainfed agriculture (a user of ‘green’ water) alongside irrigated agriculture (supplied largely by ‘blue’ water) in analyses of water-use efficiency or ‘nutrition per drop’ (Falkenmark, 2003a; Rockström, 2003). Incorporation of ‘green’ water requirements for future regional diets may help protect some of the environmental services currently provided there (Serageldin, 2001). Otherwise, the general predictions for agricultural (food) demand to 2050 for a world population of 9 billion are that 10 million square kilometres of ‘natural’ ecosystems will need converting, with an accompanying rise in eutrophication and other pollution threats (Tilman *et al.*, 2001). The estimate does not include any impacts on food demands caused by climate change. As mitigation to this impact the authors suggest land-use planning, including the restoration of decommissioned agricultural land in the developed world and a further ‘green revolution’ in crop and animal husbandry. Clearly, there appears to be a ‘silver bullet’ role for genetic modification of crops in respect of their water demand. However, another potentially profound influence on food production – ‘bioenergy’ – is at the centre of international debate at the time of writing. Scenarios are already being set (e.g. Johansson and Azar, 2007, for the USA) and we return to the topic in the Postscript.

At the time of writing this edition (July 2007), the international water community is digesting the 645-page *Comprehensive Assessment of Water Management in Agriculture*, also titled *Water for Food, Water for Life* (Molden, 2007). Using an open, participatory process, the programme arose from the identification of agriculture as a key driver of ecosystem change in the Millennium Ecosystem Assessment (MEA, 2005 or Alcamo *et al.*, 2003) and the relative lack of agricultural analysis in the World Water Assessment (UN-Water, 2006). Of particular concern is the predicted 20 per cent growth in agricultural water need by 2025, possibly 33 per cent by 2050, and the danger that water for ecosystems will diminish as a priority in a scramble for human food.

The most alerting conclusion for decision makers is that ‘Only if we act now to improve water use in agriculture will we meet the acute freshwater challenges facing humankind over the coming 50 years.’ Amongst the policy actions needed to respond are:

- Change the way we think about water to ensure food security, alleviate poverty and conserve ecosystems.
- Improve water rights, infrastructure and technology appropriate to smallholder farmers.
- Manage agriculture to enhance ecosystem services.
- Increase the productivity of water.
- Upgrade rainfed systems by managing soil moisture.
- Reform irrigation and its interaction with other essential uses, often via reforming state institutions.
- Make bold, urgent, collaborative and monitored decisions.

With the reminder that 70 per cent of the global poor live in rural areas, the Assessment makes links between agricultural water reform and the Millennium Development Goals (Table 6.4).

Table 6.4 Relationship of water management in agriculture to the Millennium Development Goals

MDG	*Role of water management in agriculture*
1 Eradicate extreme poverty and hunger. 3 Promote gender equality and empower women.	Increase agricultural productivity; maintain affordable food prices; improve access to factors of production and markets.
4 Reduce child mortality. 5 Improve maternal health.	Enhance equitable access to water and thus the ability to produce food.
6 Combat HIV/AIDS, malaria and other disease.	Contribute to better hygiene and diets; appropriate use of marginal-quality water.
7 Ensure environmental sustainability.	Integrate sustainability principles into agricultural water use and reverse loss of environmental resources.
8 Develop a global partnership for development.	Involve a diverse range of practitioners, researchers and decision makers.

Modified from Molden (2007)

6.2.2 *Irrigation: land, water* and people

Agriculture still dominates mankind's use of freshwater (Tables 5.4 and 6.5). The lion's share of the water use is by irrigated agriculture to very varying degrees of efficiency (Figure 6.4(a)), though it is vital to include in our deliberations the 84 per cent of productive agricultural land that is rainfed. No other economic activity uses as much water per unit area as agricultural applications; only evaporation from the surface of large reservoirs such as the

Table 6.5 Key data for ten countries with the largest irrigated area

Country	*Population (million)*	*Percentage population in agriculture*	*Total area (million hectares)*	*Arable land (million hectares)*	*Irrigated area (million hectares)*
India	998	55	329	170	59
China	1,267	68	960	135	53
USA	276	2	936	179	21
Pakistan	152	51	80	22	18
Iran	67	28	163	18	8
Mexico	97	24	196	27	7
Indonesia	209	45	190	31	5
Thailand	61	50	51	20	5
Russia	147	11	1,708	128	5
Turkey	65	31	77	29	4
Total	3,339		4,690	759	185
World	6,000		13,000	1,512	271

Source: International Commission on Irrigation and Drainage (ICID) (in comments to the World Commission on Dams, 2000)

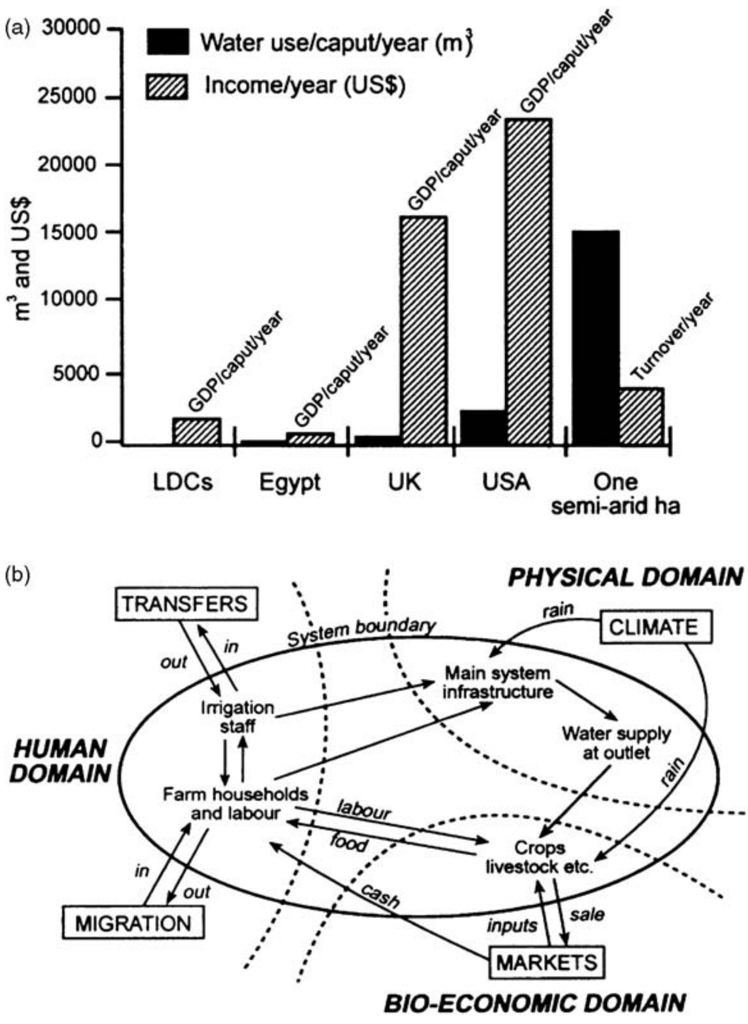


Figure 6.4 Irrigation and its water use:
(a) Water use and returns in agriculture – developing and developed world (after Allan, 1992)
(b) The domains of irrigation and their linkages (after Chambers, 1988)

Aswan dam 'wastes' so much water. Yet the 16 per cent of world agriculture which benefits from irrigation contributes 40 per cent of the world's food supplies; in Asia the proportion is higher, partly because rice is the major irrigated crop (to create paddy conditions). It is seldom acknowledged that irrigation has played a major support role in the food needs of the planet's burgeoning human population in the last 30 years (Barrow, 1999).

The *Comprehensive Assessment* (Molden, 2007) contains a chapter entitled 'Reinventing irrigation' (see below). Partly, this sentiment refers to a pressing need for irrigation to 'grow up' in terms of its wider connectivity, particularly its real costs and benefits in relation to rival uses of water. During the 'settler culture' era of dryland colonisation and development, irrigation provision had privileged but under-priced strategic and operational roles; its success was judged merely against subsistence and commodity production. The 'reinvention' reflects new priorities, e.g. environmental uses of water: 'Environmental water allocations will steadily increase and present a much greater challenge to irrigation than will cities and industries, because the volumes at stake are likely to be larger' (Molden, 2007, p. 355).

Irrigation can be defined as a human intervention to modify the spatial and temporal distribution of water occurring in natural channels, depressions, drainageways or aquifers and to manipulate all or part of this water to improve production of agricultural crops or enhance growth of other desirable crops. Barrow (1999) defines *runoff agriculture* as 'a generic term applied to cultivation, pastoral, forestry or conservation techniques that rely on tillage or planting patterns, bunds, terraces and other structures to delay and retain runoff, and to increase infiltration and counter soil erosion' (p. 7). Clearly, therefore, runoff agriculture is not simply rainfed agriculture and is closely linked to SWC (see Section 6.1.2); equally clearly, both irrigation and runoff agriculture face the scrutiny of cost-effectiveness, and social and environmental acceptability (see below).

Often 'irrigationism' (Adams, 1992) takes a political hold with no regard for the river basin context of large-scale irrigation or for the real needs of those who will work the crops to be fed. Reasons for the failure of large-scale schemes are given by Carter (1992) – see Table 6.6(a). To be more positive (because the crisis of irrigated agriculture is perhaps the most immediate of all global environmental crises), Carter also lists the 'true' parameters of irrigation potential (Table 6.6(b)), and these form the urgent research agenda for hydrologists, agricultural scientists and, crucially, social scientists. Chambers (1988) writes of three domains of irrigation systems: physical, human and bio-economic. Figure 6.4(b) shows the interactions which should

Table 6.6(a) Reasons identified for poor performance of large-scale irrigation schemes

Problems at conception and planning stage

- The inadequacy of conventional criteria for project acceptance
- Lower yields than anticipated in project plans
- Generally over-optimistic projections of benefits at conception/feasibility stages
- Inadequate time allowed for project preparation
- Insufficient account taken of land tenure and water rights
- Irrigation activities not integrated with rainfed cropping and other farming and income-generating activities

Inherent difficulties
- The complexity and problematic nature of irrigation as a form of agricultural intensification
- Problems associated with the farmers' reduced independence on becoming irrigators
- Problems of soil suitability and soil variability

Design and construction stage flaws
- Inadequate design, requiring subsequent major changes
- Poor on-farm development
- Inappropriateness of imposed cropping calendars

Operation and management difficulties
- Poor management of irrigation agencies (government departments)
- Problems involved with the management and maintenance of irrigation technology
- Poor distribution of water within the scheme
- Poor on-farm water development
- Inadequacy of extension services
- Public health problems
- Problems of salinisation and water-table rise, necessitating costly drainage and reclamation strategies
- Poor level of involvement by farmers

Financial/ economic problems
- Very high development costs per hectare
- Inadequate importance attached to funding of post-construction activities
- Heavy costs and low level of performance of irrigation agencies
- Difficulties of collecting water charges

Source: Carter (1992)

Table 6.6(b) Two paradigms of the concept of 'irrigation potential'

The simplistic myth
- Suitable land + Proximity to water = Irrigation potential

A closer approximation If the following apply:
- water supply is a major constraint to production *and*
- soils are suitable *and*
- water and affordable, maintainable water delivery technology is available *and*
- farmers wish to irrigate *and*
- appropriate farmer and/or government organisations for water management exist or can be developed *and*
- inputs – fertiliser, seed, pesticides – are available *and*
- credit for input supply is available *and*
- crop prices are attractive *and*
- markets are accessible *and*
- issues of land tenure and water rights have been satisfactorily resolved *and*
- proposed irrigation activities are environmentally sustainable

then irrigation development may be a viable option.

Source: Carter (1992)

be given equal weight in the investigation of the feasibility of a scheme and its detailed planning. The *Comprehensive Assessment* (Molden, 2007) reiterates many of these points for a global audience.

Chambers's study is of canal irrigation – the most common form of gravitational supply in constructed large-scale schemes. Box 6.2 shows, however, that there are three main other forms of irrigation scheme based upon how the water is eventually applied to the crop. The distribution of irrigation water, as Chambers explains in close detail, is where technology, economics and politics confront each other in space and time; the volume and timing of the supply of water in a canal scheme (see Figure 6.5) can make or break the efforts of the farmers. Too much irrigation water can be as damaging as too little, and water applied too early or too late means that optimum yields are missed.

As well as the potential for social 'inefficiency', the efficacy of irrigation schemes depends on the degree to which the water supplied from river, dam or pump translates into improved agricultural production; at every stage in

Box 6.2 From antiquity to the microprocessor: irrigation techniques

On many occasions in this book the importance of drylands to global civilisation and the vital role of irrigated agriculture have been stressed. Basically, irrigation requires water and gravity; where gravity is obstructed energy must be found to lift and/or distribute the water. However, crop water use is variable, relates to soil fertility as well as climate and, if not matched by an irrigation 'regime' tailored to needs, the yield is reduced and the irrigated soil may become damaged. There is thus a vast spectrum of internationally convergent techniques for irrigation, ancient and modern, with important local variants. Table 6.7 groups these into four categories and suggests the contexts in which each method is likely to provide the best results. Plate 6.3 (p. 233) shows a highly efficient but very costly computer-controlled system in Israel. However, even the most sophisticated systems require the abstraction of water from rivers to individual 'farm dams' (such as the one shown in the Plate 6.2 inset).

Flood irrigation mimics the natural 'bulk' application of water from river to land but at the field scale it is obviously the least controlled. At the sophisticated end of the spectrum are sub-irrigation, with water being applied directly to the root zone of the crop, and sprinkler irrigation, both of which require a considerable infrastructure of pipes. The costs of infrastructure figure highly in the assessment of benefits of irrigation, and energy costs are especially punishing (e.g. in pumping groundwater from depth or forcing surface water through sprinklers).

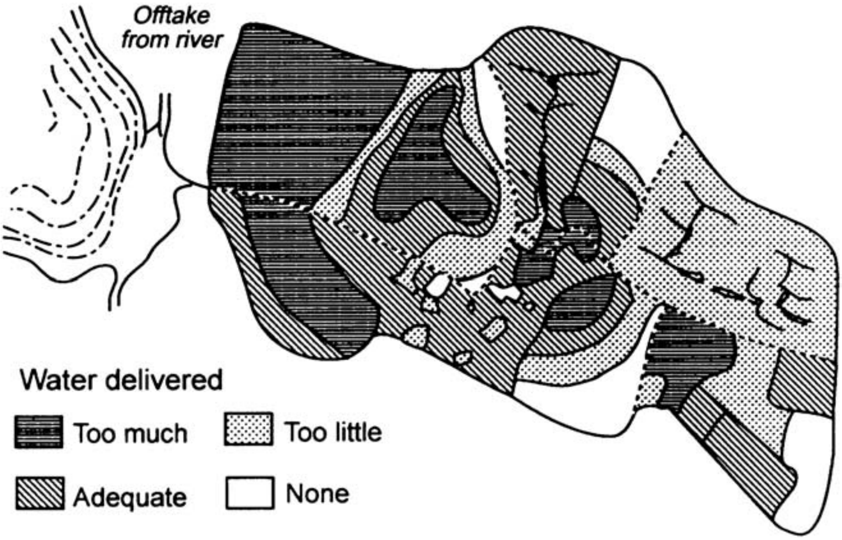


Figure 6.5 Canal irrigation: distribution problems with increasing distance from the river offtake (after Chambers, 1988).

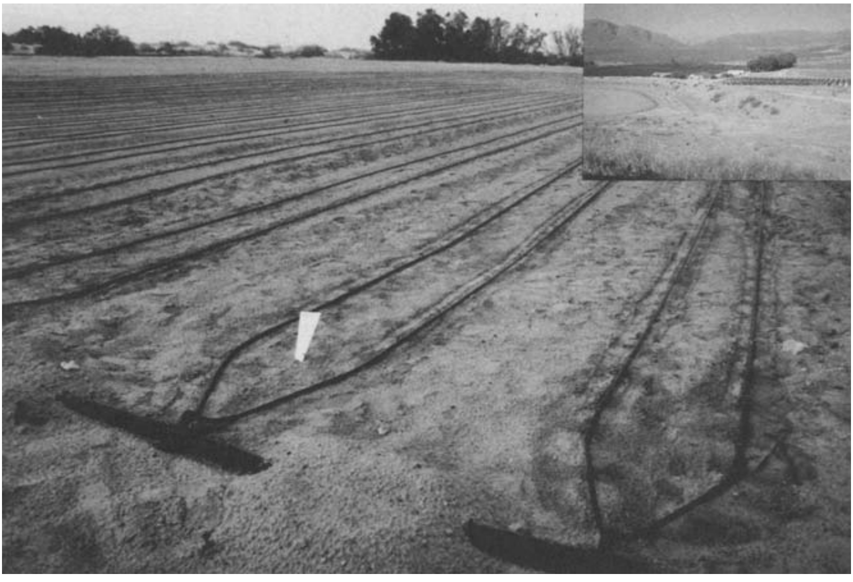


Plate 6.2 Efficient irrigation supply to crops in Israel and (inset) heavy depletion by small 'farm dams' in South Africa (photos M. D. Newson).

the water supply process to the fields there are opportunities for malfunctions and *transmission losses*. Chambers's tabulation of data for seven schemes in India shows that, whilst trivial transmission losses were anticipated (2–10 per cent), actual losses were greater in every case (6–40 per cent). It has been estimated that the gross efficiency of irrigated agriculture worldwide is 37 per cent. A notable exception to these dismal figures is Israel, which, as well as making more and more use of recycled wastewater, is using minimum-waste delivery systems, such as trickle irrigation, to deliver the water needed (and the fertiliser) according to biological and meteorological needs (Plate 6.2).

Table 6.7 Comparison of major methods of irrigation

	Canal irrigation			
Bases of comparison	*Flood irrigation*	*Furrow irrigation*	*Sub-irrigation*	*Aerial irrigation*
1 Total capital costs	Low	Low	High	Medium
2 Total annual costs	Low	Medium	Very low	High
3 Crops	Pastures, grain	Row crops e.g. corn, cotton, potatoes, vegetables, orchards	Annual root crops, vegetables, orchards	Pastures, vegetables, orchards, nurseries
4 Soil type	Adaptable to most soils but fields may be small if infiltration rate high	Adaptable to most soils having good lateral moisture movement characteristics	Must be capable of capillary rise into the root zone. Must allow good lateral movements of moisture	Adaptable to most soils
5 Topography	Slopes capable of grading to 1% max	Slopes varying from 0.5% to 12%	Fairly uniform slopes preferred	Adaptable to most slopes which could be farmed
6 Water required	Large streams	Fairly large streams are sometimes necessary depending on the number and size of furrows	Small flows may be utilised. Groundwater or farm dams	Small flows may be utilised. Groundwater (pumped)
7 Soil or crop damage	Over-watering may cause salting, puddling or surface crusting	Furrow erosion is a big problem	Extremely unlikely	Both are possible if water drops are large

Source: Adapted from Withers and Vipond (1978), Table 7.8, based on Weisner (1970)

Nearby Egypt, 95 per cent of whose agricultural production comes from irrigation, has come to realise that upgrading its traditional systems could double the yields of crops like maize. Hvidt (1998) describes Egypt's Irrigation Improvement Project, whose definition of 'efficiency' went far beyond that of 'crop per drop', in themes such as energy use for pumping, land tenure, water users' associations and the profile of individual farmers. The contribution of *drainage* should not go unrecognised in the technical improvements sought for irrigated agriculture; management of saline soil water and groundwater requires a big capital investment. In Egypt, nearly 2 million hectares of land in the Nile delta region has now been equipped with underdrains and pumps (Wichelns, 2002); there are clearly disposal costs for the salty drainage waters.

Kijne *et al.* (2003) drew out the issue of efficiency, or rather the much broader 'water productivity', from the *Comprehensive Assessment of Water Management in Agriculture* (Molden, 2007). Traditional definitions of irrigation efficiency can be misleading, including as they do such 'losses' as seepage and percolation which in fact lead to reuse elsewhere in the basin (cf. evaporation and transpiration). If reuse is considered, the opportunities for increases in overall water productivity are reduced. Even so, if water 'saved' in agriculture could be put to higher-valued uses this would be within the broader, non-engineering, concept of productivity.

In view of the continuing problems of feasibility for desalination processes at suitable scales for direct human consumption of salt water it is interesting to read in the chapters by Tyagi (2003) and Bennett (2003) of improvements in agronomy and in genetic modifications (GM) to crops which will permit reoccupation of damaged irrigated areas. Among the GM routes to greater crop productivity are reducing the non-transpirational uses of water, reducing transpiration volume without affecting productivity, salt tolerance and tolerance of submergence and waterlogging. Interestingly, Israel is already experimenting with salt-tolerant vines.

6.2.3 Social dimensions and alternatives in agriculture

As we saw in the case of soil erosion, the identification of environmental resources and hazards is part of a vernacular knowledge. Adams (1992) extends the typology of irrigation schemes to 'indigenous irrigation' in Africa. There is a continuum of traditional techniques from adaptation to natural flood patterns in wetland areas to complete water control. His main division is between flood cropping, stream diversion and lift irrigation, which in total constitute 47 per cent of Africa's irrigated area.

Just as it is misguided to think we can do without large dams in future, we have not seen the end of large-scale irrigation, and one alternative, i.e. small-scale irrigation, should not be seen as a universal solution. An essential element of small-scale irrigation is that plots are essentially small (Plate 5.3), but more important is that small farmers control the works and that those works are at a technological level which they can operate and maintain (Carter, 1992; Carter and Howsam, 1994). The differing perceptions of irrigation schemes between men and women can be revealing (Guijt and Thompson, 1994). 'Appropriate technology' for small-scale irrigation clearly needs formalising, and handbooks are available (e.g. Stern, 1979). A danger of perception of 'progress' and 'efficiency' by state water managers when dealing with traditional or modern small-scale irrigation is brought out by Haagsma (1995). Whilst the crop choice, water use, operation and maintenance of small schemes on Santo Antao (Cape Verde) may appear to be 'primitive', the overall efficiency is high when considered in relation to river basin resources and resilience in the face of water shortages. It is, however, critical to gain a detailed understanding of indigenous irrigation practices before endorsing them – an academic fascination with them is not sufficient in itself (Adams *et al.*, 1994).

Clearly 'alternative irrigation' and runoff agriculture form a continuum; the latter also has close links to SWC. However, Barrow (1999) seeks distance for runoff agriculture from both 'mainstream' irrigation and rainfed agriculture in terms of its advantages over both in a developing-world context (Table 6.8). He admits, however, that a following for runoff agriculture awaits a change in the political and financial support systems for agriculture and that the success of its adoption depends greatly on improvements in forecasting one of the great hazards to all agricultural systems: drought.

Table 6.8 The advantages of runoff agriculture

Comparison	*Advantages*
(a) Over mainstream irrigation	Suitable for adoption by the poor. Has materials and methods suitable for marginal areas. Cheap to establish – releasing funds for other development targets. Uses local materials, reducing dependency and facilitating maintenance. Implies conservation of soil and moisture. Less likely to cause waterlogging, salinisation, off-site pollution or human health problems. Diversity of approaches creates resilience to failures.
(b) Over rainfed agriculture	Better supports land husbandry and reduces soil degradation. Improved yields and more crops. Potential for production in areas unsuited to rainfed or irrigated agriculture. Represents an adaptation strategy for rainfed agriculture following climate change (if towards less moisture availability). Can improve streamflow quality and quantity,* increase groundwater recharge and reduce risk of landslides and floods.

* There are now debates about crop water use by runoff agriculture in the headwaters of water-stressed basins – see Chapter 5.
After Barrow (1999)

6.2.4 Drought

Drought is a hazard to dryland communities (Box 5.2), especially those in the southern hemisphere where rainfall variability is at its global peak (see Chapter 4, Section 4.4). However, the political configuration of drought has often failed to consider drought as 'a normal part of climate, rather than a departure' (Wilhite and Buchanan-Smith, 2005). All natural hazards may be thought of as comprising a risk term and a vulnerability term; the risk is probabilistic, revealed through statistical analysis (e.g. we speak of the 100-year event), but vulnerability is increased through poor hazard perception (e.g. hazardous locations, activities) and inadequate warning systems. Drought hazard protection is a lot less well developed than flood protection, possibly because large-scale, 'sophisticated' (e.g. urban) development in drylands is a new phenomenon and is occurring principally in those countries which do not have the capacity built for systems such as long-range weather forecasting. Even in countries like Australia, South Africa and the USA with appropriate technical capacity, a reactive approach remains more common at the national scale (Wilhite, 2005).

Drought has no single technical definition (Box 5.2); Wilhite and Buchanan-Smith (2005) stress that the definition 'must be region and application (or impact) specific'. We may envisage a time sequence from meteorological drought (a rainfall deficit for a certain period), through soil moisture deficit (involving evaporation loss – sometimes called 'agricultural drought') to various measures of extremely low groundwater levels or river flows ('hydrological drought'). Finally, under reactive policies, a socio-economic and political impact occurs. If poorly designed irrigation schemes increase vulnerability to drought their shortcomings are conveniently confused by politicians with the 'technical' drought problem (Box 6.3).

The World Meteorological Organization called for development of drought plans in 1986; progress has been slow yet drought relief programmes are infinitely more expensive (Wilhite, 1993a). Australia has, since 1990, operated a policy which reduces relief in favour of advance preparedness, education, decision support and weather forecasting; in the USA many states have drought contingency plans, but in most countries reviewed as case studies in Wilhite's 1993 volume there was little or no progress. Wilhite *et al.* (2005) update the review and suggest that the critical climatic vulnerability of Australia (due in part to El Niño and in part to insecurity of food supply) had produced the most notable policy progress. In Chapter 5 we saw that India's drought problem has brought little by way of sustainable government response.

As Wilhite and Buchanan-Smith (2005) conclude, 'Reducing the impacts of future drought events is paramount as part of a sustainable development strategy' (p. 7). The reduction of vulnerability is thus a key challenge for the economic development process, whilst the improvement of drought early warning systems (DEWS) will constitute a major science contribution,

Box 6.3 Policy responses to drought and the ‘hydro-illogical cycle’

Drought evolves slowly, offering politicians the opportunity to hope (or pray) for relief, without the need for costly intervention (yet pioneer agrarian communities are often built upon government support via ‘cheap’ water). There then operates a political ‘switch’ forcing financial relief, food aid and possibly even water carried by road tankers; the crisis may be averted but, in areas of growing water demand, each drought increases the hazard (even if the risk is not changing with climate). As Bandyopadhyay (1987) puts it, ‘The ambiguous term “drought” has been rather freely used in our country [India] to explain away the process of ever increasing water scarcity’ (p. 12). National governments are frequently caught in the ‘hydro-illogical cycle’ as regards drought hazard (Wilhite, 1993a, and Figure 6.6), and the international community may complicate matters by giving aid during the ‘panic’ stage which induces, once rain falls, ‘apathy’. This is totally unlike the adaptive strategies of diverse uses implemented by indigenous peoples in drylands. Mortimore (1989) made an intensive study of the adaptation of the Hausa, Ful’be and Manga communities in

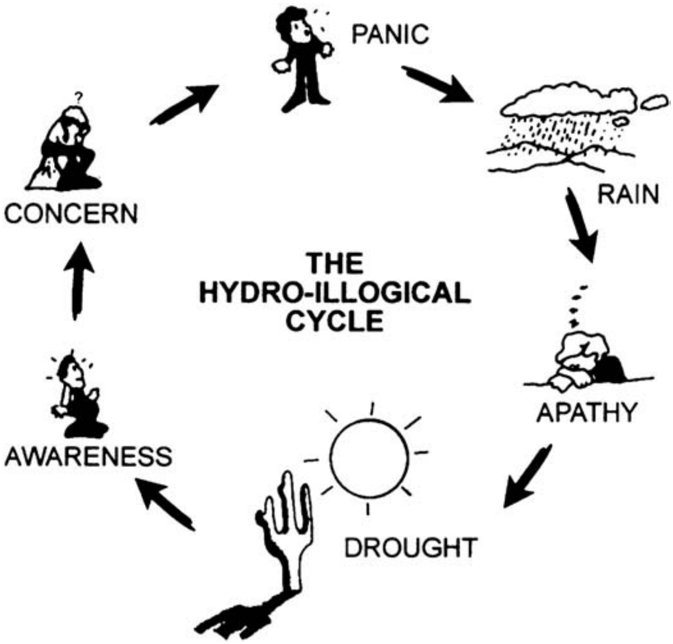


Figure 6.6 The ‘hydro-illogical cycle’ (from Wilhite, 1993b).

Nigeria to the droughts of the 1970s and 1980s; he concludes that:

> Arid and semi-arid environments call for special adaptive skills on the part of those who live there. The twentieth century has unwittingly transformed the socio-economic milieu of the inhabitants of these environments. . . . Therefore, ways must be found of supporting productive communities in such high-risk environments.
>
> (Mortimore, 1989, p. 230)

demonstrating an understanding of those large-space, long-term correlations of the global climate system that are also vital to help us adapt to climate change – and possibly more drought (see Section 6.5).

6.3 Dams and development – sedimentation, environmental flows, impact assessment

Dams:

> . . . a flawed yet still necessary development option.
>
> (Scudder, 2005, p. 1)

During the 1990s the World Bank became the focus, through its financial support for large development projects, of a protest movement against large dams. Much of the most impassioned resistance to further large dam projects came from 'dam-affected peoples', including the 'oustees' from land to be drowned beneath reservoirs. However, the more politically established environmental lobbyists had been mobilising opposition for a decade (e.g. McCully, 1996, 2001), and the International Union for the Conservation of Nature and Natural Resources (IUCN) brought the World Bank to account in April 1997. Three and a half years later, the WCD, under the chairmanship of Professor Kader Asmal, the inspiration for South Africa's Water Act, produced its report *Dams and Development: A New Framework for Decision-Making* (WCD, 2000). Professor Asmal says of the Commission, 'the imaginative fires of both our product and our process continue to blaze brightly at new forums and in different languages, fuelling discussions from riverbank village to corporate boardroom, living on through the United Nations, generating more light than heat' (Foreword to Scudder, 2005).

The positive 'light/heat' balance of the Commission's report is due partly to the heat encouraged by Asmal during the WCD's proceedings, in which Commission members were chosen for their partisan views on both sides of the argument; 950 submissions were taken from individuals, groups and institutions, four public hearings were held, 125 dams in 56 countries were reviewed and 17 detailed thematic reviews considered (Imhof *et al.*, 2002).

Imhof *et al.* also draw attention to the fact that, despite widespread international support, the Commission's precautionary approach to further dam-based development is rejected by nations such as China and Turkey, together with the International Commission on Large Dams (ICOLD) and the International Commission on Irrigation and Drainage (ICID); it attracted only a 'mixed' reaction from the World Bank.

The WCD has not stopped dam developments; critics point to the falling rate of construction of large dams from a peak in the 1970s, the falling rate of development assistance for large dams from a peak in the early 1980s, and the first signs of a dam removal movement. However, the flaws to which Thayer Scudder refers at the start of this section are now laid bare, making it hard for 'heroic' politicians to hide them (during construction, large dams are often the largest public project within a nation state).

6.3.1 Dams, reservoirs and regulated rivers: an introductory environmental assessment

We have observed the popularity of dam construction in most nations as a means of moderating the natural extremes of flow which rivers exhibit in response to precipitation episodes. Since the first aim of reservoir storage is flow moderation, this is the first impact of dam construction; river habitat is adjusted to a natural pattern of flows (or flow 'regime'). The storage itself is also vulnerable from sedimentation in still-water conditions; we therefore here treat a major off-site cost of soil erosion. The dam is perhaps best seen as a simple hinge point in a disrupted erosion/deposition system (Figure 6.7).

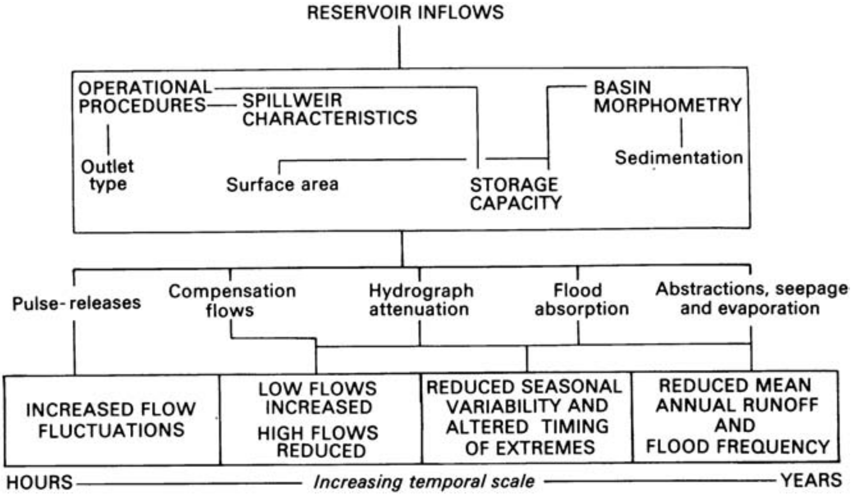


Figure 6.7 Influences of river regulation (by dam construction) on downstream flows (Petts, 1984).

For this and other reasons dam siting should be based on far more considerations than the conventional ones of foundation geology and water balance (see Newson, 1994a). The river system's network of channels contributes sediments from tributaries downstream as well as upstream of dams, and these contributions (downstream) offer the 'tools' of morphological readjustment to the impacts of sediment deprivation through the barrier effect of the dam (Figure 6.8). Impoundments create discontinuities in the river channel ecosystem; adopting the river continuum concept of Vannote *et al.* (1980), Ward and Stanford (1983) refer to the serial discontinuity concept by which the position of an impoundment within the continuum (of biotic and nutritional change) resets the channel downstream to an analogue of the river headwaters. After a certain recovery distance the continuum is resumed until the next impoundment downstream. Despite this 'reset', the water in impounded rivers worldwide is now known to have 'aged' because the natural residence time has, on average, been tripled by storage (Vorosmarty *et al.*, 1997).

Because sediments as well as water are stored by reservoirs, there are considerable changes in erosion and deposition downstream of dams; channel capacity is adjusted to the transport of both water and sediments (Chapter 2) and both are altered. Alterations also occur to water quality as a result of storage or of the uses to which the stored water is put. Impacts tend to decay downstream as natural tributaries restore the original flow regime and through time as a new equilibrium is reached, but not before primary effects

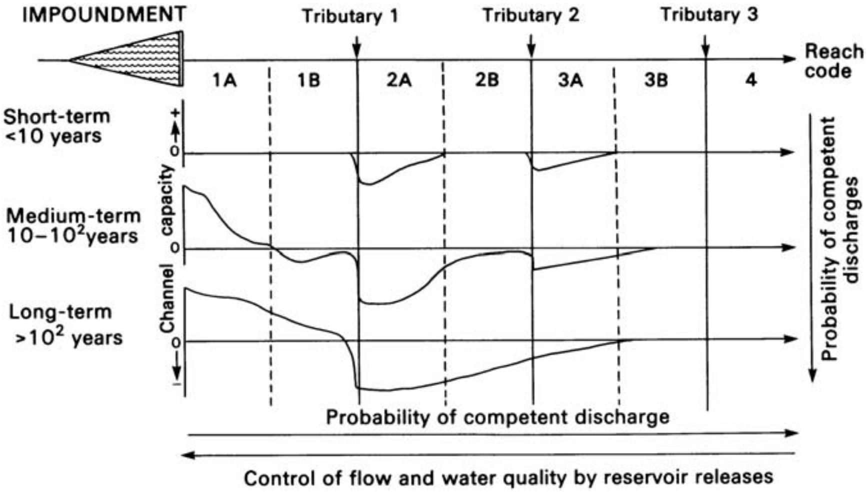


Figure 6.8 The role of tributary flow and sediment inputs in the adjustment of fluvial morphology to regulated flows below reservoirs (Petts, 1979).

of flow and sediment regulation have produced secondary and tertiary effects on the river environment (see Figure 6.9).

We now take the major impacts of discontinuity one by one, leading up to the response by science to a global clamour to allocate more water stored for human use to ecosystems – reconnecting them – and to reinstate 'environmental flows' in a more natural regime downstream of impoundments. Two more flow routes from dams, traditionally ignored or underplayed, have become the focus of intense debate since the second edition: the flow of greenhouse gases (GHGs) to the atmosphere from reservoirs and the flow

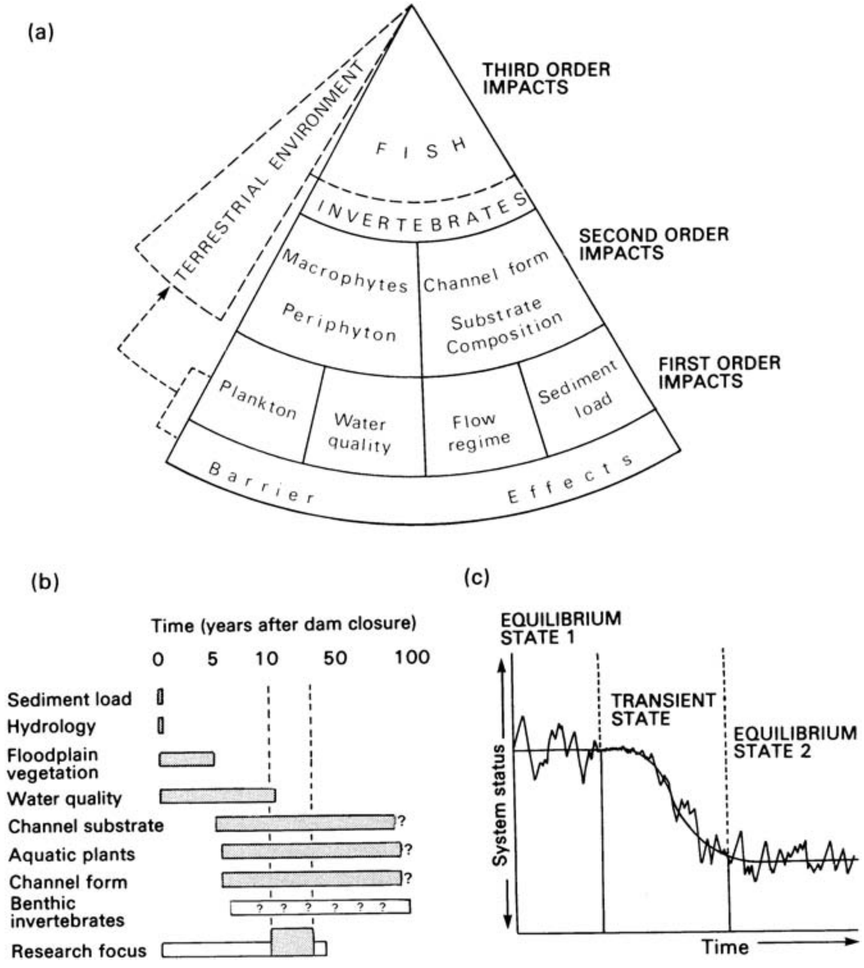


Figure 6.9 River regulation and equilibrium:

(a) Chained impacts – first, second and third orders (Petts, 1979)

(b) Reaction times recorded in the literature

(c) A hypothetical general model of adjustment through time (Petts, 1987) of electricity from hydro-power turbines in dams to communities who might otherwise be using fossil fuels (see Postscript).

6.3.2 Soil erosion and reservoir sedimentation

In Chapter 2 we saw how difficult it is to predict fluvial sediment transport and catchment yields; however, in cases of severe practical need, such as soil erosion and reservoir sedimentation, simple empirical devices are better than ignorance. Local data, such as reservoir surveys during drought, when the water level is down, can vastly improve the yield approach, as is now the case in Ethiopia (Tamene *et al.*, 2006). The process of *sediment delivery* is that which converts erosion products into a sediment yield, and the sediment *delivery ratio* links the two (Walling, 1983). Delivery ratios have been researched since the early 1950s with a view to allowing downstream impacts, notably reservoir sedimentation, to be calculated from erosion measurements (or predictions – using the USLE, for example). The source area erosion rate is considered as unity (or 100 per cent), and the intervention of storage downstream reduces this value as area increases; area is the most common variable used in delivery ratio predictions (see Figure 6.10(a)), but multiple regression equations also exist, and there have been many attempts to explain the variability, shown in Figure 6.10. As we discussed in Chapter 2, geomorphologists have a more sophisticated appreciation of basin-scale sediment storages now and have largely discredited the concept of the delivery ratio.

A further property of the erosion-deposition system which is of critical importance to predicting reservoir sedimentation rates is the *trapping efficiency* of the impounded waters (Brune, 1958). Controlling variables include:

(a) ratio of reservoir capacity to catchment size;
(b) detention time of water in reservoir;
(c) mixed variables such as:

inflow volume/reservoir volume,
detention time/velocity of flow through system.

Increasingly, dams regulate sediment accumulation in their reservoirs by flushing and sluicing; on the Blue Nile the Roseires dam forsakes the storage of water during the early part of the flood season to escape the first 'flush' of sediments; later the clearer inflows are stored as the valves close. According to Williams (2000), the effective depth of Roseires reservoir was reduced by 10–15 metres in its first decade, and sediment loads at Khartoum, downstream, were reduced by between 10 million and 30 million tonnes per annum. Clearly, major new dam projects in regions of accelerated soil erosion, such as the Three Gorges site on the Yangtze in China, face a reduced 'useful life' unless flushing operations can be matched with source controls chosen

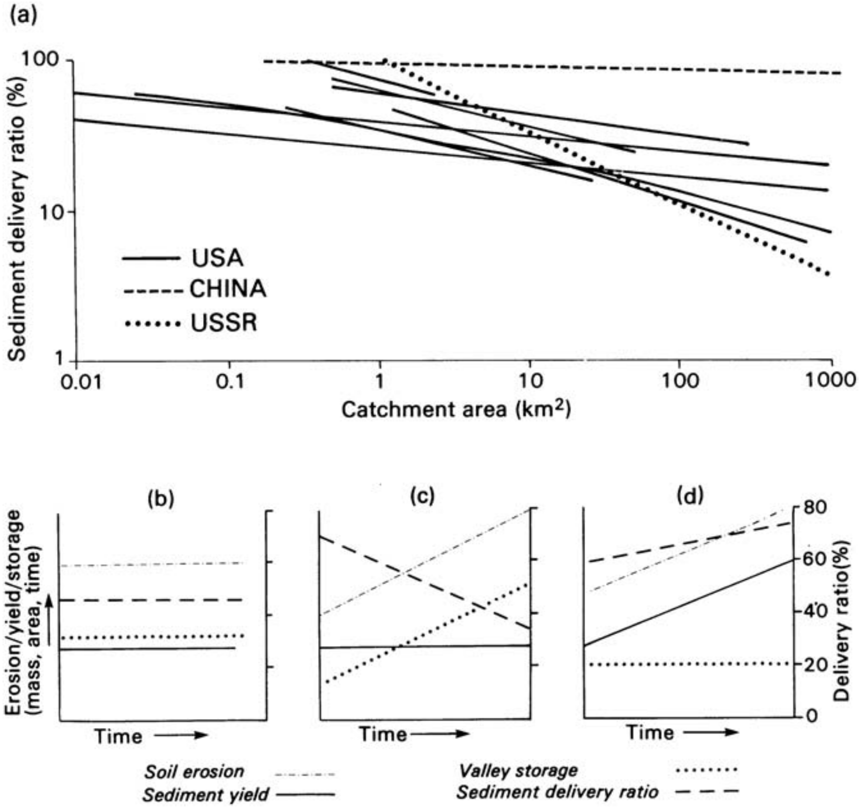


Figure 6.10 Sediment delivery ratios:
(a) Variability of empirically derived curves (Walling, 1983)
(b–d) Schematic illustration of the role of remobilised sediments in affecting delivery ratios. Periods of erosion lead to storage (c) and subsequently release (d) of eroded sediments (Boardman *et al.*, 1990)

from a knowledge of spatial patterns of sediment yields from the vast upstream catchment (Higgitt and Lu, 2001). Paradoxically, some of the sediment supply rates which exceed estimates made for the Three Gorges dam are in its local area and may increase through displacement of the local population (Lu and Higgitt, 2001).

6.3.3 Regulated rivers below dams

Broadly speaking, river regulation has been inevitable for man's habitation of Earth, considering the very small proportion of usable water on the planet which flows in river systems (3 mm rainfall depth equivalent) and the very short residence time it has in the natural storages of those systems (two weeks). If one further adds the repeated tendency for development processes to remove major elements of natural storage such as wetlands and floodplains then the need to interrupt the natural flow of rivers and its pattern in space becomes inevitable.

Dams are built for several purposes; most are multi-purpose or are adapted to be multi-purpose. They supply water from storage to domestic, industrial and agricultural users, either by feeding into *direct supply* pipelines or by *regulating* the flow of the river below the dam site (i.e. by using the river as a natural pipeline – Plate 6.3). Dams also house turbines for generating electric power from the controlled gravitational flow of water down a steep hydraulic gradient. They may also produce advantageous flow regimes for users of the river (navigation) or neighbouring land (flood control). Finally, they may have subsidiary aims of environmental enhancement, e.g. by aiding

Plate 6.3 The control of river flows by valves: inside Clywedog dam, mid-Wales, regulating the flow of the River Severn (photo M. D. Newson).

fisheries or maintaining wetlands, but as yet only small dams are built to improve habitat conditions. Some large dams capable of regulating rivers have also produced episodic benefits for recreation (e.g. canoeing) and for pollution control (flushing accidental spills).

We clearly need to consider impact decay downstream as ‘natural’ tributaries gradually restore the original regime to the river. Petts (1979) provides considerable help in his depiction of the role of unregulated tributaries (in terms of both flow and sediment contributions) and the way in which a morphological response (channel capacity) responds through time. The time dimension is vitally important as the river system re-establishes a new steady state to reflect the balance of regulated and natural inputs at all points downstream (Petts suggests that morphological responses may be minimal by the stage at which the reservoir catchment area is less than 40 per cent of the total catchment area to that point).

Returning to the temporal pattern of releases, Gustard *et al.* (1987) document the predominant types found in the UK (Figure 6.11(a)) and tabulate the frequency of use by reservoirs. They also graph the frequency of reservoirs by purpose, and Figure 6.11(b) shows the domination of direct supply reservoirs, i.e. feeding stored water to consumer centres via pipelines. Very little attention was given in the early approaches to setting compensation water rules for the protection of fisheries or wildlife below such reservoirs, a situation now completely reformed (Edwards and Brooker, 1982).

Elsewhere in Britain little monitoring was commissioned before dam construction although *post hoc* evaluations of the key processes have been carried out at high flows after dam construction (e.g. Petts *et al.*, 1985; Leeks and Newson, 1989). Prior to the construction of Kielder reservoir, Northumberland, surveys were conducted of the stability of the bed sediments under regulating flow conditions and of the invertebrates living above and below the dam site (Boon, 1987) mainly because of the importance of salmonid fisheries on the river.

A more recent *post hoc* evaluation of Kielder’s impacts was commissioned as the result of a change in the operation of the dam; because water *supply* demand has fallen, hydro-electric turbines were installed and a diurnal pattern of release waves became the norm (Johnson, 1988). Archer and Williams (1995) illustrate convincingly the effect on the flow regime below the dam, and eventually the artificial regime was considered a negative impact on a river whose riparian owners had ambitions for it to become the finest salmon fishery in England (one they have now realised). The Kielder studies will require frequent repetition: full biological adjustments may take decades and be symptomatic of a ‘complex response’. As Petts (1984) stresses, ‘Completely adjusted systems have been observed only rarely and most studies relate to the period characterized by transient system states’ (p. 258).

Turning to river regulation in the developing world, Kariba dam on the Zambezi River was the first large developing-world scheme to involve river

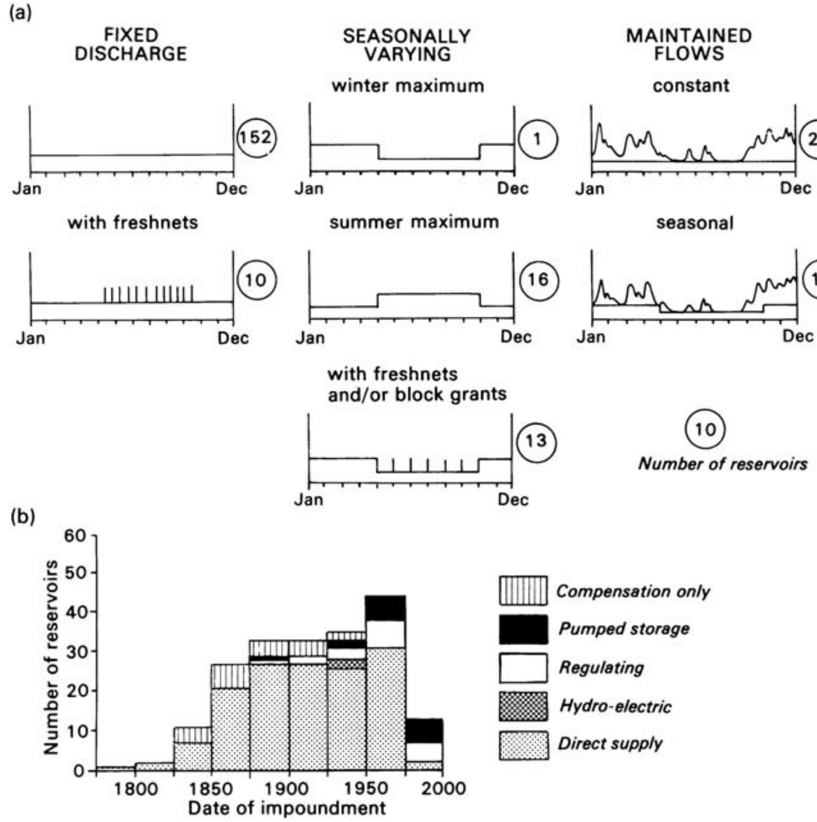


Figure 6.11 Patterns of UK river regulation:
(a) The river flow regime below typical schemes
(b) Changes in the aim of schemes built since 1750 (after Gustard *et al.*, 1987)

regulation (in 1958). Although Leopold and Maddock (1954) had written the first fundamental assessment of the physical impacts of regulation in 1954, Kariba has only been evaluated from an environmental viewpoint in retrospect, along with Volta (Ghana), Kainji (Nigeria) and the Aswan High dam (see Chapter 5) by Obeng (1978). Obeng's review of these impoundments deals with the more spectacular effects on communities, health, seismic activity, growth of macrophytes, and fisheries with only a passing mention of effects on channels. Hughes (1990) reports that large areas of evergreen forest, a relatively common vegetation type in arid and semi-arid Africa, are vulnerable to the altered regime of regulated rivers. The Tana River of Kenya (see Section 5.6.2) has a 6-kilometre-wide floodplain in its lower reaches upon which the forests are of conservation interest and of resource value to the tribal inhabitants. Both maximum and minimum flood levels and frequencies are found to control sensitively the occurrence of the forests; 'natural' rates of meander migration also help to maintain the floodplain vegetation. Consequently the impact of the water resource developments built and proposed on the Tana is likely to be adverse.

An outstanding problem in setting acceptable flow regimes for regulated rivers is uncertainty in ecosystem management; water requirements of crops are relatively well understood as a rational basis for irrigation, but flow requirements of instream biota are much less well understood. Acreman and Dunbar (2004) and Petts's (2003) editorial to a special volume of relevant papers are good starting points, and we develop their themes in the next section.

6.3.4 Improving the efficiency of river regulation: towards 'environmental flows'

Notwithstanding the often negative environmental impacts of the changed regime of dammed rivers, the *engineering efficiency* of reservoir operation is worthy of consideration simply as engineering best practice; the desired longevity of a dam often means that 'old technology' remains locked into its operations. This makes sustainable thinking even more desirable during the design stage to facilitate flexibility of operation to meet developing objectives, such as environmental flows. For example, Takeuchi (1997) has proposed a 'least marginal environmental impact rule' by which dam location should be chosen to achieve the least inundated area for any chosen original (or increased) dam height; he also proposes the 'virtual capacity extension' for any reservoir volume by operating the dam (e.g. its release valves) according to accurate forecasts of inflow and outflow conditions.

A major technical problem encountered with river regulation is that of *regulation losses. Reservoir loss* occurs because a large tract of open water is exposed to evaporation or because macrophyte plant communities colonise the reservoir and transpire without limitation. Regulation losses comprise 'operational losses', inherent in the time delay between the requirement for water use at a downstream site and the opening of a valve in the dam control room, and 'natural losses', which occur by seepage into the floodplains alongside the regulated river. Research in Britain (Central Water Planning Unit, 1979) established from field experiments under drought conditions that a release down the River Severn in 1975 was 'wasted' by approximately 20 per cent. However, another trial on the Tees in 1976 (a hard-rock and boulder clay basin) recorded only 2.5 per cent losses into the floodplain.

Further research on the River Tyne below the Kielder dam has demonstrated that use of a scour valve (set low in the dam and therefore apt to discharge water which is silty and out of temperature regime with natural flows) to generate hydro-power can significantly influence habitat downstream:

(a) Fine deposits blanket the bed material, reducing the number and diversity of invertebrates.
(b) Warmer-than-ambient water emerges from the dam in spring, disrupting the normal seasonal pattern of fish emergence from eggs.

Releases from a valve nearer the reservoir surface would reduce these effects but would be much less efficient for power generation. The Tyne study also concludes that the diurnal pattern of releases, which rises in 2 hours and falls in 1.5 hours over a tenfold flow range, produces fluctuating velocity conditions for micro-organisms and an oscillation of bed material significantly strengthening the fabric of gravel riffles; salmonid fish find greater difficulty in excavating egg-laying sites. Alongside these, albeit currently restricted, effects, the North Tyne also shows degradation and armouring for 7 kilometres downstream because of the obstruction of bedload supply and considerable growth of tributary bars where 'natural' inputs of gravels still occur into a flow of reduced competence (Petts and Thoms, 1987; Sear, 1992).

All elements of a river flow hydrograph have ecological relevance (Figure 6.12). There is rapid technological innovation in the selection of 'environmentally acceptable flows' in rivers affected by regulation schemes. 'Environmental flows' (Petts and Maddock, 1996; Dyson *et al.*, 2003; Postel and Richter, 2003) are a powerful icon in the sustainability debates between the interests of human and non-human biota. A first call in allocating such flows is clearly one of principle, such as that in South Africa, of allocating an environmental reserve of water to sustain ecosystems (see Chapter 5). Certainly the engineering tradition for flow optimisation for water resources

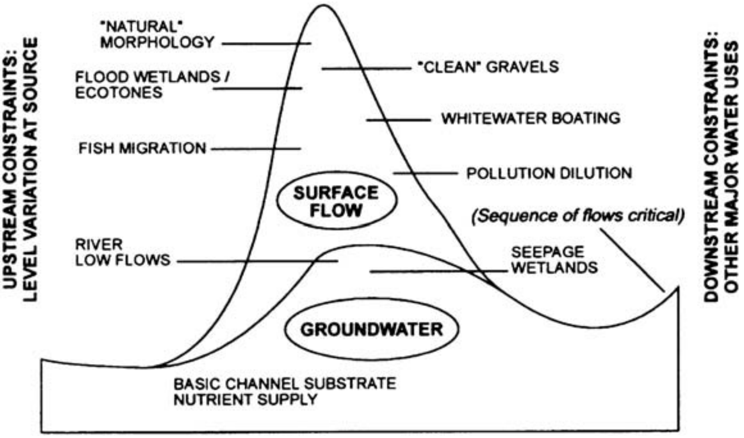


Figure 6.12 Competing uses for segments of the flow hydrograph – developed world (note that there are also upstream and downstream user constraints).

needs to be redressed to account for the 'eco-deficit'. Five critical components of the environmental flow regime are illuminated by Poff *et al.* (1997): magnitude, frequency, duration, timing and rate of change.

Petts *et al.* (1995) describe an approach used for a regulated river scheme in lowland Britain based on a hierarchical survey of the impacted channel. In addition they use the hydraulic habitat model PHABSIM to predict ecological conditions at varying flows. For PHABSIM to be successful it is necessary to know the habitat requirements (e.g. preferred water depths, velocities) of each species of instream biota which is considered sensitive (i.e. rare or economically important). Gore *et al.* (1992) use PHABSIM to simulate the conditions for fishes and hippopotamuses in the Kruger National Park of South Africa. However, the habitat simulation route to setting flows, also known as instream flow incremental modelling (IFIM), is just one of many techniques now being employed in the global move to restore a more supportive flow regime to regulated rivers (Tharme, 2003).

The use of environmental flow methodologies (EFMs) is now global (Box 6.4). Tharme's review of practice in 44 countries in six world regions focuses on hydrological, hydraulic (both simple and sophisticated) and 'holistic', scenario-based ecosystem approaches. Roughly speaking, the more sophisticated models include less uncertainty at smaller scales; the costs of

Box 6.4 Environmental flow assessment: guiding principles and a world survey of practice

Sharing river water between human and non-human needs is a new principle in water resource allocation. The problem might be simpler if the process simply involved 'carving up' the available flow volumes; however, the needs of ecosystems involve at the very least a 'natural' regime, involving seasonal variability, extremes and other features which are less acceptable to human communities and dam operators.

Setting environmental flow principles for debate and incorporation in management rules is clearly a first step; in Australia there has been political convergence on the list of principles shown in Table 6.9 (Arthington and Pusey, 2003). Turning to emergent methodologies for assessing the instream flow requirements of ecosystems impacted by current or future river structures such as dams, Tharme (2003) has concluded that hydrological models (which permit simulation of a 'natural' flow and degrees of modification) and habitat simulation techniques (such as PHABSIM) dominate. This indicates a technocratic approach, whereas the minority 'holistic' approaches avoid the illusion of numerical sophistication, using a mixture of expert guidance and stakeholder viewpoints to set the flow regime.

Table 6.9 Principles for the provision of water for ecosystems: Australian national initiatives

Principle	*Summary*
1	River regulation and/or consumptive use potentially impacts on ecology.
2	Provision of water for ecosystems should use best scientific evidence to sustain their values.
3	Environmental water provisions should be legally recognised.
4	Provision for ecosystems should go as far as possible to sustain them whilst recognising existing rights to water use.
5	Where existing uses prevent provision for ecosystems, reallocation should be investigated.
6	Further allocation for any use should only occur if natural processes and biodiversity are sustained.
7	Accountabilities should be transparent in environmental water provisions.
8	Environmental water provisions should be responsive to improved understanding through research and monitoring.
9	All water uses should be managed to recognise ecological values.
10	Appropriate demand management and water pricing strategies should be used to sustain ecological values.
11	Strategic and applied research to improve understanding is essential.
12	All relevant stakeholders will be involved in water allocation planning.

After Arthington and Pusey (2003)

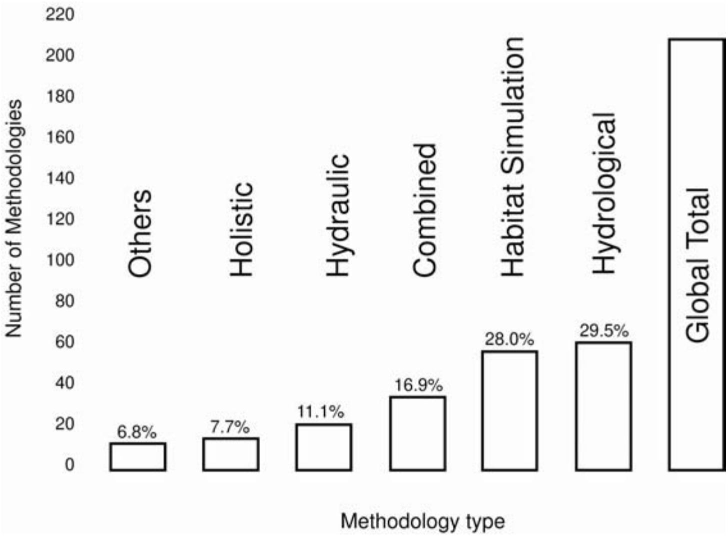


Figure 6.13 Bar graphs indicating the popularity of the available environmental flow assessment techniques (from a global survey by Tharme, 2003).

calibration in the absence of widespread appropriate survey information also militate against their use outside prestige projects.

Many of the most productive outcomes of South Africa's holistic 'building block methodology' workshops (King and Louw, 1998) concern the sharing of information about 'pinch-points' in the river system at which the combination of flow regime and local morphology exerts a major ecosystem and fisheries influence. In both data-rich and data-poor situations the ecosystem picture is built (as the name implies) from a knowledge of the sensitivity and resilience of its parts. The EU's focus on 'hydromorphology' infers the same combined approach and emphasises that the conservation of freshwater ecosystems from sound science must jointly address both the flow and the 'usable area' of channels. As in South Africa (Rowntree and Wadeson, 1998), geomorphologists in the UK have contributed conceptual and practicable assessment meso-scale units like biotopes (Newson and Newson, 2000).

In terms of ambitions for a universal standard on environmental flow assessment (EFA), Arthington *et al.* (2006) conclude that, at current levels of understanding, universal rules of thumb for 'environmental flows' do not exist and they need to be set with 'region-by-region and country-by-country analysis using hydrological classification methods combined with ecological calibration' (p. 1315). The example of Australia is used in Box 6.4 to indicate the importance of negotiated principles to establish environmental flows (Arthington and Pusey, 2003). Clearly, however, methodological choices are affected by urgency and data availability, such that the indicators of hydrological alteration by Richter *et al.* (1997) for the USA travel, with modification, to South Africa as the range of variability (Taylor *et al.*, 2003). The UK's official metrics for environmental flows (contained in catchment abstraction management strategies – CAMS) are currently unsophisticated and lack detail in the purely technical sense, but the immensity of the process by which abstractions, and the regulations affecting them, are brought into line with sustainable flow regimes means that first a simple structure suffices to initiate debate (Environment Agency, 2002a).

Even given a highly successful EFA, important aspects of ecosystem integrity remain ignored: the hyporheic zone and exposed riverine sediments are sadly neglected by our in-channel research obsession.

6.3.5 The future for large dams: impacts and inclusiveness

It is unlikely that we can proceed to manage rivers without dams and, since we constantly explore the capacity of the environment to provide resources, we need, along with asking the questions 'Is the scheme necessary?' and 'Is a dam the only answer?' to carry out very far-reaching proactive *impact assessments*. The World Commission on Dams concluded that, on balance, ecosystem impacts are more negative than positive; their *post hoc* review suggested ‘significant and irreversible loss of species and ecosystems’. Furthermore, they concluded that it is not possible to mitigate the ecosystem impacts or to engineer solutions such as fish passes. They note the growing willingness of developers to consider environmental flow requirements but conclude that ‘good mitigation results from a good information base, early cooperation between ecologists, the dam design team and affected people, and regular monitoring and feedback on the effectiveness of mitigation measures’. What formal procedures of impact assessment can be followed?

Canter (1985) offers the impact matrix for impoundments modified here as Figure 6.14; Wallace *et al.* (2003, Figure 4) offer an alternative, multi-criteria map for sustainable dam management. Such matrices now need to incorporate a climate change dimension. Reservoirs emit GHGs, especially immediately after dam construction because of rotting (drowned) vegetation but throughout their lifetime as the result of carbon inputs from the catchment area (clearly, natural lakes also contribute in this way). The WCD received estimates that reservoirs may account for between 1 and 28 per cent of the global warming potential of GHG emissions; estimates for individual hydro-power dams ranged from way below the impact of equivalent thermal power generation to an equivalent or excess, tarnishing the image of hydro-power as ‘green’. The Commission urges the world community to include GHG releases in environmental impact assessments and suggests that energy efficiency, demand-side management and use of renewable energy sources must be explored before a ‘rush to hydro’. Considering the generally welcoming attitude of developing nations in drylands to dam schemes, it is perhaps not surprising that a recent *post hoc* evaluation of dams constructed in Iran (Manouchehri and Mahmoodian, 2002) is very narrow in its critique, regretful only of poor (under-) estimates of siltation and emphatic that these failings are not the result of negligence! By contrast, Ortolando and Cushing (2002) relate a catalogue of errors by the US Bureau of Reclamation in locating, constructing and contextualising the Grand Coulee dam on the Columbia River, a project started to relieve pressure of economic depression and repay the people of Washington for presidential votes. Both denial and contrition appear to be attitudes in *post hoc* environmental assessments of large dams.

The remaining critical need in assessments for large dams, laid out in four chapters of the WCD report, is the need for *inclusiveness* for those affected; it puts the requirement as comprising ‘open, accountable and comprehensive planning and decision-making procedures for assessing and selecting from the available options’. People affected by dam schemes need an active and continuing role in management – beyond the flooded area and the irrigated area and including, especially, riparian interests. This is a task which, in the view of the Commission, is well beyond the conventional dam-building corporation.

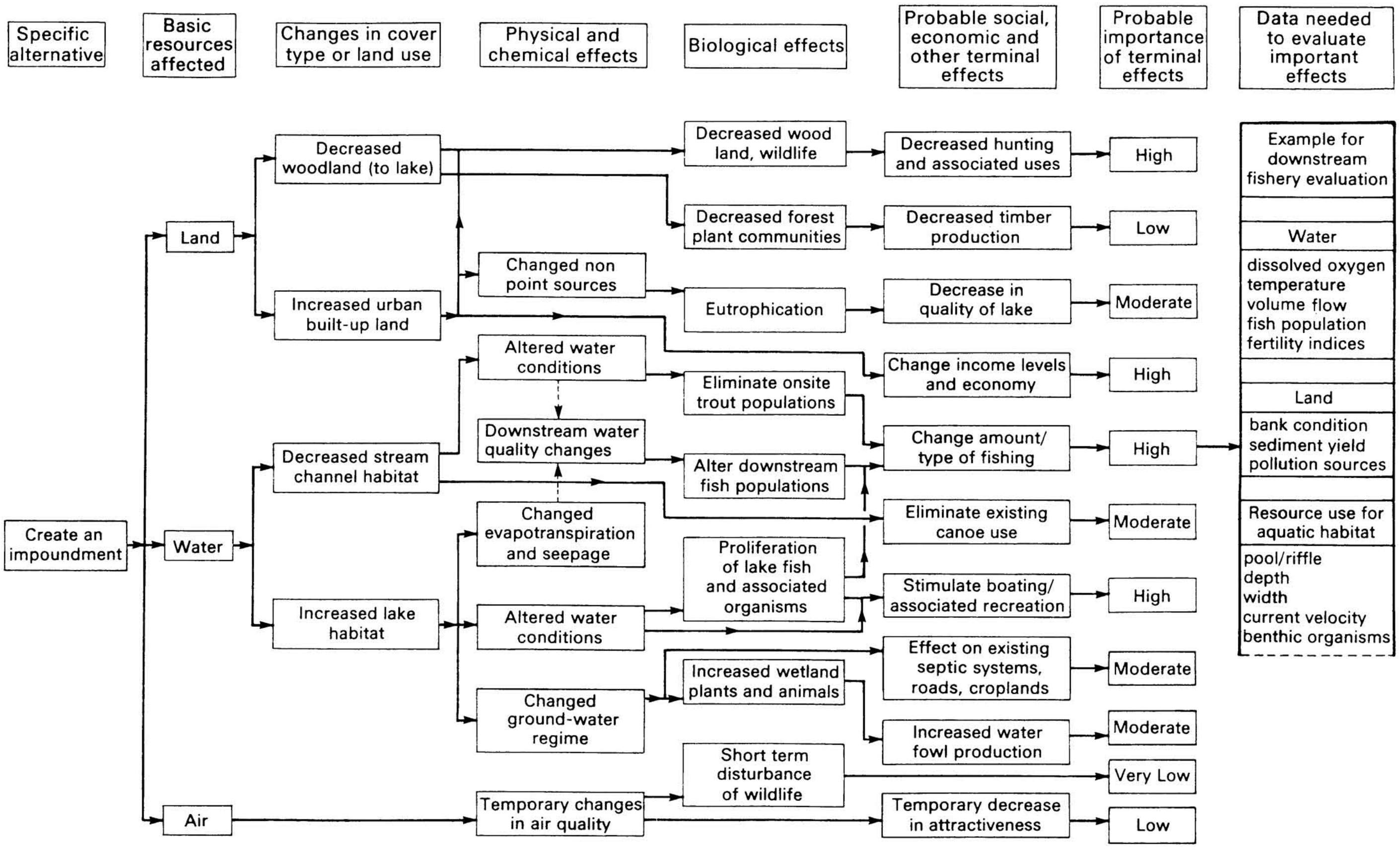


Figure 6.14 Environmental impact diagram for assessment of impoundment/regulation projects (Canter, 1985).

Inevitably, the incorporation of the distilled wisdom of the WCD in future dam schemes will encourage fewer, but larger, projects: the effort and costs of compliance will not be 'wasted' on small projects. Some environmental scientists would argue that fewer, bigger, properly planned, sited and operated structures will mean less overall damage to ecosystems. A paradox may be that it will be small and medium-size dams that are the focus of dam removal movements, although *decommissioning* plans for all dams could well be a requirement of environmental impact assessments in future. Schmidt *et al.* (1998) lay out the profound and costly fusion of science and societal/environmental values in any proposed restoration of the Colorado in the Grand Canyon: the feat would be as awesome as the scenery!

6.4 Conservation and restoration of river channels and wetlands

'Rivers for Life' (Postel and Richter, 2003) is a succinct slogan for the rapidly growing campaign for restoration (though the latter term is itself open to a very broad group of aims, objectives and operations). Ecological restoration is a general and global theme which has been added to the role of conservation by natural scientists from all specialisms as it has become obvious that, for many ecosystems, conservation is too late (Sear *et al.*, 2000). As well as writing of 'disconnected rivers', Ellen Wohl has offered us 'compromised rivers' (Wohl, 2005), relating to those which may have an attractive form but may have *lost function*. She tables ten channel and catchment activities during the Anthropocene which have compromised the ecological and geomorphological function of rivers in the Colorado Front Range, USA. Brookes and Gregory (1988) graph a 'channel change ratio' in relation to indirect impacts such as afforestation and urbanisation. More generally, Gregory (1995) has tabulated (here Table 6.10) the many recorded dimensional impacts on river channels resulting from direct and indirect human influences; there is thus a very general problem of restoration, but to what (Newson and Large, 2006)? It is clear that true, sustainable river restoration can only proceed if the catchment context (particularly of the sediment system – Sear, 1994) is appreciated (see also Wohl, 2005). The expenditure implied by this 'purity' of approach may mean that we are likely to be most frequently offered *enhancement* or *rehabilitation* as less ambitious options to assist the basin's spontaneous regulation functions.

6.4.1 River channel restoration

River restoration capitalises on the innate ability of freshwater biotic systems to recover from damage; indeed, 'assisted natural recovery' is a viable restoration strategy. The indirect methods of restoration include, obviously, restoration of hydrological stability and the improvement of water quality, but

Table 6.10 Human-induced river channel changes

		Average change ratio		*Minimum change ratio*		*Maximum change ratio*		
Cause of change	*Channel character*	*UK*	*Other*	*UK*	*Other*	*UK*	*Other*	*Total no. of studies*
Urbanisation	Width	1.16	–	1.16	–	1.16	–	2
	Depth	1.06	–	1.06	–	1.06	–	
	Capacity	2.50	–	2.50	–	2.50	–	
Reservoir construction	Width	0.85	1.14	0.29	0.01	1.49	1.56	489
	Depth	0.92	3.42	0.34	0.01	1.62	8.10	
	Capacity	1.25	–	0.29	–	2.29	–	
Channelisation	Width	1.33	–	1.00	–	2.02	–	57
	Depth	1.06	–	0.59	–	1.67	–	
	Capacity	1.39	2.70	1.00	2.70	2.53	2.70	
Land-use change	Width	1.41	0.94	0.96	0.80	1.88	1.05	221
	Depth	–	2.31	–	1.58	–	3.97	
	Capacity	–	2.15	–	1.53	–	4.11	
Water transfers	Width	0.57	–	0.57	–	0.57	–	
	Depth	0.84	–	0.84	–	0.84	–	
	Capacity	–	–	–	–	–	–	

Source: Gregory (1995)

direct methods are becoming prominent too: instream habitat structures and management of the riparian zone. Restoration is largely successful because it:

- involves a committed professional and public approach;
- uses a systems approach, tackling quite extensive reaches;
- is feasible in terms of land-take and therefore of ownership and control.

The latter point is critical in river basins where ownership confers rights, simply because water agencies, conservation and amenity agencies have very little ownership of land.

'River restoration has a short history but is experiencing a steep growth curve' (Newson, 1992a). In the first edition of this book it was possible to relegate restoration to a small mention near the end (p. 317). This 'steep growth curve' has continued, forcing river restoration into the mainstream of technical issues in river management, although, in the UK, it has been concluded that restoration remains subverted to the dominant engineering model (Adams *et al.*, 2004). In addition, wetland scientists have also begun to carry out restoration schemes on floodplains and in catchment headwaters alike. Both movements suggest that managing river basin systems along ecosystem lines can now incorporate a specific *post hoc* technical approach to the spontaneous regulation functions of the Marchand and Toornstra model (see Table 5.3). Indeed, the European Union's Water Framework Directive (see Chapter 7) implies that conservation of good ecological quality or restoration to that quality is vital for all but the most heavily modified parts of the river basin system. The danger might be that developers can risk damage or destruction of these functions in the knowledge that, after a 'quick profit', they can be restored. A realistic balance may be that, if damage or destruction is an inevitable corollary of development, an equivalent, compensatory capacity is created in the same system by the developer, not merely rehabilitation or enhancement.

Perhaps the best (most realistic) appreciation of the potential of river and wetland restoration can be gained from serious attempts at *definitions*. The US National Research Council (1992) offers: 'return of an ecosystem to a close approximation of its condition prior to disturbance. Both the structure and functions of the ecosystem are recreated' (p. 18). It also stresses that what cannot be achieved is 'setting the clock back' to the conditions and timescales through which the ecosystem evolved – imperfections are therefore inevitable. Brookes (1995b) tabulates other, similar, definitions but helpfully offers two alternatives to restoration: rehabilitation (return to pre-disturbance for a limited number of attributes) and enhancement (improvement of one or more attributes). Kern (1992) chooses 'rehabilitation' because the German *Leitbild* vision of channels, following improvements in water quality, is to improve the structural and aesthetic qualities. McDonald *et al.* (2004) utilise the concept of 'rivers of dreams' to emphasise the social dimension of restoration, in which scientific rigour often has to fall back in favour of vernacular visions of a neighbourhood river environment. Fisheries managers have been particularly active in 'enhancement' (e.g. Hunt, 1993) – installing channel structures to improve flow characteristics for the sometimes confused purposes of improving the *fishery* and improving *fishing* (Figure 6.15). There has, however, been a reaction against the 'cook-book' approach (Doppelt *et al.*, 1993; Wohl, 2004; Sear *et al.*, in press) on the grounds that a landscape-scale strategy is needed for river restoration (Poole, 2002): space, rather than place, particularly for some of the migratory fish species in whose habitat interests local channel structures are installed.

Gore's (1985) volume on river restoration used case studies from the United States, where the preoccupation was then with mitigating the impacts of surface mining. Hasfurther's chapter in Gore's book represented the sole geomorphological contribution, but it is the geomorphological contribution to understanding instream physical habitat and the relationship between channel, riparian, floodplain and valley-floor processes (see Chapter 2) which has grown most in ten years (Newson and Sear, 2001; Newson *et al.*, 2002).

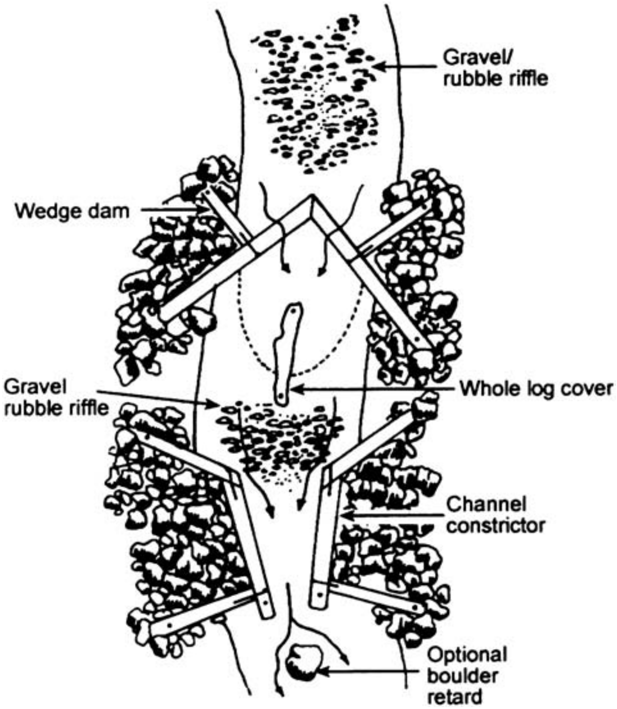


Figure 6.15 River rehabilitation via instream structures – frequently used by fisheries interests.

The kinds of guidance for restoration coming from fluvial geomorphology are shown in Table 6.11.

After an initial overemphasis on meander planforms and the riffle–pool sequence as vehicles of channel restoration (see Keller, 1978; Hasfurther, 1985), geomorphological knowledge is now seen as an important input to channel management for flood defence, water resources, pollution control, conservation, recreation and amenity functions (Brookes, 1995a; Newson *et al.*, 2002). Perhaps the most significant demonstration of confidence was the publication of *The Rivers Handbook* (Calow and Petts, 1992, 1994), the *Rivers and Wildlife Handbook* (Lewis and Williams, 1984), *The New*

Table 6.11 Geomorphological guidance for river restoration

Type	*Content*	*Limitations*
Channel profiles (long-section and cross-section)	Knowledge of variation of channel morphology along a reach, particularly in relation to pools, riffles and planform	Sparse data on typical width – depth ratios for a range of channel types
Low-flow width in channel design	Best obtained from neighbouring natural section of same slope and geology	Site-specific measurement required. Natural widths for a range of channel types related to catchment area largely unavailable
Design and location of pools and riffles	Information on topographical, sedimentary and flow characteristics, size, location, spacing and slope values at which they occur	Knowledge base particularly for gravel-bed rivers. Limited knowledge of adjustments during and after flood flows
Substrate reinstatement	Reinstatement of gravels for different channel types (either to remain static – armoured/ segregated bed – or to be mobile)	Most knowledge is for mobile gravel-bed rivers
Prediction of channel changes	Use of historical records, maps or surveys to predict nature and locations of future channel change (including lateral and vertical change)	Imperfect knowledge for a wide range of channel types (e.g. sand-bed rivers). Assumes change at a site will be an ongoing process
Bank erosion/protection locations	Good knowledge of location of natural bank erosion mechanism, especially for gravel-bed rivers. Some understanding of how artificial influences (e.g. boat-wash erosion) modify or initiate patterns of erosion	Bank erosion mechanism not fully understood for all key channel types

Source: After Brookes (1995b)

Rivers and Wildlife Handbook (Ward *et al.*, 1994) and the titles selected by Hey's contributions on 'Environmentally sensitive river engineering' (Hey, 1994) and 'River processes and management' (Hey, 1995). A number of prestigious restoration schemes have permitted geomorphologists to 'cut their teeth' in taking designs from drawing board to the cab of an excavator (Box 6.5).

Geomorphologists have also been involved with contributions to an understanding of the meaning of 'natural' rivers (Newson and Large, 2006), tending to stress the relevance of process rather than form and the overall system ideal of 'integrity' (Karr, 1991; Harper *et al.*, 2000). In this respect, they have moved slightly away from the 'cook-book' approaches of the earlier handbooks; part of the geomorphological message was its practicability and success, but now we admit that the science base needs updating. Channel form is not without lessons for our restoration efforts, notably when a detailed understanding of the form of palaeochannels is available and when

Box 6.5 'Model' river restoration projects in the UK: the rivers Cole and Skerne

As yet, opportunism has been helped to promote practical river channel restoration, and considered scientific documentation is sparse, most schemes being, as Brookes (1995a) puts it, an amalgam of the scientific and pragmatic. This is Brookes's experience of participation on a prestigious European Union LIFE project in Denmark and England (Brookes, 1992; Brookes and Shields, 1996). In the UK the River Restoration Project took two English lowland rivers, the Cole and the Skerne, and 'restored' 2 kilometres of each, partly by excavating new channels and partly by changing channel profiles and vegetation. The rural Cole has been the simpler case because no housing was threatened in the floodplain; the Skerne flows through urban Darlington (Plate 6.4) and it was necessary both to maintain flood conveyance and to protect urban infrastructure (Kronvang *et al.*, 1998). Practical experience suggests that monitoring is essential if the apparent success of the geomorphological design procedures is to be translated into ecosystem recovery – at the moment this is an act of faith (Clarke *et al.*, 2003; Newson and Clark, 2008). The UK River Restoration Project utilises, for example, multi-stage channels, meanders, pools, riffles, shoals, islands, backwaters, bays and substrate improvements as part of its site works. Its experience has been distilled in two editions (1999, 2002) of the River Restoration Centre's *Manual of Techniques*; the Centre was formed to support and promote restoration following the Skerne and Cole projects.

Plate 6.4 The restored River Skerne, Darlington, UK, showing the introduced meanders and rehabilitated floodplain (photo copyright AirFotos, Newcastle upon Tyne).

these indicate the severity of the modifications which have occurred, both direct and indirect, during the Anthropocene (Brown, 2002).

Boon (1992) lists the motives for river conservation as maintenance of Earth's life support systems, practical value (e.g. erosion control), economic importance (minerals, tourism), scientific research, education, aesthetic and recreational value and ethical considerations. He establishes (Figure 6.16) a range of management options which depend on the evaluation of the existing condition of the river system in relation to the 'natural' (effectively 'semi-natural' because of mankind's all-pervading influence on rivers). Newson and Large (2006) point to many areas of uncertainty and indeed ignorance in setting the niches for management intervention on the 'natural' to 'degraded' spectrum.

Schemes to assist this evaluation have appeared, such as Rosgen's classification of channels in the USA (Rosgen, 1994) and *River Habitats in England*

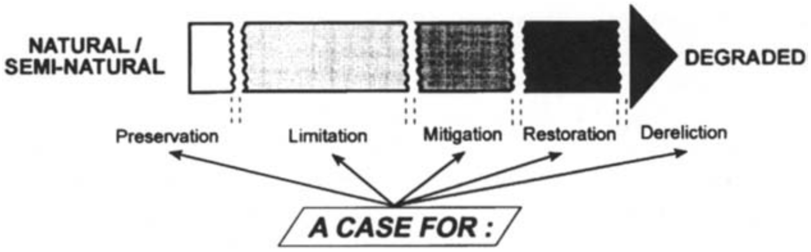


Figure 6.16 The case for conservation: matching effort to system conditions (after Boon, 1992).

and Wales (NRA, 1996). Whilst the latter system yields channel characteristics that confound classification (Newson *et al.*, 1998), the assessment of quality and departures therefrom can be used as a strategic guide to 'what needs restoring where' (Walker *et al.*, 2002).

As yet we have very few *post hoc* evaluations of the success of restoration schemes; generally biological recovery and public satisfaction are positive, but disasters (even small ones!) are rarely reported and post-project appraisal is generally left short of funds. Even scarcer is attention to the impact of restoration downstream from the sites restored (Sear *et al.*, 1998). Sear *et al.* report considerable channel adjustment for the River Cole (Wiltshire, UK) following the engineering of an environmentally diverse channel, with the eroded sediments from the adjustment process impacting downstream reaches, generally in a benign way but one which should be considered in restoration strategies.

6.4.2 Beyond the channel: wetland, floodplain and riparian restoration

Losses of wetland area have been a spectacular accompaniment to the settlement of the humid-temperate developed world. The huge losses which have occurred in the United States were considered contributory to the severity of the 1993 Mississippi floods (see Chapter 4). Losses in Europe have also been spectacular (Baldock, 1984) (for a world review see Maltby, 1986; Dugan, 1990). It is now appreciated that wetlands offer many more spontaneous regulation functions in pristine river basins than the storage of floodwaters. Table 6.12 shows that they play a major part in a range of management functions in the undeveloped basin.

The restoration of wetlands varies according to the basic controls on their origin and dynamics; simple flooding is often not their *raison d'être*: raised and blanket bogs – a feature of cool, humid upland areas – require inputs from precipitation. They are ombrotrophic, and only rainfall water quality is

Table 6.12 Functions, related effects of functions, corresponding societal values, and relevant indicators of functions for wetlands

Function	*Effects*	*Societal value*	*Indicator*
Hydrologic			
Short-term surface water storage	Reduced downstream flood peaks	Reduced damage from floodwaters	Presence of floodplain along river corridor
Long-term surface water storage	Maintenance of base flows, seasonal flow distribution	Maintenance of fish habitat during dry periods	Topographical relief on floodplain
Maintenance of high water table	Maintenance of hydrophytic community	Maintenance of biodiversity	Presence of hydrophytes
Biogeochemical			
Transformation, cycling of elements	Maintenance of nutrient stocks within wetland	Wood production	Tree growth
Retention, removal of dissolved substances	Reduced transport of nutrients downstream	Maintenance of water quality	Nutrient outflow lower than inflow
Accumulation of peat	Retention of nutrients, metals, other substances	Maintenance of water quality	Increase in depth of peat
Accumulation of inorganic sediments	Retention of sediments, some nutrients	Maintenance of water quality	Increase in depth of sediment
Habitat and food web support			
Maintenance of characteristic plant communities	Food, nesting, cover for animals	Support for furbearers, waterfowl	Mature wetland vegetation
Maintenance of characteristic energy flow	Support for populations of vertebrates	Maintenance of biodiversity	High diversity of vertebrates

suitable. By contrast, fenland ecosystems require a water quality (high in bases) characteristic of groundwater (Large *et al.*, 2007). Both these (extreme) cases prove that merely to obstruct drainage already installed to drain wetlands does not restore them. Even where damming, flooding or 'irrigation' is used to restore wetlands, a complex seasonal regime may be necessary to suit the needs of the biota forming the original ecosystem. Wheeler *et al.* (1995) explore the approaches and relative success rates of restoration in the wide variety of wetland sites in the temperate zone; there is also, however, a critical need to conserve wetlands in dryland river systems (see Hollis, 1990) and in humid tropical basins. The United States has now initiated a major programme of wetland research to create a functional assessment of wetlands, linking their dynamics and impact to their landscape position in river basins in an attempt to economically value and ecologically protect these vital natural regulators (National Research Council, 1995). In Israel, the Huleh Valley wetlands of the Jordan Valley were rehabilitated after it was realised that peat drainage was unsustainable.

Championing the integration of rivers and wetlands, Petersen *et al.* (1992) lay out a progressive 'undrainage' agenda in which the valley floor is returned to its pristine condition. Many practical restoration schemes are meeting many of these criteria, as evidenced by the Rhine scheme shown in Figure 6.17. The joint restoration of rivers and wetlands as adjacent ecosystems has a further justification in that it creates 'ecotones', defined by Decamps and Naiman (1990) as consisting of 'active interactions between two or more ecosystems (or patches), with the appearance of mechanisms that do not exist in either of the adjacent ecosystems' (p. 2). Pinay *et al.* (1990) offer practical proof of the effectiveness of ecotone processes, for example in reducing nitrate concentrations in the Garonne system; an intact channel–riparian wetland interaction is also important to the nutrient spiralling which helps in the chemical equilibrium of channel flows. Riparian ecotones have achieved most attention in attempts to extend the principles of instream ecosystem protection to other parts of the valley floor landscape (Malanson, 1993).

Wetland restoration according to functional analysis is illustrating a way forward for geomorphological restoration which needs to move away from a form-based approach to a process-based approach. Restoration of form may be appropriate to 'rivers of dreams' in that the improvements are often immediately visible. However, *restoration of process* imparts a resilience to the restored system which helps ensure a sustainable outcome (form improvements can be lost in one major flood or as a result of catchment changes). Kentula (2000) illustrates the importance of precision in judging wetland restoration success, dividing between 'compliance success', 'functional success' and the broader resource context of 'landscape success'. She also, however, counsels against one-off assessments of success; restoration should remain work in progress to allow refinements in scientific principles to

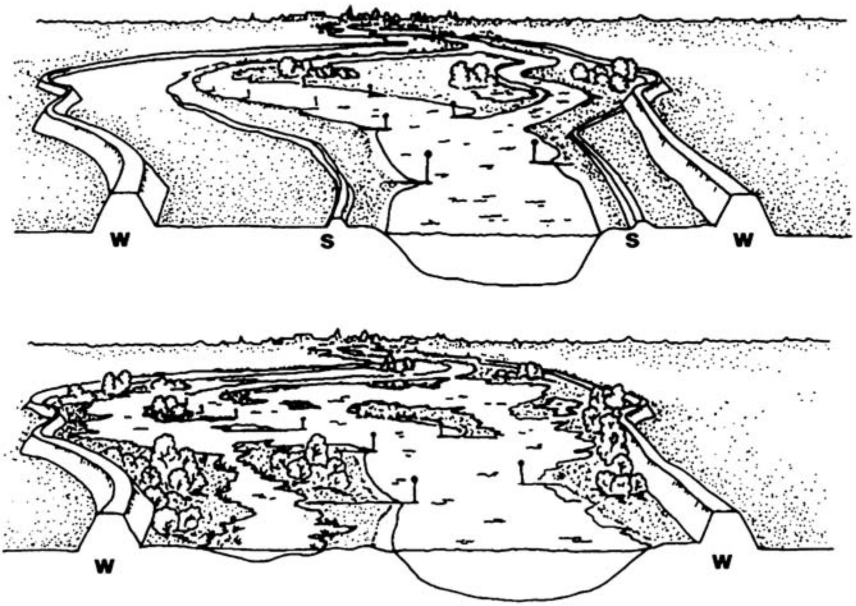


Figure 6.17 Restoration of Netherlands tributaries of the Rhine (S = summer, W = winter dykes; the summer ones are removed to restore the floodplain).

become incorporated within a framework of adaptive management. If this message is to be effective, resource managers must understand how to incorporate and manage uncertainty in restoration schemes (Darby and Sear, 2008; Newson and Clark, 2008), and funding sources must consider the essential role of post-project appraisal and long-term monitoring (Roni, 2005).

6.5 Climate change and river basin management

It would be naive of the author to report 'little change' between the state of this issue in 1997 and now; the Preface to this edition already shows this is not the case, but it is revealing to see what has and what *has not* changed. The second edition, Section 6.5, begins thus (extracts):

> Man-induced climatic change is a major issue for *environmental science* in the 1990s.
>
> A good measure of agreement between climatologists in *'scenario setting'*.

> Prediction of the components of the *water balance* and of their extreme values is especially difficult.
>
> The *International* Panel on Climate Change* updated its findings in 1992 (Houghton *et al.*, 1992) but this report mainly substantiated, rather than refined, the earlier predictions.
>
> The crisis of confidence (in science) now facing the *world's political leaders* is one of trusting the evidence of progressive climatological trends and, furthermore, of taking actions which curtail economic growth by accepting the causal interpretations of change.

The critical pathway through the issue for this book is pointed up by the addition of italics in the list above. The issue remains a top priority and a crisis for confidence in science whose best efforts remain best configured as scenarios, despite the assembly by the IPCC of the best available 'numbers' (IPCC, 1990, 1995, 2001, 2007a). The 2001 report of the IPCC was significant in listing a round-up of changes occurring in the twentieth century (here Table 6.13): the century in which most readers of this book were born.

Numerical predictions are particularly difficult for our chosen spatial unit – the river basin and its fluvial cycles, each of which builds in memory of past driving variables as well as current changes, and which is massively affected by other human responses to climate such as land use and protection against extremes (e.g. dam building and flood control engineering). The spatial unit of the river basin also introduces further scientific hurdles, such as upscaling and downscaling – our best estimates of future change continue to come from global circulation models (GCMs) scaled to best suit our knowledge of atmospheric processes, not those vital to flood-wave propagation, sediment transport or the life cycle of the salmon! Prudhomme *et al.* (2003) show how difficult it is to downscale GCM outputs to small catchment areas (10–300 square kilometres) to predict changes in the flood regime; the process makes the choice of GCM the largest source of uncertainty.

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* It is a measure of the progress of awareness that this typographical error crept through in the second edition but could never do so now. The Inter*governmental* Panel on Climate Change (IPCC) was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme; since then it has slowly become the most authoritative and respected source of information in the global debate on climate change, its impacts and its mitigation. It has access to around 2,500 research scientists; by 2001 it was able to attribute most of the global warming in the preceding half-century to human causes. The most recent, 2007, report from IPCC was greeted by *New Scientist* with the headline 'Nowhere to turn for climate change deniers', an indication of the Panel's status. The same magazine also said, 'Never before have scientists presented governments with such a challenge. We are about to find out how creative our political leaders really are' (*New Scientist*, 12 May 2007).

Table 6.13 Twentieth-century changes in the Earth's atmosphere, climate and biophysical system

Indicator	*Observed changes*
Atmospheric gas concentrations:	
CO_2	31 ± 4% increase.
CH_4	151 ± 25% increase.
N_2O	17 ± 5% increase.
O_3 (tropospheric)	35 ± 15% increase.
O_3 (stratospheric)	Decrease.
HCFs, PCFs and SF_6	Increase.
Weather indicators (all labelled likely or very likely):	
Global mean surface temperature	Increased by 0.6 ± 0.2 °C.
Northern hemisphere surface temperature	Increased; 1990s warmest decade.
Diurnal surface temperature range	Decreased – night-time minima increased.
Hot days/heat index	Increased.
Cold/frost days	Decreased for nearly all land areas.
Continental precipitation	Increased 5–10% northern hemisphere; decreased North and West Africa, parts of Mediterranean.
Heavy precipitation events	Increase mid- and high northern latitudes.
Frequency and severity of drought	Increase in recent decades: parts of Africa, Asia.
Biological and physical indicators (labelled likely or very likely):*	
Global mean sea level	Increased 1–2 mm.
Duration of ice cover of rivers/lakes	*Decreased by *c.*2 weeks northern hemisphere.
Arctic sea-ice extent and thickness	*Thinned 40%; decreased 10–15%.
Non-polar glaciers	Widespread retreat.
Snow cover	*Decreased by 10%.
Permafrost	Thawed, warmed and degraded: parts of polar, sub-polar and mountainous regions.
El Niño events	More frequent, persistent and intense.
Growing season	Lengthened 1–4 days per decade in northern hemisphere.
Plant and animal ranges	Shifted polewards and upwards.
Breeding, flowering, migration	Earlier, including emergence of insects in northern hemisphere.
Coral reef bleaching	Increased frequency, especially during El Niño events.
Economic indicators:	
Weather-related economic losses	Inflation-adjusted losses rose an order of magnitude, partly socio-economic.

For conditional time periods, see IPCC (2001)
Modified from IPCC (2001)

6.5.1 Can we believe climate change data and models?

As any TV viewer or newspaper reader will know, it is vital to understand the planet's inherent climate *variability* before seeking scientific evidence of *change*. News editors continually use the latest weather extreme to ask whether the event confirms or refutes 'global warming' – the banner of climate change. Divisions between scientists make this kind of reporting much easier, but it is a fair reflection of public, and therefore political, disquiet about taking fundamental steps to mitigate impacts – an illuminating example of an evidence-based Risk Society in action. An essential item to remember in what follows is that those changes in climate variables most affecting the way river basins 'work' are not dominated by newsworthy extremes but by the unreported shifts in averages, in cycles of freezing and thawing, wetting and drying, and in the soil, not in the air.

The physical science working group of the IPCC, reporting in 2007 (IPCC, 2007a), provided *inter alia* the following expansion of detail contributed by their huge network of researchers:

- Carbon dioxide concentrations increased in the global atmosphere from a pre-industrial 280 ppm to 379 ppm in 2005; it is the most important anthropogenic greenhouse gas (GHG), and its current concentration is the highest in over 650,000 years.
- As a consequence of increases in known GHGs there is now very high confidence that the net effect of human activities (principally fossil fuel burning and land-use change) has been one of warming.
- Eleven of the years 1995–2006 rank among the 12 warmest years in the instrumental records of global surface temperature since 1850, suggesting a warming of 0.74 °C for the twenty-first century, compared with 0.6 °C for the twentieth century.
- Water vapour content of the atmosphere has increased, oceans have absorbed 80 per cent of global warming, and mountain glaciers and snow cover have declined in both hemispheres.
- Global average sea level rose at 1.8 mm per year between 1961 and 2003, partly in response to expanding (warming oceans) and partly in response to losses from the ice sheets of Greenland and Antarctica.
- Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has occurred in the Sahel, Mediterranean, southern Africa and southern Asia.
- More intense, longer and broader-spread droughts have been observed since the 1970s, particularly in the tropics and subtropics.

Continued GHG emissions at or above current rates would steepen these trends for the twenty-first century; a range of emission (and economic growth) scenarios is then used to create the range of forecasts for these trends. These allow politicians, e.g. the European Union's ministers, to select a temperature limit around which emissions can be regulated – a 2 °C anthropogenic rise in the EU's case, because this does not promote the 'dangerous climate change' brought about by a 4 °C rise.

Table 6.14 uses the IPCC's terminology for confidence levels (see key) in predictions for key climate elements, a vital element in making clear to policy makers that this is uncertain science. In attempts to provide the vital detail missing from the global predictions, the IPCC produced special reports on regional impacts (IPCC, 1997) and on land use (IPCC, 2000), the latter to make clearer the role of forests, the forest cycle and comparative land

Table 6.14 Climate trends, human influence and projections

Phenomenon and direction of change	*Likelihood that trend occurred post-1960*	*Likelihood of a human contribution to observed trend*	*Likelihood of future trends in twenty-first century*
Warmer/fewer cold days and nights over most land areas	Very likely.	Likely.	Virtually certain.
Warmer/more frequent hot days and nights over most land areas	Very likely.	Likely (nights).	Virtually certain.
Warm spells/heat waves – increased frequency over most land areas	Likely.	More likely than not.	Very likely.
Heavy precipitation events – increased frequency or proportion of total over most areas	Likely.	More likely than not.	Very likely.
Area affected by drought increases	Likely in many regions since 1970s.	More likely than not.	Likely.
Intense tropical cyclone activity increases	Likely in many regions since 1970s.	More likely than not.	Likely.
Increased incidence of extreme high sea level (excludes tsunamis)	Likely.	More likely than not.	Likely.

Key:
Virtually certain >99%
Extremely likely >95%
Very likely >90%
Likely >66%
More likely than not >50%
Very unlikely <10%
Extremely unlikely <5%
Adapted from IPCC (2007a)

covers in relation to some of the policies promoted by the Kyoto Protocol (see page 265).

Taking the regional perspective first, each of ten regions has an impact analysis for ecosystems, hydrology and water resources, food and fibre production, coastal systems and human health. Table 6.15 summarises the findings on hydrology and water resources. Clearly, governments within many 'rich' nation states have been able to fund research on impacts at a national level. In the UK, the UK Climate Impacts Programme has listed the following effects (UKCIP, 2002):

- Warming will continue, with high summer temperatures more frequent and cold winters increasingly rare.
- Winters will become wetter and summers drier but snowfall amounts will decrease.
- Heavy winter precipitation will become more frequent, sea level will continue to rise and extreme sea levels will be experienced more frequently.

6.5.2 River basin impacts: reconstructing past changes

Heavy precipitation and drought feature in Table 6.15; the IPCC Fourth Assessment (2007b) also contends that by 2050 river runoff and water availability are projected to increase by 10–40 per cent at high latitudes and in some wet tropical areas and decrease by 10–30 per cent in the dry tropics and some other water-stressed areas. Those nations (*c.* one-sixth of the world population) whose water availability also includes glacier sources will witness a reduced supply. Reviewing more than 60 predictive studies of climate change impacts on hydrology and water resources in California, Vicuna and Dracup (2007) can draw out only very generalised conclusions – consensus findings that, for example, spring runoff has begun earlier. For this reason, river basin scientists often put more credence in historical reconstructions; palaeohydrology has become a focal effort in this field.

For example, Stahl *et al.* (2007) use tree-ring analysis to search for historical droughts in North America since 1300. Three 'megadroughts' have affected the vulnerable western part in this time, but only one continent-wide event in the tree-ring record matches the instrumental period. The wetter start to the twentieth century is unmatched in the tree-ring record. Russell and Johnson (2007) reconstruct 1,400 years of drought in central Africa by using calcite found in lake cores. Severe drought is frequent, especially in the 'Little Ice Age' (1400–1750), and the twentieth-century precipitation regime was 'unusually conducive' to human livelihoods in the region. Thus, a major function of palaeohydrology relates to its ability to interpret the 'natural' climate regime, and to infer 'natural' processes of response before the complications of the Anthropocene.

From records preserved in sediments, morphology and human cultures it is

Table 6.15 Regional impacts on hydrology and water resources

Region	*Changes predicted of relevance to hydrology and water resources*
Africa	Increase in water-stressed nations: population growth plus degradation of watersheds. Some GCMs predict reduction in precipitation and increasing variability. Anthropogenic water pollution and disease likely to increase.
Polar regions	Thaw: more running and standing water, changes in Arctic drainage systems.
Middle East/arid Asia	Water shortages may be exacerbated; changing in cropping and improved irrigation vital. Glacier melt may boost flow in some rivers temporarily.
Australasia	Variability already high, will increase, a particular threat to drought-prone areas of Australia. However, urban flooding may also increase. New Zealand glaciers will melt, boosting river flow temporarily.
Europe	Like the UK, split between a generally wetter north and generally drier south. Floodplain development a big issue in the north, pollution and water stress in the south. Up to 95% of Alpine glacier mass likely to melt by 2100: navigation impacts.
Latin America	Arid and semi-arid zones vulnerable to change in water availability. Hydro-power and agricultural production impacted. Impact on water resources 'could be sufficient to lead to conflicts among users, regions and countries'.
North America	Water quality and quantity particularly sensitive to climate change. Potentially wetter winters and drier summers, with much reduced soil moisture. Alternating drought and flood periods.
Small island states	Freshwater shortages are common but the coastal threat dominates.
Temperate Asia	Decreasing water supply, except in a few basins. Possibly 25 per cent decrease in glacier mass by 2050. Northern China may be particularly vulnerable. Critical uncertainties concern the monsoon and El Niño weather systems.
Tropical Asia	The Himalayas exercise a critical control. Glacial lake outburst floods but a longer-term decrease in headwater runoff. Increased population will place stress on resources, especially in the drier zones.

After IPCC (1997)

possible to invoke analogues in the past for those changes in major variables such as temperature now proposed for the immediate future (see contributions to Brown and Quine, 1999). Newson and Lewin (1991) used analogies between current trends and the warming in Britain following the Little Ice Age; this recovery occurred during the eighteenth and nineteenth centuries and was accompanied by increased storminess and flooding. These authors refer to the 'forcing function' of climate in controlling river basin evolution; land use is a weaker control but tends to bear the imprint of climatic variability, in which the record of extreme conditions is most marked.

6.5.3 Climate change and UK rivers

In the UK the use of analogues of past cool and warm periods within the climatic database allowed Palutikov (1987) to predict a general increase in wetness for the north of England but reduced river flows for the south, posing critical 'headroom' problems for water resources in the main economic growth region (see Chapter 7).

Further analyses of data sequences for the UK have yielded contrasts, as have comparisons with trends in *precipitation* and those of *flow*. Utilising the very long record of rainfall at Durham University Observatory, Burt and Horton (2006) conclude that seasonal distributions of both rainfall totals and intense falls have changed most. Following a notable wet period in the 1870s, rainfall has generally declined slightly, with summers drier and winters wetter in the twentieth century. Whilst heavy falls were generally more frequent in the most recent record, there was no regular relationship with 'global warming'. This analysis departs from the general impression in the UK of a much more hazardous fluvial flooding regime, with large regional floods in 1998, 2000, 2001, 2005 and 2007 and torrential 'flash floods' in the summers of 2004 (Boscastle) and 2005 (North York Moors). The authors stress, however, that the lowland, easterly location of Durham creates a rainfall regime which is less sensitive to climatic shifts. These analyses are of daily rainfall amounts; the trigger for flooding in small catchments is normally intensive rainfall over much shorter intervals, for example an hour or less.

Using 146 rainfall records, again daily, Osborn and Hulme (2002) confirm that more significant changes have occurred in winter further west, principally towards heavier precipitation on wet days but partly towards more wet days (the latter is not a feature of stations further east). Multi-day sequences of heavy rain have also increased, a trend confirmed for the north and west by the regional analysis of Fowler and Kilsby (2003); the long duration of rainfall figured highly in recent regional-scale floods in England. Indeed, more protracted high flows are a significant outcome of the analysis of 5–30 river records by Robson (2002). However, Robson's conclusions are that changes such as this can be explained by climate variation, not change, and that there is no direct evidence of a change in peak flows in the last 30–50 years.

Geomorphologists have a separate 'take' on the effective flood record, based on, for example, lichen-dated flood deposits in sparsely gauged upland catchments (Macklin and Rumsby, 2007); these authors detect a reduced magnitude and frequency of upland floods (often labelled 'flash floods') over the last 50 years – again the North Atlantic Oscillation is identified as exercising a forcing role in rainfall–runoff relationships since 1750. The impact of intense headwater floods is spectacular, and 'flood-rich' periods have been linked to threshold change in river morphology. However, it seems that in many areas river channel planform is more 'robust' than others: Werritty and Leys (2001) suggest that the sensitivity to flood-rich periods noted for northern England relates partly to mining and to land-use change on valley sides closely coupled to the channel sediment system. There is surely a message here about the resilience to climate change forfeited by careless or unplanned catchment development.

Nevertheless, the need for policy analysis and development forces modellers into further scenario production, as described by Hall *et al.* (2003). The outcomes make clear that the UK's 'flood protection' effort must transform into 'flood risk management' and make very profound changes to policy, even given the modelling uncertainties: 'business as usual' will be accompanied by large increases in flood damage. There are also water resource implications of trends in climate: by coupling climate models of precipitation change to simple river flow models, Arnell and Reynard (1996) demonstrated the impacts on 21 catchments in Great Britain. The drier areas of southern and eastern England show the greatest sensitivity to climate change, with the driest scenario leading to reductions of up to 30 per cent in annual runoff. Changes in the north and west are much smaller, as are changes in winter compared to summer.

Perhaps the least considered impact of climate change in the UK (and the rest of the European Union) will be on delivery of the Water Framework Directive objectives (Wilby *et al.*, 2006). Some have questioned whether a uniform 'good ecological status' can be an objective across the current range of climates in the EU, let alone keep the programme going through climate change (Table 6.16).

Empirical evidence of current impacts of climate change drivers on freshwater ecosystems is scarce. Bradley and Ormerod (2001) and Durance and Ormerod (2007) have used the intensively researched Llynn Brianne catchments in central Wales (UK) to suggest a link between invertebrate species' composition/abundance and the North Atlantic Oscillation (a quasi-cyclic alternation between Atlantic and continental influences in the UK) and to separate this climate signal from those of water quality (though, significantly for 'global warming', stream temperature may be involved). Durance and Ormerod predict a 21 per cent reduction in spring season macroinvertebrate abundance for every 1 °C rise in water temperature.

6.5.4 Change, management and resource stress

Significantly, the IPCC's Working Group II focuses on impacts, adaptation and vulnerability across the board (IPCC, 2007b). Its predictions include the increased threat of extinction to 20–30 per cent of plant and animal species, changes in ecosystem structure and function resulting in loss of biodiversity, the loss of coral reefs and mangrove forests, poorer human health, increased proportions of GDP used for coping with hazards, and human migration. Perhaps of most relevance to the management of river basins, considering the dominant role of agricultural water use in developing countries, are the impacts predicted for 'food, fibre and forest products'.

Table 6.16 Potential climate change impacts on Water Framework Directive objective of 'good ecological status'

Parameters	*Potential impacts*
Physico-chemical	Changes in water temperature and dissolved oxygen. Decreased dilution capacity of receiving waters. Increased erosion and diffuse pollution. More frequent flushing of storm sewer overflows. Photoactivation of toxicants. Exceedence of water quality standards.
Biological	Changing metabolic rates of organisms. Changing ecosystem productivity and biodiversity. Plant and animal geographical distributions. Fish migration patterns and dispersal corridors. Increased eutrophication and prevalence of algal blooms. Changes in aquatic flora and fauna at reference sites. Changes in species assemblages in designated areas.
Hydromorphological	Changing river flows and sea levels – coastal erosion. Indirect impacts from land-use practices. Hydrological connectivity of slopes, channels and coastal zone. Diffuse and point sources of sediment increased. Long-term bed material calibre and transport change. Processes driving dynamic/diverse habitats. Channel changes.

After Wilby *et al.* (2006)

The sensitivity of global food production to climate change is a vital consideration in setting global policies. Although the atmospheric CO_2 content (via the process of photosynthesis) and water availability are vital components of yields, it is widely thought that 'global warming' of 1–3 °C will tend to increase crop productivity, particularly in high latitudes, but with greater warming the world food system begins to break down, affecting first the subsistence growers at low latitudes. Timber productivity may also increase with warming, but clearly the global volume may become controlled by the balance of planting and felling, partly controlled by mitigation policies such as the Kyoto Protocol. Whilst coasts are treated separately, the implications of sea-level rise for global food supply include loss of a highly productive coastal plain, saline water intrusion and increased food pressure inland through migration of the coastal population. Sea-level change is of profound significance to river basin dynamics and water resource stress: Milliman *et al.* (1987) quantify the additional pressure on land and population likely to be suffered by Egypt and Bangladesh as the result of losses of delta land to sea-level rise. Between 15 and 30 per cent of habitable land could be lost, especially where the rise of coastal waters is accelerated by depriving the deltas of sediments as the result of dam building on the contributing rivers.

The importance of the USA for grain production has a further influence on world flood resources (and hence water management) in the event of more frequent droughts, although some agronomists point to the improved conservation of water practised by plants in an atmosphere which contains double the present amount of carbon dioxide (Allen *et al.*, 1991). Individual crop responses are important; Allen *et al.* show how corn and winter wheat require less irrigation water in a 'greenhouse' world.

Gleick (1987) considers that international conflict (over resource pressures and the severe social stress caused by large numbers of refugees and migrants) may well be the major result of CO_2-induced warming (Figure 6.18), with many international river basins the scene of potential warfare over scarce resources (see also Chapter 5).

An early example of strategic assessment of the implications of climate change for river basin management (Arnell *et al.*, 1994) uses a matrix approach to assessing the sensitivity of all river basin (and coastal) management functions in England and Wales. All aspects of the hydrological and marine system are influenced (Figure 6.19). There are also possible impacts on river water quality and therefore on stream ecosystems and fisheries.

6.5.5 Mitigation and adaptation: global approaches

There exists in the signals we receive from science about anthropogenic climate change, however uncertain the 'numbers', a clear call for concerted action to reduce the atmospheric 'forcing' of change and to adapt to the ramifications of change in the resource and hazard systems considered above.

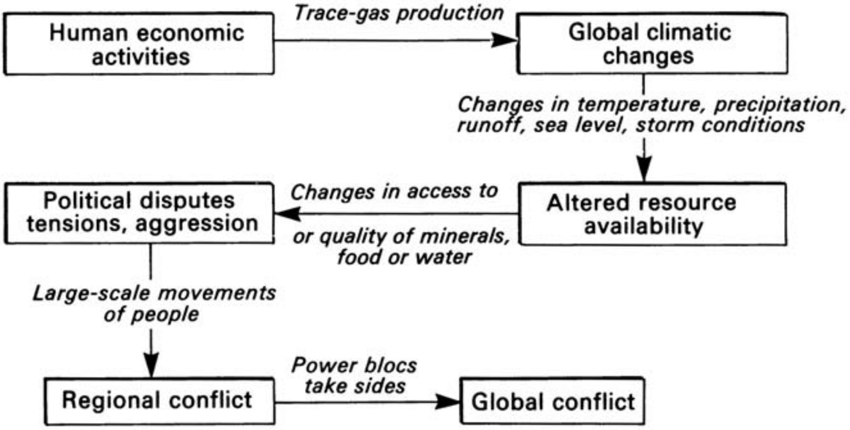


Figure 6.18 The critical path to global conflict over water and other major resources following climate change (after Gleick, 1987).

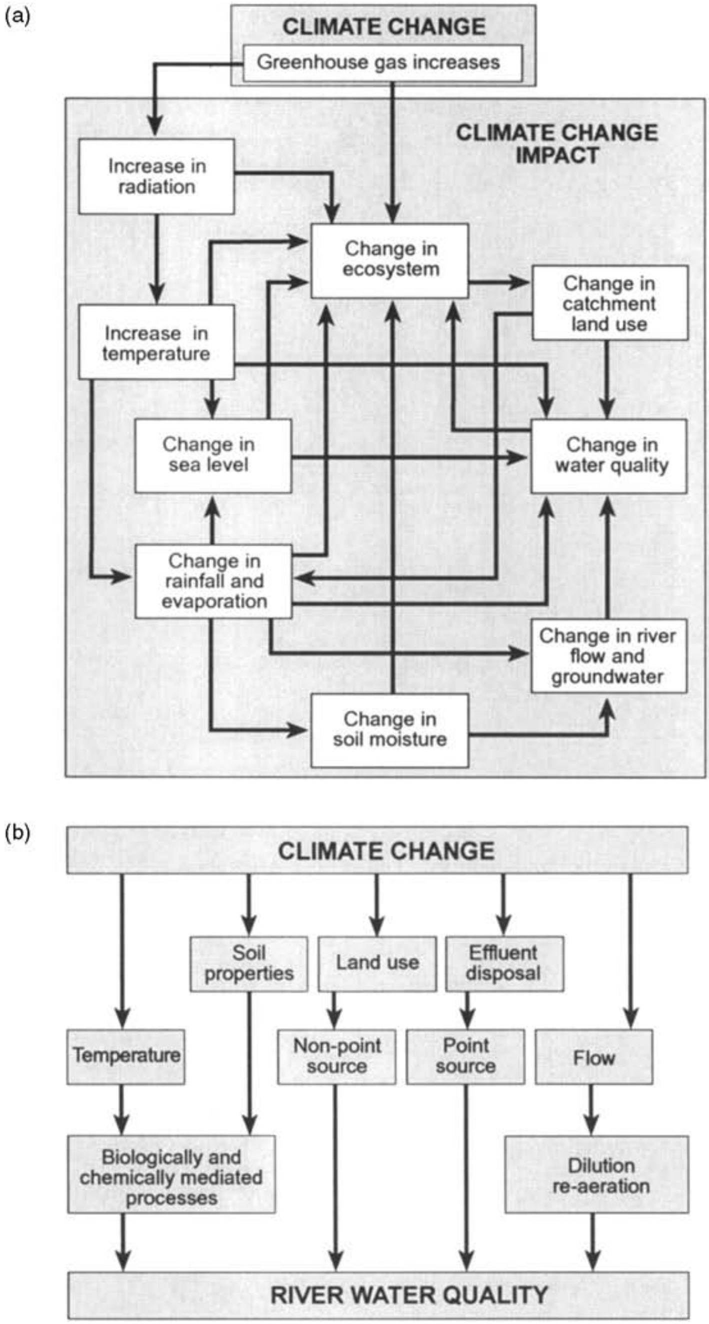
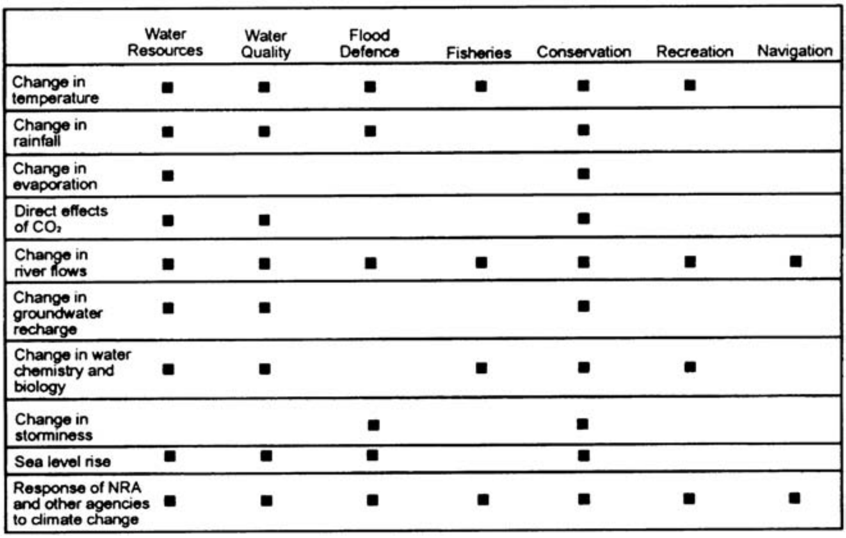

(a)
CLIMATE CHANGE
Greenhouse gas increases
CLIMATE CHANGE IMPACT
Increase in radiation
Change in ecosystem
Change in catchment land use
Increase in temperature
Change in sea level
Change in water quality
Change in rainfall and evaporation
Change in river flow and groundwater
Change in soil moisture
(b)
CLIMATE CHANGE
Soil properties
Land use
Effluent disposal
Temperature
Non-point source
Point source
Flow
Biologically and chemically mediated processes
Dilution re-aeration
RIVER WATER QUALITY

Figure 6.19

(c)



	Water Resources	Water Quality	Flood Defence	Fisheries	Conservation	Recreation	Navigation
Change in temperature	■	■	■	■	■	■	
Change in rainfall	■	■	■		■		
Change in evaporation	■				■		
Direct effects of CO_2	■	■			■		
Change in river flows	■	■	■	■	■	■	■
Change in groundwater recharge	■	■			■		
Change in water chemistry and biology	■	■		■	■	■	
Change in storminess			■		■		
Sea level rise	■	■	■		■		
Response of NRA and other agencies to climate change	■	■	■	■	■	■	■

Figure 6.19 Climate change and river management in England and Wales:
(a) General context and linkages
(b) Impacts on water quality
(c) Impacts on management functions for each element of change
(National Rivers Authority, 1994)

The Kyoto Protocol is an enforcing document for a much weaker global agreement deriving from the Earth Summit in Rio in 1992 – the United Nations Framework Convention on Climate Change. Its objective is the stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. A 'basket' of GHGs is covered, their emissions to be reduced by more than 5 per cent on 1990 levels by 2012. Here we have neither the intention nor the space to develop 'Kyoto' further, except to say that land use in river basins may come under the influence of its clean development mechanism (CDM), as might dam building. This is an official form of carbon offset, in which, simplistically put, trees are planted to absorb CO_2, thus permitting further conventional economic growth with fossil fuels in the same country or elsewhere in the world. Hydro-power generation also qualifies under the CDM. Offsets have become a popular act of private conscience in the developed world too, but their volume (in terms of the 740 million tonnes of carbon offset under 'Kyoto') is tiny.

The IPCC has quantified the benefits of this form of mitigation (IPCC, 2000), showing how improved management of existing land use can offset almost 700 million tonnes of carbon per year, whilst land-use change (principally agroforestry instead of cropping) can offset over 400 million tonnes. It is also a reflection of the anthropogenic impact on the carbon cycle that to offset our annual *individual* carbon dioxide 'footprint' would require more than 500 trees to be planted in the tropics (where uptake is most efficient).

Humans already modify their activity to suit the climate, both informally and as a societal response. *Adaptation* to climate change is therefore a powerful weapon against predictable outcomes; strategies can also be chosen to anticipate and be resilient to surprise events – climate shocks (POST, 2006b). The UKCIP02 scenarios are the current basis for adaptive strategies in the UK, and the UKCIP researchers have provided an online 'wizard' to help businesses and other organisations integrate climate risks into their decision making. 'Improving social, economic and technical resilience' (POST, 2006c) will help protect the development process whilst at the same time selecting traditional coping mechanisms. Owuor *et al.* (2005) paint the picture of coping mechanisms in a dryland mountain environment in Kenya already facing extreme droughts; the flexibility of land resource exploitation from farm to forest, crop to livestock, well to spring is, however, shackled by the 'modernization of resource governance'. The outcome, without an adaptive strategy, will, in drylands, be further land degradation which may itself exacerbate local climate change. Under threat, communities first intensify their land use, then exploit the margins and then migrate (if they can). Providing adaptive advice for flood-prone communities, the International Rivers Network (McCully, 2007) advocates a range of adaptive strategies.

Moving sideways from global information and welfare to global commerce, Julia and Duchin (2007) use the driver of comparative advantage in food production to suggest that, broadly, trade is an adaptive mechanism to climate change, although the study did not incorporate important factors like trade barriers, water availability or energy crops. Australia, under its risk-based drought policy, is likely to adopt a re-jigged macro-economic structure, perhaps within an adaptive world trade pattern: 'virtual water' may play a part in this process. Economic assessments gain headlines but depend critically on the scenarios selected. Sir Nicholas Stern's report to the UK Treasury (Stern, 2007) advocated mitigation to prevent dangerous climate change (warming of 5–6 °C) which might set back the economy by 20 per cent of GDP by 2050; the cost of mitigation was put at 1 per cent of current GDP.

6.6 Conclusions

This chapter has made clear that an era dominated by simple engineering 'solutions' to river basin management has ended, in favour of setting up technical options which have multidisciplinary or interdisciplinary authorship and a very large socio-economic component in delivery. Each topic demonstrates the vital new component of technical management: it is inefficient, ineffective and often invalid on its own, requiring (as shown classically by soil erosion control and efficient irrigation) large inputs of social science and vernacular science too. As the damage done by unsustainable development to river basin ecosystems becomes clearer and is converted into costs to those who benefit from that development, restoration, rehabilitation and enhancement are bound to figure highly in future. The problem underlying future schemes, in terms of the long timescales demanded by sustainable thinking, is the uncertainty about climate change. This uncertainty, too, imposes a social component and makes the science–politics interface more active than ever before; it is to aspects of this interface that our coverage now turns.

Chapter 7

Institutional issues in river basin management

Stasis and change in England and Wales

IWRM and IRBM are vehicles for sustainable river basin management and will inevitably be delivered through institutional and organisational structures; in this chapter we refer mainly to the agencies which are set up specifically to manage river basins. Agenda 21 states (Chapter 18.21) that, ‘Although water is managed at various levels in the socio-political system, demand-driven management requires the development of water-related institutions at appropriate levels, taking into account the need for integration with land-use management.’ Figure 7.1 illustrates the range of society’s groupings deemed by the Agenda to have key roles in sustainable development. Underlying their involvement are the basic human institutions of finance, education, law, etc. As Delli Priscoli (1989) puts it, ‘Institutions are the embodiment of values in regularized patterns of behaviour. The institutions and organizations that supply and distribute water resources reflect society’s values towards equity, freedom and justice’ (pp. 33, 34).

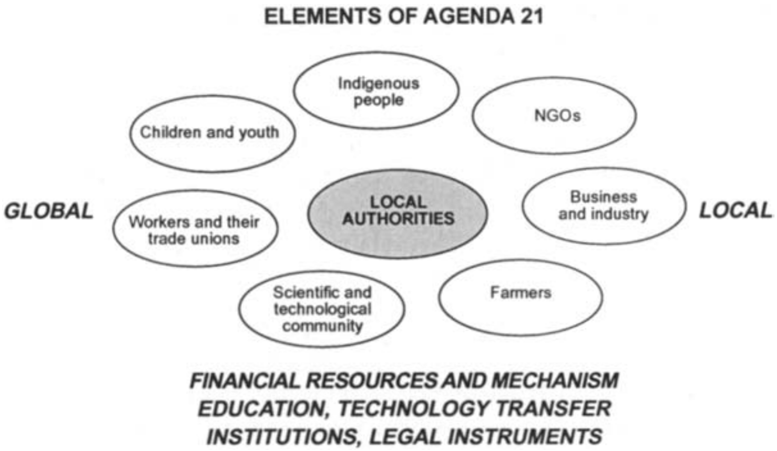


Figure 7.1 The social scales and groupings of Agenda 21 implementation.

In considering the need for such institutions to evolve to match their context and knowledge-base we will look at the case of England and Wales. Global evolution of the context is illustrated by the fact that in the second edition we noted a transition, during the late twentieth century, from engineering-dominated *distribution* philosophies to hydrology-dominated *collection* philosophies. The move away from wholly technocratic solutions has now seen a change to *allocation* as a focus: a dilemma rather than a philosophy. The institutional implications of this change are considered before the case study.

7.1 Delivering IWRM/IRBM within contexts of rights and governance

IWRM and IRBM now need to consider the profound differences between Agenda 21 and the Millennium Development Goals (MDGs – see also Chapter 5). IWRM receives attention and support in the MDGs but under different, more social, objectives. IWRM is seen as playing a part in helping globalisation to gain a positive impact by reducing poverty and inequality (Vayrynen, 2005) and as part of achieving ‘healthy urban futures’ (Tipping *et al.*, 2005). As Barbara Schreiner (2006) put the new set of challenges:

> As water managers, instinctively we understand that anyone without access to a reliable source of good quality water is poor. Access to water is not, in itself, sufficient to eradicate poverty, but it is a necessary condition of the bigger process of sustainable development.
>
> (Schreiner, 2006, p. ix)

As a senior manager in South Africa, Schreiner has witnessed the re-positioning of sustainable river basin management across the divide between human rights and the rights of non-human biota (Box 7.1).

Those protecting non-human biota in the interests of biodiversity are also forced to consider rights issues (Le Quesne *et al.*, 2007). The ‘way in’ for an environmental pressure group like WWF is clearly at the point of allocation of, for example, environmental flows, rather than simply to ‘plug’ best technical practices. Le Quesne *et al.* therefore point up the need for the organisation to be involved with policy and legislative formulation, management strategy development and institutional capacity building.

Brooks (2007) extends the rights argument to one of *water governance*. Al Jayyousi (2007) details governance as:

> a range of political, social, economic and administrative systems that are in place to regulate the development and management of water resources and provision of water services at different levels of society . . . a prerequisite to fulfill the human right approach for water.

Box 7.1 Water as a human right (in the contexts of supply and sanitation)

What are human rights to water and at what level of subsidiarity can they be assured? Clearly a globalised legal framework is the ideal for human rights, but changes to international law require precision and systems of support (Irujo, 2007). Perhaps for this reason, international agencies have vacillated between water as a basic need and water as a human right (Abu-Zeid and O'Neil, 2007). In 2003 the United Nations Committee on Economic, Social and Cultural Rights reported that 'Water is a limited natural resource and a public good fundamental for life and health. The human right to water is indispensable for leading a life in human dignity.' The Committee divided the right into *freedom* from interference with existing supplies (disconnection, pollution) and *entitlement* to a system of supply and management where this does not presently exist. A follow-up meeting of experts, reported by Abu-Zeid and O'Neil, listed several areas needing clarification, among them:

- Is water a basic need or human right?
- If a right, what are the duties of various levels of government and users (subsidiarity)?
- If water is to be priced how does this square with its status as a public good?

The line taken by this book is that delivered to the meeting by Brooks (2007), namely that the right to domestic water supply should be beyond question but needs extending to *rights to food* (thus including land rights) and *rights to a viable environment* in which water supports the ecosystem. As such, the UN's Food and Agriculture Organization (FAO) has a Livelihood Support Programme (Hodgson, 2004) which stresses rights to a variety of natural resources as part of sustainable poverty reduction and points to the way in which rural water rights are subsumed within land rights, a much more fiercely contested political field.

The rights of non-human biota are a fiercely contested philosophical and political field; in some nations there are traditional cultural or religious codes and in others 'green' politicians have encoded national legal principles. A less controversial entry point for relevant debate may well be through assessment of the *values* of 'nature' to a society and the important question of ecosystem services (Chapter 9).

Perret (2006) considers the rationale and role of governance in the water sector: decentralisation, participation and liberalisation are key attributes of catchment management agencies, water users' associations and the general establishment of policy frameworks and tools, all of which come under our umbrella term 'institutions', especially Saleth's (2006) definition of institutions as 'rules that define action situations, delineate action sets, provide incentives and determine outcomes'. Cleaver and Franks (2005) warn against assumptions that 'good' governance will cure all ills, notably poverty, and that, without subsidiarity, models such as IWRM/IRBM fail to address the responsibility of water institutions within a governance structure. There are particular dangers of a continuing lack of gender awareness, in that masculinities can be perceived in much of the rationality claimed for 'new ways with water' (Laurie, 2005).

Newson (2004a) argues for a new debate about the apparent rationality of IWRM/IRBM. Looked at from the social science perspective, this guidance from the biophysical 'side' is debatable, a view succinctly put by Wester and Warner (2002) as: 'The assumptions on scale, boundaries, appropriate institutions and procedures underlying this new model are, however, not as self-evident as they seem. Rather, they are the outcome of socio-political choices' (p. 61). Newson continues:

> As further views from the social sciences emerge there are considerable dangers that, if criticisms of 'catchment consciousness' (and its translations into river basin institutions and governance) are not debated and the implications/alternatives not explored, expectations of IWRM in terms of sustainable river basin development will be raised at a strategic level, but tangible benefits will not be delivered.
>
> (Newson, 2004a, p. 440)

Ironically, as critiques of IWRM begin to emerge, so do new challenges thrown up by institutional adoption of its principles (Box 7.2).

Box 7.2 IWRM: the emerging critique (simultaneous with the challenges of the EU Water Framework Directive)

IWRM has, as we have noted, become exposed to the criticisms inevitable given its popularity; it is neither panacea nor sinecure, and faces dangers of associations with the past (technocratic residues) and lack of registration with the future (uncertain science). Watson *et al.* (2007) provide a review of its current problems of principle and practice.

Table 7.1 takes on board a range of criticisms, mainly in the area of the development process and perhaps influenced by the larger geographical scales now being confronted by water analysts, e.g. international basins and world trade in 'virtual water'. However, the more critical point is that IWRM/IRBM will be for ever mired in purely strategic policy, never becoming operational because it lacks tools, a sure failing in the field of water. Table 7.1 can be compared with Tables 7.1(a), (b) and (c) in Newson (1997), indicating the change from advocacy to reflection for the river basin unit as a policy framework, but it is of note that the European Water Charter has had many repercussions in what we now make a central example of integrated water policy for ecosystems – the EU Water Framework Directive (WFD). Thus Table 7.2 infers something of a 'come-back' for IWRM in defining a major legislative framework for water, focused on the freshwater ecosystem, yet impinging on the lives of almost half a billion people in the 27 nations of the European Union. The nature of the relationship between IWRM and the WFD is explored further in Box 7.3.

Table 7.1 Emerging critiques of integrated water resources management as a manifestation of 'catchment consciousness'

Author	*Critique of 'catchment consciousness'*
Rhoades (1998)	'Watersheds as closed human management units are external bureaucratic or researcher fantasies, not indigenous ones' (p. 5).
Winpenny (1994)	'[G]eography and hydrology do not necessarily define the best scale for planning and problem solving. Nor do they justify the use of "integrated" or "comprehensive" plans for water development' (p. 23).
Wouters (1997)	'Neither state practice, nor the cases . . . justify . . . the juridical unity of a drainage basin from its physical geography. An argument based on geography alone does not carry conviction' (p. 15).
Wester and Warner (2002)	'Reconceived as political units, river basins become territories of governance' (p. 68).
Brichieri-Colombi (2004)	'Today the idea of viewing a river basin as a closed system in anything but hydrological terms is largely redundant' (p. 318).
Biswas (2004)	'[E]veryone is for integrated water resources management, no matter what it means, no matter whether it can be implemented, or no matter whether it would actually improve water management processes' (p. 248).

7.2 Can basin authorities work? From the TVA to CMAs and RBDs

Chapters 4 and 5 deal extensively with the kinds of river basin institutions to be found in the developed and developing worlds – some successful, some tragic failures. It is appropriate to begin with the Tennessee Valley Authority (TVA). Much of the criticism of the TVA and its achievements stems from an American cultural distrust of large public authorities (as redolent of socialism). However, despite recent criticism of the heavy dependence upon

Table 7.2 Aims and objectives of the European Union's Water Framework Directive

Aim	*Objective*
To replace existing legislation	Surface Water Abstraction Directive, Freshwater Fish Directive, Shellfish Waters Directive, Groundwater Directive, Dangerous Substances Directive.
To improve the ecological health of inland and coastal waters, requiring most to reach 'good status' by 2015	Also prevent further deterioration, help 'heavily modified' water bodies reach ecological potential and protect against diffuse pollution through better land management.
To progressively reduce the pollution of surface and groundwater	Using the precautionary principle and the polluter pays principle, e.g. to exclude priority hazardous substances, merging discharge and ambient approaches.
To recognise water as an economic entity	To take account of all costs and benefits and of a fair balance between supply and demand management.
To mitigate the impacts of floods and droughts	Sustainable policies for anticipating and coping with extremes.
To encourage public consultation and support decision making	To establish river basin districts as the basic units of governance, achieved through a cyclic process of strategic planning; water bodies remain as the monitoring unit for compliance.
To designate as 'protected areas' conservation sites identified under the Habitats and Birds Directives	(Set by other legislation.)

dam building, it is to the integration of land and water management that supporters of the TVA most look for praiseworthy achievements. Degradation and impoverishment were largely repaired by improvements to land management and erosion control, with dams and navigation improvements bringing power and salience to a neglected peripheral region.

The TVA supporters would therefore claim that the Authority had trailblazed the field of IWRM/IRBM, led by economic regeneration. Downs *et al.* (1991) have referred to the sometimes platitudinous or rhetorical use of the term 'integrated river basin management'. They prefer to separate the term *comprehensive* river basin management, where several components are involved, retaining *integrated* basin management for schemes where the components interact (though one may lead); they then interject *holistic* river basin management to cover both divisions but emphasising system energetics, change and human interactions. Thus, the TVA was a comprehensive organisation but had too little hydrological basis to be integrated and, since the working definition of 'conservation' was wholly anthropocentric, it had little concept of sustainability.

The *Comprehensive Assessment of Water Management in Agriculture*

(Molden, 2007), with its roots in the water–land relationship, makes a plea that water stress requires 'reshaping the role of traditional hydraulic bureaucracies and seeking political support for more polycentric and collaborative modes of governance'. Furthermore, '*not all problems can or should be solved at the river basin level*' (emphasis added). The Assessment quickly returns us to the theme of the previous section in that 'the politics of governance are embedded in socio-political realities and lie at the heart of river basin development and management'. Theorists have tackled the position of the river basin in development, Molle (2003) treating the process as one which progressively harnesses the basin's available (and then renewable) resources through phases of exploitation, conservation and augmentation. As water use approaches the available supply, *river basin closure* occurs (a term introduced by Keller *et al.*, 1998). The socio-political inference of the closure concept is that there are unique solutions in the augmentation/adaptive phase where actions are essentially those of allocation. As a result, a 'one-size-fits-all' river basin authority is unlikely to be the institution for the job. Table 7.3 is drawn from the *Comprehensive Assessment* and is generic only in functional terms; in institutional terms a wide variety of configurations and scales is implied: described are basin authorities, basin commissions or committees, coordinating councils and international river commissions.

In judging the success or failure of a river basin management institution it is clearly too late to leave analysis until its fiftieth anniversary (as was the case

Table 7.3 Essential functions for river basin management

Function	*Definition*
Plan	Medium- to long-term plans for managing and developing water resources in the basin.
Construct facilities	Design and construction of hydraulic infrastructure.
Maintain facilities	Maintaining the serviceability of hydraulic infrastructure.
Allocate water	Mechanisms and criteria to apportion between different uses, including the environment.
Distribute water	Ensuring allocated water reaches its point of use.
Monitor and enforce water quality	Keeping pollutant concentrations at or above accepted standards.
Preparedness for extremes	Flood and drought protection and warning. Emergency works and coping mechanisms.
Resolve conflicts	Provision of space or mechanisms for negotiation and litigation.
Protect ecosystems	Priorities and actions to protect ecosystems, including awareness campaigns.
Coordinate	Harmonisation of policies and actions relevant to land and water management.

After Molden (2007)

with the TVA); what is required is a checklist characterising the ideal or proven strengths of such agencies. In the past we have examined the recommendations of the OECD (1989) and Mitchell (1990). The OECD report includes around 100 case studies and over 50 country reports, allowing it to conclude on the relative importance of 13 administrative/institutional characteristics leading to effective integration of management. Mitchell's (1990) list also includes legitimation, but also context, functions, structures, processes/mechanisms and cultures/attitudes. More recently, Jonch-Clausen and Fugl (2001) have advocated a 'firming up' of the concepts of IWRM. They say that IWRM is not a goal in itself but a process of balancing and making trade-offs between different goals in an informed way.

In the following pages we shall begin to advocate a view that, in order to implement sustainable development of river resources and to influence those bodies concerned with land use, land management and other livelihoods, a strong agency will be prepared and able to carry out authoritative resource *planning*, a political process because it involves spatial allocations. Political validity for planning can now only be achieved by participation at a variety of scales appropriate to the issue 'on the table'; a basin authority needs to 'hold the ring' on the stakeholder platform. Geographical scale is not just an important criterion for overall performance (Hooper, 2005) but affects the willingness of stakeholders to participate, the implementation of consensus actions and the linkages to spatial hierarchies of other plans, including those for land use (Newson, 2004b). Box 7.3 outlines the preferred institutional hierarchies of the EU WFD and the South African National Water Act (see also Box 5.3).

Box 7.3 IWRM and emergent river basin institutions and policy frameworks: the European Union and the Water Act of South Africa

The European Union's Water Framework Directive (WFD) tasks member states to nominate 'competent authorities' for 'river basin districts' (RBDs); the latter comprise groups of watersheds or catchments which may have been (as in the UK) the scale of previous planning and management units. For example, in England and Wales, 159 catchment management plans have become 11 RBDs. By 2009, these authorities must have consulted on and published plans for 'programmes of measures' by which the constituent water bodies (lengths of a few kilometres) are brought to or retained at 'good' (ecological) status; assessment of compliance will be at the water body scale by the year 2015. Thus the requirement for river basin management plans (RBMPs) drives both the institutional arrangements and the incorporation (at the least through economic analysis and public participation) of some of the holistic ideals of IWRM/IRBM (Kaika, 2004). Public consultation on the RBMP process has already revealed a craving for *smaller geographical units* as the basis of participation, and we desperately need to include scale as a performance criterion. On the face of it the WFD will promote national-scale competent authorities (normally, where in existence, the current river basin or water authority), RBD-scale holistic processes and water body-scale *metrics* for compliance and reporting (but not consultation).

The only major token shown to administrative boundaries, rather than river basin boundaries, in the EU WFD is in border areas for national jurisdictions, e.g. between England and Scotland. Under South Africa's 1998 Water Act, however, the 19 catchment management associations (CMAs) are scaled to create competence, i.e. either by including many small catchments or by subdividing catchments like the Vaal which would be too large for effective participatory management. Several institutions were created within CMAs, including water user associations and catchment committees (see Chapter 5). The national coordinating institution under the Act remains the Department of Water Affairs and Forestry.

7.3 Case study: the evolution of basin management institutions in England and Wales

There are many reasons for a special study of water institutions in the UK besides this author's nationality, e.g. the UK has a century and a half of institutional developments from which to select trends. A historical survey of one nation may repay our detailed attention to highlight the importance of cultural and traditional factors in river management systems. Here we are concentrating on England and Wales; there are entirely separate patterns of organisation in Scotland and Northern Ireland. England and Wales also face much heavier current demand pressures against the 'headroom' available for water supply, especially in the south and east of England.

A pivotal point in the institutional history of UK river management was the construction of water mills from source to mouth on many rivers, threatening the traditional allocation of a fundamental resource. Later, in the first stage of the Industrial Revolution in England it was the issue of navigation which forced the local by-laws into a larger scale of relevance: the construction and filling of canals had a profound influence on rivers (Rolt, 1985). Kinnersley (1988) views the canals as 'among the first privately financed large constructions intended for use by all comers' (p. 43). The canal companies required water from rivers, interconnection with river users and the agreement of landowners for construction; the latter were well represented in Parliament and so the Canal Acts provided a balance between gaining and losing interests and wider public rights.

The extension of this institutional structure to municipal water supply and sewerage was, however, much less straightforward. Two important books develop the critical themes of *local institutional development* (Rennison, 1979, for Tyneside) and the role of health reformers and engineers (Binnie, 1981). Public health was to become the single issue around which the emerging local democracies for cities – the municipalities – could form. Chadwick's 'Report on the sanitary condition of the labouring population of Great Britain' (1842) was followed by the facilitating legislation for private bills developing corporate powers for water supply. This was in 1847; by 1878 there were 78 municipal water undertakings.

The rapid expansion of city buildings and roads led to a big surface water drainage problem; surface drainage and foul sewers became combined systems. Rivers became the sink for the sewerage systems of the neighbouring cities, once again without considering the immediate or eventual capacity of the river ecosystem to cope. Owing to the state of the Thames, Parliament itself had to meet behind sheets soaked in disinfectant in the 1870s; a series of Royal Commissions eventually led to the Public Health Act 1875 and the Rivers Pollution Prevention Act 1876. It became almost inevitable that basin-scale authorities would be set up and, as is perhaps the norm in public affairs, it was the crisis in flooding and agricultural land drainage which promoted the next significant institutional changes.

7.4 A flood-prone nation: land drainage leads the way

England and Wales are especially prone to water-logged agricultural soils and to flooding (Figure 7.2) from both rivers and the sea; the first 'Commissions of Sewers' to control local drainage date back to the thirteenth century. Drainage has, therefore, been of paramount importance in the settlement of and optimum agricultural use of the land in the UK; it has therefore been endowed with awesome political power. Only recently can we detect changing attitudes to this function as it progressively changed its title from *land drainage* to *flood protection* (or flood *prevention* as Hall (1989) and some journalists wrongly recorded it) and thence to *flood risk management* (Fleming, 2002). The sub-title of Fleming's book is revealing: *Learning to Live with Rivers*, an apt slogan for the new approach prevalent throughout much of Western Europe.

Land drainage interests are powerful enough in England and Wales to have led to the creation of special local institutions. For the 235 internal drainage boards (IDBs) in England and Wales, the security of life and economy still centres around efficient land drainage. Their power to levy rates in order to create and maintain arterial drains dates back to medieval times, but their formal inception came with the 1930 Land Drainage Act, which established 47 catchment boards. Here at last was, for each major river catchment, an

Figure 7.2 The drainage problem in England and Wales: flood-prone rivers and wetlands (from Newbold *et al.*, 1989).

institutional context free of the compartmental strictures of local government yet very widely representative and able to devote investment according to specialist engineering designs across whole catchment areas. The Ministry of Agriculture, which continued to control land drainage, also organised catchment-wide fisheries boards (from 1923). Fishery interests are a continuing thread in UK river basin management, mainly because they combine the interests of the unpolluted environment (fish act as 'miners' canaries' for pollution) and property rights.

The traditional form of flood protection in England and Wales has been structural; only in recent years has the creative use of floodplain storage been contemplated for sites where further structural protection would completely separate a river from access by the public (see Plates 7.1(a) and 7.1(b)).

7.5 Basin-scale regulation: water resources and pollution

The basin-wide needs of fisheries and land drainage for coordinated action to manage resources and hazards led to strong and purposeful specialist

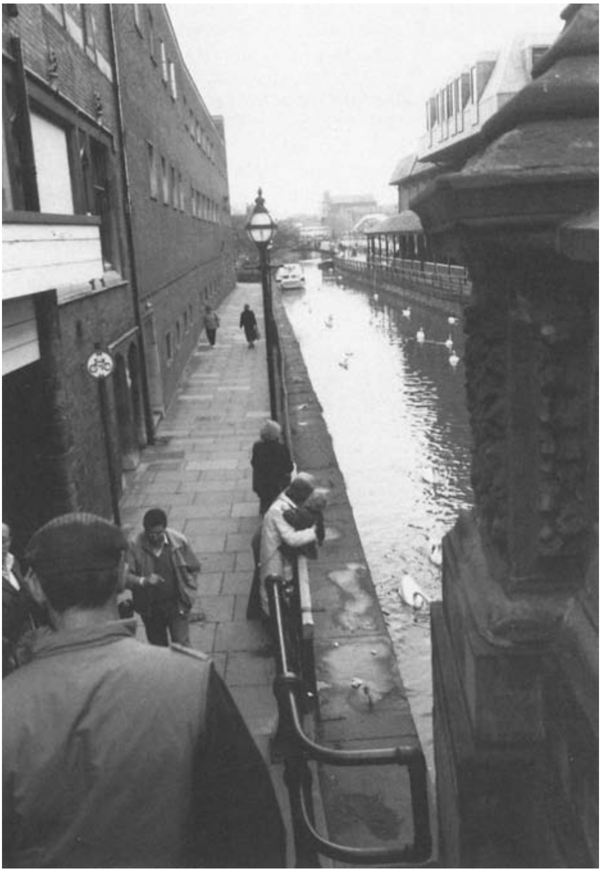


Plate 7.1(a) Flood risk in the centre of Lincoln is high. It has been reduced by creative use of farmland upstream.

Plate 7.1(b) At high flows water which would normally flood Lincoln is now released on to this floodplain farmland (photo M. D. Newson).

institutions working clear legal and financial systems. The 1948 River Boards Act set up 32 boards (plus the Thames and Lea conservancies). These boards were to become the administrators of the system of *licences* introduced first for discharging pollutants to rivers (1951 Rivers, Prevention of Pollution, Act) and, after a further reorganisation into river authorities, licences to abstract water resources (Water Resources Act 1963). Whilst the concept of *comprehensive* basin management therefore began to grow, the extensions beyond land drainage (flood protection) and fisheries powers for the basin authorities were to be weak, especially in the field of pollution control. Existing dischargers were exempt from licensing, the 'consents procedures' were kept secret (even though the public had a fundamental right to know the sources of river drainage) and the municipal council representation on the boards often led to a muted approach to improving sewage discharges (mainly from municipal sources!).

Until the 1960s there were no specialist agencies dealing with *water resources*. From the Victorian period of health reforms, during which seeking the purity and clarity of upland waters had taken on an almost religious fervour for municipal suppliers, each city wishing to dam an upland valley and pipe its supplies merely took a private Act of Parliament through Westminster. Not only did the Water Resources Act 1963 perpetuate river basin institutions which were broadly representative in decision making (34 boards became 29 authorities) but water became a resource or raw material like any other.

Reviewing the procedures by which water resource planning was achieved during this centralist (and highly technocentric) phase, Rees (1969) pointed to the remoteness and technical domination of the schemes proposed. She revealed the lack of published data on demand and supply, without which 'no definitive statements can be made on . . . future demands for water, or the characteristics of water users, on the possible effects of resource planning and controls, or on the influence of water as a location factor' (p. 2). Her own survey revealed the irony of central planning for a burgeoning demand but the failure of water supply or effluent disposal to influence industrial activity in any major way. Effectively, water supply provision had become an industry in itself.

Between the years 1974 and 1989 England and Wales had ten multifunctional regional water authorities (RWAs) charged with operating the human use of the hydrological cycle (i.e. a much more comprehensive brief) within river basin boundaries. Once again the decision making lacked transparency (Kinnersley, 1988; Hall, 1989).

Water problems had shifted from *quantity* to *quality* of supply. An organisational framework which put polluters and prosecutors under the same roof was always open to suspicion, but as an additional reassurance the Control of Pollution Act, passed in the same year as the RWAs began work, made public the consent registers and pollution monitoring data; unfortunately this did not become reality until 1985. Ironically, in the light of the strong political and technical movement away from water resources, the first major practical test of the RWAs was the drought of 1976 (Doornkamp *et al.*, 1980). The only centralised function in the new structure – the National Water Council (which had a pensions and pay negotiating role) – was able to proclaim, 'We didn't wait for the rain' (National Water Council, 1976).

When the newly elected Conservative government of 1979 began its long campaign for executive efficiency in public life, privatisation had begun ten years before its enactment.

7.6 Private or public? Economics and environment

It is no secret that the concept of integrating river management was championed by the professionals in the RWAs; many made explicitly antagonistic statements during the run-up to privatisation, mourning the proposed loss of total functional integration.

By the mid-1980s the regular surveys of river water quality carried out by the RWAs were beginning to cause concern: deterioration had replaced the steadily improving trend since the first surveys in 1975. New sources of pollution were partly to blame, such as spillage of slurry and silage liquor from livestock farms and nitrate from arable land; groundwater was becoming polluted, and the European Community was steadily tightening the standards for river water, supply water and coastal water. However, a major component of the RWAs' problem remained their decaying infrastructure of sewerage and sewage disposal. The legacy of the Victorian reformers, when not maintained and replaced by modern investment, became a liability, and the progress made by Margaret Thatcher's government in reducing public investment had badly hit the RWAs. A key mistake had been made in terms of sustainability: deterioration of assets had set in, and private capital offered a politically ideal escape route.

In fact EU law does not permit private companies to operate the regulations contained in EU directives: Thatcher eventually lost her arguments in Brussels. The government's response to blocking of the move by Brussels was a dual public and private system. A National Rivers Authority (NRA) was formed in 1989 to carry out the regulatory, environmental and flood defence functions for the same river basin areas as the privatised water supply and sewerage authorities. The full list of duties for the NRA was water resources (planning, licensing), pollution control, flood protection, fisheries, conservation, recreation and navigation; its staff were described as 'guardians of the water environment'. It had ten regional units, each with a large measure of public consultations including regional rivers committees, regional fisheries committees and regional flood defence committees. It also had a firm central administration in London (60 staff, compared with 6,500 in the regions).

If we consider a rough balance sheet of pros and cons of privatisation of the 'pipework' element of water in England and Wales (Table 7.4) we see that much depends on the regulatory framework in which private capital is allowed to work – there is certainly no 'free market'. The current regulatory framework is illustrated in Figure 7.3. The presence/absence and strength/

Table 7.4 Privatisation of water services in the UK: some 'pros' and 'cons'

Pros	*Cons*
Improved regulatory framework for sewage discharges: regulator separate from polluter.	Water services initially spared costs by setting of 'soft' standards – to attract investors.
Improved consumer access to action on standards and prices via OFWAT.	Water service companies in poor position to manage demand of a commodity they sell: Environment Agency promotes demand management.
Cost-recovery mechanisms forced on Environment Agency – thus charges for polluted discharges.	Directors' salaries and shareholders' dividends have attracted public criticisms as they rise: companies have diversified for profitability.
Opportunities for joint public education and promotion retained.	Early phase of disconnections for those unable/unwilling to pay hotly debated.

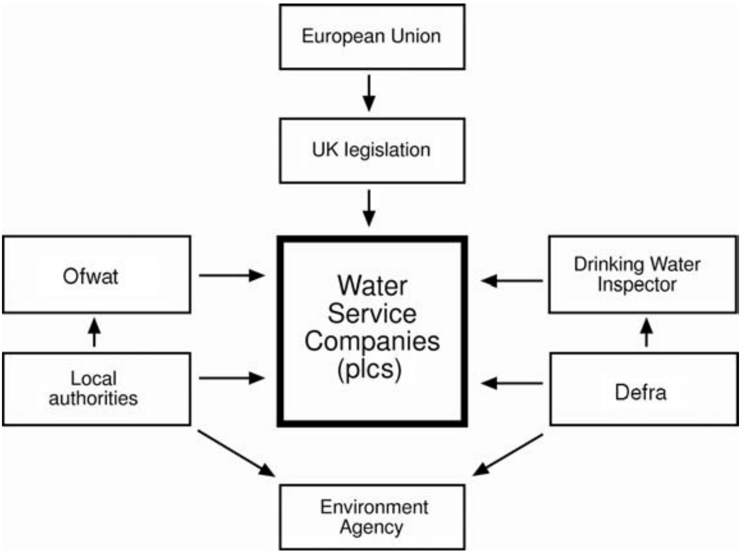


Figure 7.3 Institutional checks and balances following the privatisation of water services in England and Wales.

weakness of a regulatory framework which is open to customer representation are vital parameters in the global argument about 'private water'. In the early days of commodification in the UK many were concerned that, without economic values for unpolluted rivers, sewage treatment investment would be neglected, perhaps in favour of elevated executive salaries in the water utility companies. Responding to this criticism some, it seems, took their attention off water resources. In Yorkshire Water's case, an unreliable trust placed on declining demand and reduced leakage led to damaging cuts to consumers during a major drought in 1995 (Haughton, 1998); such was the adverse reaction from consumers and local politicians that the company was forced to entirely reform its policies during a public inquiry.

Water UK, which represents UK water and wastewater service companies, has reminded us of 'the value of water' (Water UK, 2005). Water supply and sewerage provision represents a very small proportion of domestic expenditure, around the same as use of a mobile phone and only two-thirds of the outlay on beer! The report 'talks up' the role of such a reasonably priced asset in creating wealth, health and cultural value in the UK.

7.7 An Environment Agency – for sustainable development and the WFD

The Environment Agency (EA) was formed from the National Rivers Authority in April 1996, gaining *regulatory powers in air and solid waste* in addition to those over rivers but retaining the river basin outlines used by the NRA. This constituted a considerable policy coup, placing catchments on a similar administrative footing to local government boundaries. Another coup was to follow when the Ministry of Agriculture, Fisheries and Food was merged, in 2001, with the 'greener' functions of the former Department of the Environment to create the parent government department for the EA: Defra (Department for Environment, Food and Rural Affairs). Whilst funding for the flood protection function remained dominant for the EA, many saw its umbilical cord to a powerful agricultural (cf. rural) lobby as being cut; other changes to, for example, 'flood risk management' were perhaps more significant. Another contested element of the new arrangement has been to maintain a competent authority (in EU terms) to control the quality of water supplied for consumption. Here Defra has a Drinking Water Inspectorate, formed in 1990, which reports annually on tests made on water from the supply system (privately controlled but thus regulated). The water service companies are much more actively regulated (generally quality is good) over their pricing, assets and spending plans, in this case by Ofwat, a regulatory body heavily controlled by consumers and one which can protect their interests to the level of a £12 million fine on Thames Water in 2007 for failing to make refunds in lieu of excessive charges to consumers.

It is fair to say that minor stakeholders (perhaps dealing with big, relevant issues) and the general public continue to find the EA regional committee structure impenetrable. The river basin planning process inherited from the NRA thus constitutes a major opening for public participation. The EA was quick to regroup and republish the NRA's catchment management plans in the form of local Environment Agency plans (LEAPs – covering all functions and couched in the language of sustainable development); these will now be partly replaced with river basin management plans under the WFD (Figure 7.4). A review of the implications of the WFD for river management in England and Wales is provided in Box 7.4.

By 1996, when the EA began its work, it was clear that the politics of water resources had changed in respect of anticipated shortages and less uncertainty that climate change would exacerbate the situation, changes in the devolution of power within the UK and to the regions, anticipation of the Water Framework Directive and additional pressures for demand-side management. A new water resources strategy is published in 2008 but much of the responsibility for assessing long-term needs has been passed to the privatised water service companies under the Water Resource Management Plan Regulations. The EA is, however, reserving responsibility for the thornier problem of identifying areas of water stress (EA, 2007). The south-east of England is regionally stressed, particularly in the light of growth in population by 2 million, with per capita use of water up 8 per cent, and the EA is re-examining the justifications put forward in the early 1970s for large-scale water transfers to the south-east from northern England or Wales.

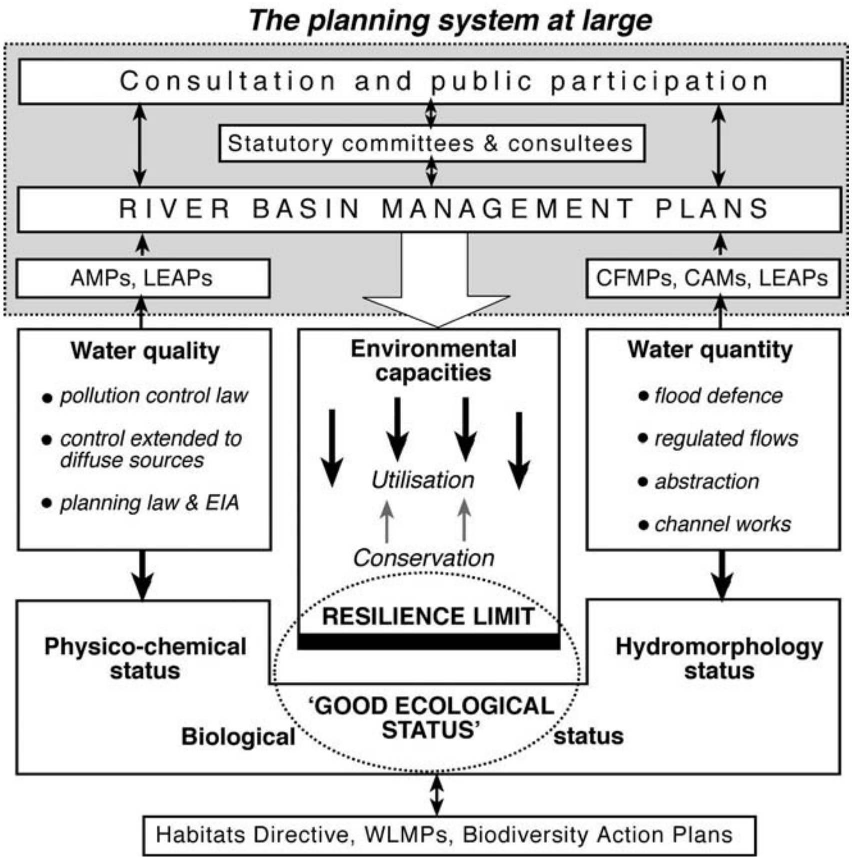


Figure 7.4 Integrating institutional plans with functional responsibilities for river basin management in England and Wales, within a context of sustainable ecological limits and the WFD (after Newson, 2004b).

Box 7.4 The impact of the EU Water Framework Directive on river management in England and Wales

The Water Framework Directive (2000/60/EC) is the most substantial piece of legislation ever produced by the European Commission (see Box 7.2). The overall aim is for all water bodies (more than 6,000 in England and Wales), except where there is a socio-economic justification for classing them as 'heavily modified', to reach or be maintained at 'good (ecological) status' by 2015, and the situation will be reviewed every six years thereafter. Whilst the physico-chemical state of water bodies (traditional pollution metric) remains a prime component of concern, the biological performance receives a boost and there is also a requirement to assess water bodies in terms of their 'hydromorphological' status. Whilst the latter is of equal rank to the other scales only in the case of the very best water bodies (high status: equivalent to reference condition), hydromorphology enters strongly, for example, the reform of flood defence (and hence planning) issues. Deterioration of status cannot be allowed because of flood or drought hazards except under special circumstances. Below 'good status' come 'moderate', 'poor' and 'bad', nominal categories which are in the process of being precisely defined but which owe much to previous iterations of pollution indices and of freshwater 'health' (Karr, 1999).

In short, the directive poses an incredible strain on the science base to come up with tools which will stand up to legal scrutiny as 'fit for purpose' in a climate of increased exposure to public scrutiny through participation (EA, 2002b). The directive will require a much more widespread effort on river restoration than the local, high-profile schemes so far prevalent, and this will require strategic evaluation such that restoration benefits not just the individual water body but its neighbours in the system (Skinner and Bruce-Burgess, 2005).

The costs to those regulated by the WFD in the UK vary wildly, e.g. £63 million to £287 million to remedy diffuse pollution (cost to agriculture) and £1 billion to £4.5 billion to improve river flows and sewage management (cost to water service companies). Regulatory impact analysis (on the economy) is still proceeding; the most recent parliamentary answer provided suggests annual costs of implementation for England and Wales will be £450 million to £630 million, as against benefits of £560 million per annum. At the first sign of faint-heartedness in the face of this economic impact, the environmental pressure groups which played a big part in achieving the passage of the directive through the Brussels bureaucracy began to collate pictures of the quality of implementation in member states (e.g. WWF and EEB, 2005). This report concluded that the quality of transposition into national legislation and subsequent implementation was low. Of interest within the UK is the much more positive reception given by NGOs to the direct transposition of the WFD into law in Scotland, via the Water Environment and Water Services (Scotland) Act 2003.

Water availability is now included as an issue in the Treasury's comprehensive spending reviews which drive fiscal policies. Increased per capita water demand remains a likely scenario (Downing *et al.*, 2003), despite demand management, because the soft-drinks, brewing and leisure industries will respond to climate change, as will irrigation. Arnell and Delaney (2006) have set up a model of adaptation suggesting varied capacity amongst the water supply companies in England and Wales, depending on the regional variation of change, the organisation, and the regulatory and market contexts.

Improvement has begun to occur to public participation in assessments of water resource development and in ending what many regard as a traditional 'free-for-all' in granting water licences to abstract (from groundwater or rivers, lakes and reservoirs). The latter aspect was the major feature of a Water Act in 2003. To provide an overall regulatory strategy and context for decisions on existing and future abstractions, another layer of river basin-scale planning has been introduced. Catchment abstraction management strategies (CAMS) are a hydrologically based (see Chapter 6, Section 6.3) rationale for assessing available volumes of water in all rivers and aquifers and the environmental risks of withdrawing towards, at or beyond these volumes (EA, 2002a).

Lobbying has long been characteristic of the broad 'green' movement in the UK, which functions through single-interest groups whose power combines their large membership and their subscriptions/donations (Lowe and Goyder, 1983). Table 7.5 compiles some of the influential publications of these groups, specifically those dating from the 1990s addressing water resource issues, effectively an exercise in uninvited participation in policy! Through such pressure, managing human demand has become politically acceptable. Added to this has been public irritation that leakages in the

Table 7.5 A selection of water resource policy (England and Wales) documents by pressure groups and other environmental agencies, 1990s

Date	*Title*	*Source*
1992	*Water for Wildlife*	RSNC – the Wildlife Trusts Partnership, Lincoln
1992	*Draining our Rivers Dry*	Friends of the Earth, London
1993	*Water for Life: Strategies for Sustainable Water Resource Management*	Council for the Protection of Rural England, London
1995	*Water Wise*	Royal Society for the Protection of Birds, Sandy, Beds.
1996	*Impact of Water Abstraction on Wetland SSSIs*	English Nature, Peterborough
1997	*Wildlife and Fresh Water: An Agenda for Sustainable Management*	English Nature, Peterborough
1997	*Freshwater*	UK Round Table on Sustainable Development, London
1998	*Low Flows, Groundwater and Wetland Interactions*	Institute of Hydrology, Wallingford, Oxon.
1998	*Hungry Housing* ('thirsty homes')	Council for the Protection of Rural England, London

supply system have been substantial (currently 28 per cent of abstraction and approaching the volumes demanded by the privatised water industry in reservoir developments). Leakage is now a celebrated cause in water supply circles; it has a new significance in that it is often 'powered' by high pressure in the pipes which is in turn the result of fossil-fuel-derived energy: the biggest cost in UK water supply is the energy cost of moving water through pipes.

7.7.1 Demand management and water efficiency

With water allocation the prime policy dilemma of modern times, but with large commercial institutions seeking to sell it, how does the environmental interest compete in this simple market arrangement? One can hardly expect companies to restrict use of their 'product' to reduce sales! With over 40 per cent of abstracted water in England and Wales used to meet domestic demand, the institutional response to water stress has focused heavily on direct human consumption. The demand by irrigated agriculture (largely to spray-irrigate traditional crops like potatoes) is currently only 2 per cent but has doubled since a hike during the drought of 1989.

Demand management/water conservation has been promoted by a variety of bodies, government, private and commercial; some of the latter offer householders an on-line assessment of water-use efficiency in the home (e.g. the major store B&Q). There is now a cross-sector Water Saving Group (WSG) to promote best practice and effective regulation; web-sites include advice on aids such as:

- installing a low-flush or dual-flush toilet;
- switching from baths to showers;
- buying water-efficient appliances like washing machines and dishwashers;
- maintaining plumbing – reducing leakage and waste within the home;
- saving water in the garden.

The Environment Agency's own National Water Demand Management Centre (NWDMC) has been promoting all routes towards savings and collates the latest ideas and outcomes through its *Demand Management Bulletin* (1993–). Progress up to the late 1990s (NWDMC, 1998, 1999) categorises the following for its case study review:

- water-saving devices;
- water management in buildings;
- water recycling and reuse;
- waste minimisation schemes;
- integrated water conservation schemes and education/information schemes.

Whilst government policy proposals for sustainable future housing incorporate codes for potable water consumption (in terms of cubic metres per bedspace per year – ODPM, 2006), the bigger challenge for areas of water stress such as south-east England is to retro-fit devices such as variable- and low-flush toilets and low-flow showers and to install water metering (EA, 2007). The EA concludes from this study that comprehensive installation of all these, with maximum incentives to householders, would be cost-effective. In the longer term there is room for techniques such as using 'grey water' (from baths and basins) to flush toilets, or recycling wastewater to drinking quality and, of course, economic incentives such as *metering*. Metering has often appeared too politically sensitive in the UK, despite the inferences of a water and sewerage charge linked to property value and the fact that only inessential uses are now contributing to the rise in per capita domestic consumption (Dresner and Ekins, 2006). Nevertheless, fears that personal hygiene or 'the poor' will suffer if domestic metering is made compulsory can be assuaged by careful design of the tariffs used. A further advantage is that tariffs can be made to reflect changes in either the economic or the physical climate. Water metering is a voluntary act by the consumer in the UK, except in severe droughts: the government granted the Folkestone and Dover water company 'water scarcity status' in early 2006, allowing it to make domestic metering compulsory. There has, however, been criticism of demand management that simply seeks the most effective instrument rather than exploring the cultural milieux of water supply and consumption (Sharp, 2006); to some extent Sharp is following the pleas made by Ward (1997) for a re-engagement of the water consumer with its supply sources and its cultural significance.

The water service companies in England and Wales have also been the whipping boy for much *point-source pollution*, since the majority of it originates at sewage treatment facilities. These works have been the target of improvement both under the influence of the EU (e.g. the Municipal Wastewater Directive) and through *asset management investments* agreed with the industry's regulators (the EA to drive up standards, Ofwat to keep down consumer prices). Failures to treat sewage to high standards still occur, and heavy fines are imposed by the EA through the courts; they mainly occur through overloads to unimproved works or by the system of storm sewer overflows (discharges direct to rivers of raw sewage during flood-producing rainfall).

These failures apart, the attention of the EA is now firmly on non-point source ('diffuse') pollution, deriving from many points across entire catchment areas, e.g. from agriculture in the case of eutrophication and forestry in the case of acidification (see Chapter 3). In a sense this requires land-use planning, but in practice rural land has never been successfully incorporated by planning law in the UK and it is to urban and suburban issues such as flooding that we now return.

7.8 Integration with land-use planning: flooding leads again

The first seeds of truly integrated management (involving land-use planners) and holistic vision for catchments were already planted at the time of the 1989 Water Act. Thames Water Authority (NRA, then Environment Agency, Thames region, post-1989) began to formalise public consultation in the late 1980s, particularly in connection with flood protection projects. A handbook of their experiences played an influential role at this stage (Gardiner, 1991). *Catchment management planning* had, like the first river basin authorities, been born in the flood protection sector, and it seems likely that this is typical: each national situation will spawn institutional development from within the most hazardous sector of the river basin management portfolio; in some cases more comprehensive and integrated functions follow.

Broadening the agenda for protecting agriculture, industry and communities against flooding has continued unabated (POST, 2001; RGS, 2001). Moves away from simply responding to demand for protection using engineering solutions (albeit confined slightly by cost–benefit considerations) have continued despite the several apparent justifications for retrenchment provided by widespread flooding from 1998 to 2007. The 'Millennium Floods' have attracted particular research attention and are responsible for shifting further the economic and social dimensions of flooding (Howe and White, 2002; Tapsell *et al.*, 2002; Penning-Rowsell and Wilson, 2006). There has been an implicit reduction in aspirations to 'flood prevention', but this has had a knock-on impact in raising aspirations for flood warnings and emergency services/disaster relief. Qualitative significance is again in the terminology now being used: 'Learning to live with rivers' (ICE, 2001; Fleming, 2002) led to 'Making space for water', a cross-government programme, dating from 2004 and heavily based on consultation with 'the flood and coastal erosion risk management community' and consisting of four themes for ongoing projects:

- a holistic approach to managing risk;
- achieving sustainable development (a stronger version is at the core of Scotland's flood policies – Werritty, 2006);
- increasing resilience to flooding;
- funding.

'Making space' is already a theme woven into even the smallest floodplain protection schemes as, for example, flood banks are 'set back' to allow more conveyance volume within the channel and riparian zone (Plates 7.2(a) and 7.2(b)).

Hall *et al.* (2003) describe the new approach in terms of data and information gathering, risk assessment, options appraisal, communicating awareness

Plate 7.2(a) 'Making space for water': reinstatement of a flood bank to protect a recently damaged rural community – higher, stronger, but further from the river: removal of the old flood bank.

Plate 7.2(b) The new flood bank completed.

and with stakeholders and coordinating risk management actions. The science challenge has been partly answered by a *Flood Estimation Handbook* (Centre for Ecology and Hydrology, 1999), although the traditional 'design flood' mentality is to be rethought as part of risk communication and in the light of improved mapping of floodplains (Thompson and Clayton, 2002). A small industry has grown up around those who wish to manage flood risk to *their own property*; property owners and communities have a significant role to play in reducing flood damage (Bramley and Bowker, 2002). The historical trends and institutional challenges represented by the new approach are laid out in Tables 7.6(a) and 7.6(b).

The UK government is keen to match its approach to floods to the (eventual) requirements of the Water Framework Directive for regulating our response to extremes, principally by adopting 'a whole catchment approach'; catchment flood management plans will continue to carry forward the Thames Water theme of the late 1980s, and the crucial relationship with urban development will be strengthened through revised planning guidance. However, as Johnson *et al.* (2007) point out, the aspirations of this holistic explosion of risk management capability have to be judged against the power of the economy to deliver; their point was proven by reactions to the Exchequer's allocations of cash to flood protection following the summer floods of 2007 in lowland England. The insurance industry (whose role is described by Green

Table 7.6(a) Action to protect against flooding in England and Wales post-1945

Belief system	*'Land drainage' 1945–1970s*	*'Flood defence' 1980s–1990s*	*'Flood risk management' 2000–*
Nature of humans	Dominion over nature – land is for human use.	Power over nature (mechanised!) and increasing accountability to use it.	Humans in the ecosystem – working towards Water Framework Directive strictures and budget controls.
Priority of values	Priority on food security within the national economic context.	Economic growth, national security and welfare standards.	Sustainability criteria – economy, society and ecology.
Fundamental policy position	To improve and protect land by river 'training': 'getting the water away'.	To defend people and property from flooding.	Manging flood risk equitably and accountably within sustainable, precautionary principles.
Basic policy mechanism	Investment in an extensive arterial system from drain to sea.	Economic appraisal favours urban schemes in national priority criteria.	Focus on decisions that satisfy social and economic needs whilst maintaining the ecosystem.

Modified from Johnson *et al.* (2005)

Table 7.6(b) Flood risk management in England and Wales – the new extended agenda and its institutional implications

Risk management action	*Effect of action*	*Institutional players*
Development control in floodplains	Limit construction of buildings and infrastructure: controlling vulnerability.	Planning authorities.
Improved flood resistance of buildings	Reduced flood damage.	Property developers and owners.
Increasing awareness/ preparedness	More effective public action to avoid contents damage.	Occupants.
Urban drainage	Reduced probability of flooding.	Water, local and highway authorities.
Flood defence planning, design, construction, operation, maintenance.	Reduced probability of flooding.	EA, local authorities.
Real-time flood forecasting and warning	Reduced flood impact if followed by public.	EA, Met Office, emergency services.
Emergency repair of flood defences	Reduced probability of flooding.	EA, emergency services.
Evacuation of people and property in floods	Reduced public safety and health impacts.	Emergency services.
Post-flood recovery and reconstruction	Reduced social, health and economic impacts of flooding.	Local authorities, insurers.

After Hall *et al.* (2003)

and Penning-Rowsell, 2002) was particularly critical, since an implication of keeping public budgets tight is that private budgets are vulnerable; this balance is a feature of flood risk management in the United States (see Chapter 4). Insurers are particularly keen to achieve a balance of financial risk in those areas of the south and east of England targeted for big increases in housing and general economic growth (National Audit Office, 2001). The planning system is not yet robust enough to prevent many of these properties being built in flood-risk zones, raising the total financial risk by 5 per cent of the national total (ABI, 2005).

The most rapidly adopted form of flood mitigation in the UK, which also doubles as an improver of water quality (and thence conservation and amenity), is sustainable urban drainage systems (SUDS; see also Box 3.5). Developers and the construction industry appear convinced that the installation of, for example, permeable surfaces, infiltration devices, vegetated channels, ponds and wetlands will 'slow the flow' sufficiently to mitigate the higher volumes and velocities of urban runoff, whilst trapping and removing some of its content of pollutants (CIRIA, 2000, 2001). Whilst these manuals focus development in England and Wales, a very large experimental use of SUDS has occurred in Glasgow (79 sites) and Edinburgh (103 sites), and the importance of these is that they are being rationally designed and evaluated, particularly against water quality criteria (Scholz *et al.*, 2005; Scholz, 2006a, 2006b). Early in 2008 Defra declared 'war' on the paving over of gardens to create car parking space, a fashion which collectively has significantly increased the impermeable proportion of most towns and cities. The insurance industry simultaneously announced that many of the houses planned in the growth programme for England would be on floodplains and could not be granted flood insurance.

7.9 The spotlight of sustainable development

There has been an important cascading process from Agenda 21 as an international agreement, particularly to UK local government as Local Agenda 21 (Manchester City Council, 1995; Local Government Management Board, 1998) and to the Thames Region of the former NRA (as 'Thames 21': NRA, 1995). Operationalising the principles of sustainability is a vital aspect of its adoption; we once again encounter the transition between uncertain knowledge and concepts into 'tools'. There has been little change in the academic viewpoint on sustainability (except, maybe, 'sustainable development as freedom' – McDonald, 2006), but we can see evidence of increasing focus on the role of economic values, with economic instruments as an alternative to regulation (traditionally rather naive about its economic consequences). Cashman (2006) complains that 'formal regulation has had a pervasive influence in guiding and overseeing the measures and actions that have been undertaken within the water sector'; he does so from an opinion that it is 'weak sustainability' which is regulated into the system, whereas what is needed is 'the use of economics within sustainability to support adaptive changes'. The UK government has adopted a 'market opportunities, competitive advantage' framework for business in its approach to scenario building for sustainable development. Known as 'Foresight', it explores governance systems covering *enterprise, world markets, global sustainability* and *local stewardship*.

Table 7.5 contained reference to the *Freshwater* document (UK Round Table on Sustainable Development, 1997) which very clearly laid down the sustainability definitions and indicators for all organisations involved in water management (Box 7.5). Responses from government were concentrated in *Directing the Flow* (Defra, 2002b), which picked up the sustainability theme and forged policy links to the implementation of the Water Framework Directive. In 2006, nine bodies formed a coalition to promote a 'Blueprint for Water': WWF, the Anglers' Conservation Association, the Association of Rivers Trusts, the National Trust, the Royal Society for the Protection of Birds, the Salmon and Trout Association, Waterwise, the Wildlife Trusts and the Wildfowl and Wetlands Trust. The Blueprint chooses 2015 (the year in which compliance with the WFD's regulatory targets is binding) for the following steps:

- Waste less water.
- Keep our rivers flowing and wetlands wet.
- Price water fairly.
- Make polluters pay.
- Stop pollutants contaminating our water.
- Keep sewage out of homes and rivers and off beaches.
- Support water-friendly farming.
- Clean up drainage from roads and buildings.
- Restore rivers from source to sea.
- Retain water on floodplains and wetlands.

Box 7.5 The UK government's Sustainability Round Table – specific recommendations on water

The Round Table listed the following indicators of sustainable development relevant to fresh water:

- *Economic:*
  - balance between income, running costs, investment and dividends to shareholders, ensuring the long-term viability of the water industry;
  - leakage per kilometre of mains (pipes) per day;
  - unit costs of abstraction, treatment to potable standard, distribution and treatment of wastewater prior to discharge;
  - number of water meters installed;
  - energy use per unit of water supply.
- *Environmental:*
  - water quality (biological and chemical), with emphasis on nitrate, phosphate and pesticide loadings;
  - number of reported pollution incidents;
  - total sediment and pollutant load delivered to the sea by a river;
  - changes in the extent of wetland habitats and their biodiversity;
  - changes in the patterns of river flow and groundwater fluctuations, including changes in the baseflow index (BFI) and the hydrological sensitivity index (HIS);
  - changes in the water table in cities.
- *Social:*
  - affordability (a measure of the ability of the poorest consumers to pay, which might be the cost of water supply as a percentage of disposable income);

number of disconnections for non-payment;
interruptions to supply (including hosepipe bans and serious reductions in pressure);
drinking water quality (including health warnings about it);
the use of water per capita (including the components of use);
the numbers of people using lakes and rivers for angling and other water-based forms of recreation; contingent valuation techniques may allow this indicator to be expressed in monetary value.

In response, the government's *Directing the Flow* (Defra, 2002b) came back with sustainable development as its priority, including recognising the benefits of water to people, respecting environmental limits, taking full account of environmental impacts in cost–benefit sums, relating water policy to all relevant sectors, regions and social groups, applying 'precautionary' and 'polluter pays' principles and being open and transparent with stakeholders. The report also refers to ensuring the sustainability of the actions of the UK water industry, including its work in other countries. Its plea for 'better policy integration' mentions specifically agriculture and fisheries, biodiversity, tourism and recreation and land-use planning.

The EA laid out its principles for sustainable development early in its life (EA, 1996). However, water supply and sewerage are a regulated private commercial activity, exposed to pressures of sustainable profitability. The privatised water industry (there are currently 23 companies) is proud of its emerging record as possibly the UK's first sustainable sector of industry (Entec, 2006). The number of regulatory fines is now falling and, whilst energy use and leakage continue to cause alarm, the companies' response to climate change, their catchment management (reservoir catchments are often in their ownership) and their approach to demand management are all ahead of expectations. There is now talk of 'water neutrality' and of reducing the 'water footprint' for commercial companies and for all major new developments.

Direct regulation of the physical environment will increasingly be through EU directives (POST, 2006a). Thus, for example, to meet the Habitats Directive requirements at 414 designated sites in England and Wales, water abstraction must be reduced by a total of 250,000 cubic metres per day, but only a few per cent of this reduction will impact on domestic supplies (leakage is currently 12 times this). Regulation which reduces economic growth has no political future! Thus, we return to the *economics* of sustainability, a theme usefully explained by Dresner (2002). Dresner attempts to provide historical, philosophical and practical guidance to the 'ecology–economy' dialectic; he uses the concept of natural capital throughout – its relationship with human-made capital is central to the 'strength' metric for sustainability. Can non-declining natural capital (strong sustainability) be assured through economics? Dresner makes a depressing conclusion that, 'as far as sustainability is concerned, consumerism is a large part of the problem. As far as capitalism is concerned, consumerism is essential' (p. 171).

7.10 River basin institutions and developing nations

As put by Brown and Harper (1999), 'the single most important resource necessary for any development is water, and for sustainable development in regions where there is a scarcity of water, holistic management of the entire hydrological cycle is vital' (p. 4). The detailed sequence of institutional change above is unlikely to apply to most nations experiencing contemporary development of their river basins; it merely indicates the twists and turns of context and knowledge and, frequently, the operation in policy of the 'law of unintended consequences'.

'While much can be learned from institutional arrangements for river basin management in affluent countries, these arrangements do not operate in the same way in the conditions of low-income countries' (Molle, 2003). It may be that 'affluent countries' possess something more than capital wealth. There are systematic problems involved with operating *knowledge-based systems*; if river basins are to be managed successfully there has to be knowledge. Science cannot be stopped from contributing to what it perceives as rational management and so, whatever political debates ensue about the desirable structure of river basin management, its contributions to a holistic understanding continue to accrue (e.g. Nienhuis *et al.*, 1998; Smits *et al.*, 1998; Leuven *et al.*, 2006).

Adams (1992) suggests that river basin planning proved too attractive a model to emerging African governments in the 1960s because of the large-scale, technological and centralised nature of the development it promoted. The use of basin authorities to bypass difficult ministries or traditional laws was common. Adams concludes (p. 127): 'The structures created so far in Africa simply do not warrant [such] hope, demonstrating planning failure on a vast scale.' How can the 'accepted wisdom' and 'sanctioned discourse' of IWRM be rendered accessible and appropriate (if ever it is) to developing nations?

Clearly the view of the Global Water Partnership is via a toolbox, resembling the handbook which comes with a new car or computer. A flavour of the toolbox is presented in Table 7.7.

Clearly, few developing nations have the capacity to 'tool up' and avoid the project cycle and the dependency on external consultants which it normally implies. For this reason Agenda 21 is emphatic that *human resource development* and *capacity building* are central components of the sustainable development paradigm. Brown and Harper (1999) write of an inbuilt naivety, *Table* 7.7 Major headings within the IWRM toolbox developed by the Global Water Partnership

The enabling environment:	
Policies	Preparation of a national water resources policy. Policies with relation to water resources.
Legislation	Water rights. Legislation for water quality. Reform of existing legislation.
Financing and incentive structures	Investment policies. Public sector institutional reform. Role of the private sector. Cost recovery and charging policies. Investment appraisal.
Institutional roles:	
Creating an organisational framework	Forms and functions.
Institutional capacity building	Developing human resources.
Management instruments:	
Water resource assessment	Understanding resources and needs.
Plans for IWRM	Combining development options, resource use and human interaction.
Demand management	Using water more efficiently.
Social change instruments	Encouraging a water-oriented civil society.
Conflict resolution	Managing disputes, ensuring sharing of water.
Regulatory instruments	Allocation and water-use limits.
Economic instruments	Using value and prices for efficiency and equity.
Information management and exchange	Improving knowledge for better water management.

often based upon lack of effective interdisciplinary cooperation, in tackling 'tropical catchments and *people*'. They recommend scale-conscious applications of sustainable development, with, in the case of land and water management, an intermediate level (10^3–10^4 km^2, but interlaced with village participation) for the best results.

The *Comprehensive Assessment of Water Management in Agriculture* (Molden, 2007) includes a list of 'essential elements of sustainable and effective institutions and policies'. It cites:

- publicly available knowledge about resource availability;
- policies establishing allocations, rights, priorities, cost recovery and governance;
- rules, laws and regulations codifying how policies are to be implemented;
- definition of roles and responsibilities for implementation;

- infrastructure to deliver services in terms of the rules and allocations;
- incentives for people to participate and invest;
- capacity to adapt to changing circumstances based on lessons.

It is possible that our (my!) hydrocentric emphasis of the river basin unit is less useful than it seems in terms of initiating institutions for sustainable water management: the Assessment's view is that 'water governance, management and use must be considered comprehensively, within a problem analysis context that looks at "problemsheds" – the boundaries of particular problems as defined by a network of issues – rather than at watersheds' (p. 209).

7.11 Institutions for international river basin management

There are reputedly 263 international basins (Giordano and Wolf, 2002), with Europe leading the continental score with 69, Africa next with 59; Asia has 57, North America 40 and South America 48. They constitute almost a half of the world's land area, generate 60 per cent of the freshwater flow and house 40 per cent of the population.

In the context of 'virtual water', all river basins are international, and the concept is playing its part in opening what might otherwise be construed as the closed system of IWRM/IRBM (Brichieri-Colombi, 2004) despite a continuing debate about its definition and relevance (Allan, 2003; Merrett, 2003a). One might easily fall into complacency when realising that agreements between riparian states outnumber violent disputes by 295 to 37 (Giordano and Wolf, 2002). Logic suggests that diplomacy is the obvious tool to resolve conflict, if necessary within a framework set by international laws. Hydropolitics suggests otherwise, and there has been a brisk market in hydropolitical models. For example, many favour the power-analytic approach of Frey (1993) and its refinement in 'hydro-hegemony' (Zeitoun and Warner, 2005). Frey considers that 'the prospects for consensus on a legal doctrine for international rivers still seem slim' and thus an analysis should incorporate both 'high politics' (national security and foreign policy) and 'low politics' (economic and welfare matters). These categories resolve into 25 issues for profiling in the case of each potential conflict. The use of power has, Frey admits, become disguised via reducing demand (e.g. virtual water trade) but occupies a more central place in 'hydro-hegemony'; whilst still not deploying armaments, powerful nations like Egypt can control the institutional space of the Nile through other, political manoeuvres, such as configuring the issues via knowledge construction.

Once again, we may create counterproductive frustrations by assuming that we require hydrocentric institutions for these major basins, especially since the international law of river basins is weak (Box 7.6) and because *diplomacy* has an enduring role in the allocation and protection of international resources.

The time is right for new approaches to rationalising the basis for 'rivals' in international basins. Like Kliot (Table 7.8), Brichieri-Colombi (2004) also tabulates data for riparian nations, but for the Nile and the Ganges, and using

Box 7.6 The law(s) governing international watercourses: a potted history

International law on watercourses dates back to the Harmon doctrine, which gives riparian states sovereignty over the river in their territory. By 1966 the International Law Association had introduced the Helsinki Rules, which entitled riparians 'to a reasonable and equitable share in the beneficial uses of waters of an international drainage basin'. To this was added, amongst 32 articles of a new proposal, the 'obligation not to cause harm'; this proposal, by the International Law Commission (ILC), a branch of the United Nations General Assembly, is laid out in the introduction to a book on conflict resolution in the international basins of Asia (Chatterji, 2002). The ILC's recommendations were adopted in the 1997 UN Convention on the Law of the Non-Navigational Uses of International Watercourses (adopted by 103 nations).

Kliot (1994) has provided a penetrating analysis of the options and constraints for managing international basins under law. She offers four principles for interaction between riparian nations:

(a) absolute territorial sovereignty (each nation develops the river according to need);
(b) absolute territorial integrity (respect for the needs of the other nations);
(c) common jurisdiction (jointly agreed management via basin agencies);
(d) equitable utilisation (sharing the resources).

Clearly (a) and (b) are extreme positions whilst (c) and (d) are intermediates. Kliot takes the Helsinki Rules and applies them in principle to several of the problem international basins of the Middle East, including the Nile and the Jordan.

The most important Helsinki Rules include:

(a) Equity of distribution is the governing factor among riparians.
(b) Equity does not mean distribution by equal share, but by fair shares, which can be decided by the following factors:
    the topography of the basin, in particular the size of the river's drainage area in each riparian state;
    the climatic conditions affecting the basin in general;

the precedents about past utilisation of the waters of the basin, up to present-day usages;
the economic and social needs of each basin state;
the population factor;
the comparative costs of alternative means of satisfying the economic and social needs of each basin state;
the availability of other water resources to each basin state;
the avoidance of undue waste and unnecessary damage to other riparian states.

Table 7.8 demonstrates the application of the Helsinki Rules to the Jordan. Other authors are less methodical in coming to the conclusion that ‘water wars’ are the inevitable outcome of failure to reach rational accords of the type advocated by the Helsinki Rules (Bullock and Darwish, 1993; Ohlsson, 1995). Allan and Karshenas (1996), writing about the Jordan basin, suggest that the national economies of the riparian states have responded to the challenge of the water deficit in ‘predictably different ways’. Restating their concept of ‘virtual water’, they suggest that nations have the option of the ‘creation of new livelihoods which use water to greater economic effect’. Clearly, two weaknesses are exposed in the Helsinki Rules by this discussion: they are almost entirely based upon water resource considerations and they neglect that flexibility which exists in the deployment of resources.

Table 7.8 The relative ranking of the Jordan basin co-riparians according to the Helsinki and International Law Commission rules

Features	*Lebanon*	*Syria*	*Jordan*	*Israel*
Proportion of basin	4	1	2	3
Runoff contribution	4	1	3	2
Climate	4	2	1	3
Use: past	4	2	1	3
present	3	2	1	1
Life expectancy	1	1	2	3
Infant mortality	3	2	1	4
Per capita GNP	n/a	3	2	1
Total debt	n/a	2	1	2
Population (1990)	4	1	3	2
Annual population growth	4	1	2	3
Cereal imports	4	2	3	1

Source: Kliot (1994)

interval data for 14 economic indicators besides the existing and future needs for water resources. The main point is to demonstrate that, within these basins and given the role of 'virtual water', there is no need for further abstraction. Wichelns (2005) reinforces the role of the 'virtual water metaphor' in suggesting to nations a comparative advantage of switching agricultural and industrial product bases to trade out water insecurity – such has been the experience of Israel and its water-demanding orange export. There is perhaps no reason why environmental services, properly costed, should not also enter the economic analyses of this type.

A new line of reasoning has recently entered the debate about institutions for managing international basins: cooperation (Sadoff and Grey, 2005). This approach does not dispute the conflict model but seeks to promote cooperation as creating a 'regional public good' (Jägerskog *et al.*, 2007) by way of attracting development funding. Sadoff and Grey attempt a general model of the 'continuum for securing and sharing benefits'; it demonstrates the progressive benefits of shifts from unilateral action to coordination and thence to collaboration and eventually joint action. At the two ends of the continuum are dispute and integration, and the authors attempt to cite case studies along it: Indus, Mekong, Rhine, Orange and Senegal. Table 7.9 summarises the basis of this sanguine approach, not surprisingly deriving from the World Bank.

Clearly, however, in cases of unilateral action there remains a need for impact assessment of water resource, hydro-power and other large projects. Transboundary impact assessment (TIA) has become an important tool in gaining development finance, but a recent assessment (Bruch *et al.*, 2007) concludes that TIA consistently underestimates the impact of such projects.

Table 7.9 Benefits of cooperation on international rivers

Type	*Challenge*	*Opportunities*
Increasing benefits *to the river*	Degraded water quality, watersheds, wetlands and biodiversity.	Improved water quality, river flow, soil conservation, biodiversity and overall sustainability.
Increasing benefits *from the river*	Increasing demands for water, sub-optimal water resources management and development.	Improved water resources management for hydro-power, agriculture, extremes, conservation and recreation.
Reducing costs *because of the river*	Tense regional relations and political economy impacts.	Policy shift to cooperation away from dispute/conflict, to food security and away from military expenditure.
Increasing benefits *beyond the river*	Regional fragmentation.	Integration of regional infrastructure, markets and trade.

After Sadoff and Grey (2005)

7.12 Sustainability and subsidiarity – scale-sensitive institutions/organisations which can plan basin development

Paradoxically, as geographical scale increases to the natural drainage basin outline, including sources and users of water, polluters and conservers of the aquatic environment, the challenge of sustainable management and planning grows, as does the seriousness of the outcome, but there are far fewer means of tackling that task. Schramm (1980) concludes that there is a negative relationship between basin size and the scope of work undertaken by planning institutions. It may, therefore, be an essential feature of large basin management to set goals for small areas, e.g. the 'priority watershed approach' in Wisconsin, USA (Konrad *et al.*, 1986), a theme returned to in Chapter 8.

The onerous burden of 'plan-making for sustainability' has recently been highlighted in New Zealand by Eriksen *et al.* (2004); their critique of the regional and local councils' plan-making reveals that a central policy plank of the 1991 Resource Management Act (Chapter 4) has been weak and ineffective in most instances. Incidentally, these authors do not regard the planning work of the Catchment Authorities highly: 'Comprehensive and integrated water and soil planning in the combined catchment/water boards did not progress that well' (p. 78). Nevertheless, it is clear that where local councils make an extra effort, as with the Tasman District Council's resource management plan, integrated catchment management (ICM) can become a focus for sustainable development (Bowden *et al.*, 2004).

Catchment management planning became a centrepiece of river management in the UK in the early 1990s (Slater *et al.*, 1995). Its aims and objectives covered all scales of development in the basin, thanks to the coexistence of a local government planning system which is open to comment by the public and by 'relevant' organisations such as the Environment Agency. In England and Wales, planning has become almost second nature within the tight regulatory framework and broad functional responsibilities of the Environment Agency and its neighbouring agencies. Tables 7.10(a) and 7.10(b) illustrate the plethora of plans at various scales (see also Figure 7.4) which have been developed in advance of the river basin district plans required in future under the Water Framework Directive. However comprehensive or wise or reconcilable between scales these plans become, professional and academic planners frequently alert us to the institutional barriers to 'joined up thinking' between land-and-water and *land development*; planning operates to control the latter in the context of the national economic need (Carter, 2007; Kidd and Shaw, 2007). These institutional boundary problems are even more common in other parts of the European Union (Moss, 2004).

It may not be through the priority interest of the river basin organisation that planning influence is achieved; for example, it was the fisheries and

Table 7.10(a) Strategic planning in England and Wales relating to water

Type of plan	*Bodies involved*	*Purpose*
Local Environment Agency plans (LEAPs)	Environment Agency and many others.	Consultation on environmental improvements for a local area.
Asset management plans (AMP)	Water companies, Ofwat, Environment Agency.	Setting out future water company investment and determining price limits.
Catchment abstraction management strategies (CAMS)	Environment Agency, water companies.	Sustainable use of water resources within a catchment.
Catchment flood management plans	Defra, Environment Agency, consultants.	Rational provision of flood protection; precautionary approach to development/ restoration for floodplains.
Shoreline management plans	MAFF, maritime local authorities, Environment Agency.	Strategic planning for coastal defence.
Coastal zone management plans (CZMP)	Local authorities, Environment Agency, others.	Balancing flood defence needs with other coastal activities.
Estuary management plans (a type of CZMP)	EN/CCW, Environment Agency, others.	Links management of estuaries for conservation with other needs and uses.
Water level management plans	Environment Agency, EN.	Balancing or integrating the water level requirements for a particular inland area.
Habitats Directive – management scheme for European marine sites	EN/CCW, Environment Agency, others.	Management of marine Habitats Directive sites.
Coastal habitat management plans (CHaMPs)	Environment Agency, EN, Defra, DETR, Centre for Coastal and Marine Sciences, others.	Balancing coastal defence needs and conservation objectives at Habitats Directive sites.
Biodiversity action plans (including habitat and species action plans), Local Agenda 21 plans	Many.	Implementing Rio Convention and subsequent UK Biodiversity Action Plan – improving biodiversity.
Plans drawn up as part of local partnership schemes, e.g. for river restoration and catchment 'best practice'	Local communities or pressure groups and activists such as anglers.	Cost-effectiveness under the 'think globally, act locally' aphorism.

Key to acronyms:
CCW: Countryside Council for Wales
Defra: Department for Environment, Food and Rural Affairs
DETR: Department of the Environment, Transport and the Regions
EN: English Nature (now Natural England)
After Foster *et al.* (2000)

Table 7.10(b) Bodies other than the Environment Agency with important roles in the WFD

Area of interest	*Bodies involved*
Land-use planning	Local authorities.
Conservation	English Nature, CCW, Countryside Agency.
Recreation	Countryside Agency, Sports Council, local authorities, British Waterways.
Fisheries	MAFF, Sea Fisheries Commission.
Water resources	Water companies.
Flood defence	MAFF, local authorities, internal drainage boards.
Navigation	British Waterways, local authorities, port authorities.
Agriculture	MAFF, National Farmers' Union.
Forestry	Forestry Commission.

After Foster *et al.* (2000)

conservation interests in the UK that first persuaded the Forestry Commission to plan and manage plantations with stream sensitivity in mind (Forestry Commission, 2003), yet the water losses by interception are more costly but had had no influence. Similarly, the nitrate pollution issue has forced the identification of 'sensitive areas' and 'vulnerable zones' in the UK agricultural landscape; nitrate is of unproven toxicity yet has achieved a policy change impossible to arrange for the more serious issue of land drainage and flood protection.

No government is going to allow a primacy to its water management organisations; they must achieve influence by various means and it appears that 'sensitive areas' and 'best practice' are a good way to publicise the interests of sustainable basin management; they also have a profound educational value. To intervene in land issues is a large political step in any system of government; the intervention is highly determined by the context of the information held about land and the policy framework surrounding land. These matters are worth a chapter on their own (Chapter 8).

Chapter 8

Sustainable river basin management with uncertain knowledge

> Although the river and the hillside . . . do not resemble each other at first sight . . . one may fairly extend the river all over its basin and up to its very divides.
>
> (Davis, 1899)

> To protect your rivers, protect your mountains.
>
> (Attributed to Emperor Yu of China, 1600 BC)

> Catchments are thus unknowable in objective terms.
>
> (Ison *et al.*, 2007)

These quotations serve to re-emphasise the huge appetite for data, information and knowledge inherent in our ambition to coordinate the human exploitation of the resources of any river basin *ecosystem* and to make that exploitation *sustainable*. Our penchant for constructing myths (Chapter 3) illustrates a basic desire for rationality, one denied to us by catchments being inherently 'unknowable'! We might recall the words of the philosopher Bertrand Russell, who remarked that 'Uncertainty . . . must be endured if we wish to live without the support of comforting fairy tales.' As Hillman and Brierley (2002) put it, 'Expectations of certainty are placed on the biophysical sciences because of a widespread public perception that they can provide black-and-white answers' (p. 625). Whatever the expectations, two roles remain central for the biophysical sciences: *policy formulation* and *decision support*, but to perform either demands more than simply 'writing up' research results. Scientific outputs require careful translation into the more or less reliable (in a legal sense) 'tools' of evidence-based public policies. In legal parlance, evidential proof is divided into 'beyond reasonable doubt' and 'on the balance of probabilities'; much of the scientific guidance we have discussed in this book has fallen into the latter category. Our first challenge is to understand the broad societal context into which the science is to be translated: hence the need, once again, to 'have a go' at understanding sustainability.

8.1 A 'watery form of sustainability'

This sub-heading stems from a paper by Cashman (2006) in which he argues that our regulatory system is currently encouraging a weak form of sustainability; the 'strength' of sustainability is a useful political diagnostic. Pearce (1993) suggests that there are three main forms of sustainability: *ultra-weak, weak* and *strong*. Turner (1993) adds *very strong sustainability*, which has a moral dimension of biotic rights – in other words respect for total ecosystem integrity; this is generally assumed to be politically naive and impracticable in the present era. Strong sustainability puts ecosystem *functional* integrity at the core of its policies: 'natural capital' and 'human capital' (what we produce from natural resources) are not seen as interchangeable.

Pezzey (1989) describes 61 definitions of sustainable development, a concept first widely publicised by the World Conservation Strategy (IUCN, 1980) but gaining an international spotlight via the Brundtland Report (WCED, 1987), which defines it as: 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (p. 43). This is the definition which has become most widely remembered and hence used. More suited to our subject matter is a definition by Daniel Loucks (1997), who went on to edit an important book on the topic (Loucks and Gladwell, 1999): 'Sustainable water resource systems are those designed and managed to contribute fully to the objectives of society, now and in the future, while maintaining their ecological, environmental and hydrological integrity' (Loucks, 1997, p. 518). In Loucks and Gladwell (1999), a whole chapter is given over to defining 'watery sustainability', and the panel of experts who wrote under Daniel Loucks's chairmanship concluded that guidelines included:

- developing shared visions of the future;
- developing coordinated approaches;
- maintaining economic vitality alongside environmental quality, biodiversity and health;
- respecting private property rights whilst developing community goals;
- *integrating the best science into decision support* (emphasis added);
- *measuring change* against baselines and monitoring to assess progress;
- being adaptive to change in all variables.

Graphical presentations of sustainability – as a triangle – abound, and a 'watery form' has been presented by Macdonald (2001), whilst Newton (1998) has refined pathways to sustainability for the Environment Agency in England and Wales, drawing attention to two very different political complexions for sustainability (Box 8.1).

Box 8.1 Putting the detail on sustainable development in the water sector: parameters and route maps

Macdonald (2001) has revised for us the ‘sustainability triangle’, perhaps the most popular presentational format for the concept and one which has gained as much use as the verbal ‘Brundtland definition’. It is repeated here as Figure 8.1, and the full labelling is phrased in tabular form (Table 8.1).

Newton (1998) has divided between *reductionist* and *contextualist* routes to reconciling the sides of the triangle. The former has the following landmarks:

- objective information;
- the rational consumer;
- the market and individual choice;
- expert decision making within:
- representative democracy.

The latter is routed through:

- subjective communication;
- the ethical citizen working in new institutions;
- inclusionary decision making within:
- participatory democracy.

The science support to both routes (‘compass’ in the terms of Lee, 1993) is very different, since the reductionist approach requires linear cause–effect models, whereas the contextualist approach requires historically specific, place-sensitive relational models. Newton suggests that the Environment Agency in England and Wales needs to choose a route, or at least be aware that choices exist.

The contribution of scientific knowledge is vital in guiding our decisions in all versions of sustainability but it is particularly critical to our choice of how ‘strong’ we want our policies to be. Nienhuis *et al.* (1998) claim that ‘sustainability is held prison in the triangle “ecology–economy–sociology”, in which strong, ecological sustainability is the victim of weak, economic sustainability’ (p. 364). Functional integrity implies reliable knowledge of *processes*, always more difficult to derive than a simple appreciation of input–output. Sustainability is now often defined in terms of general systems theory, from which we can derive principles of resilience and sensitivity (Clayton and Ratcliffe, 1996).

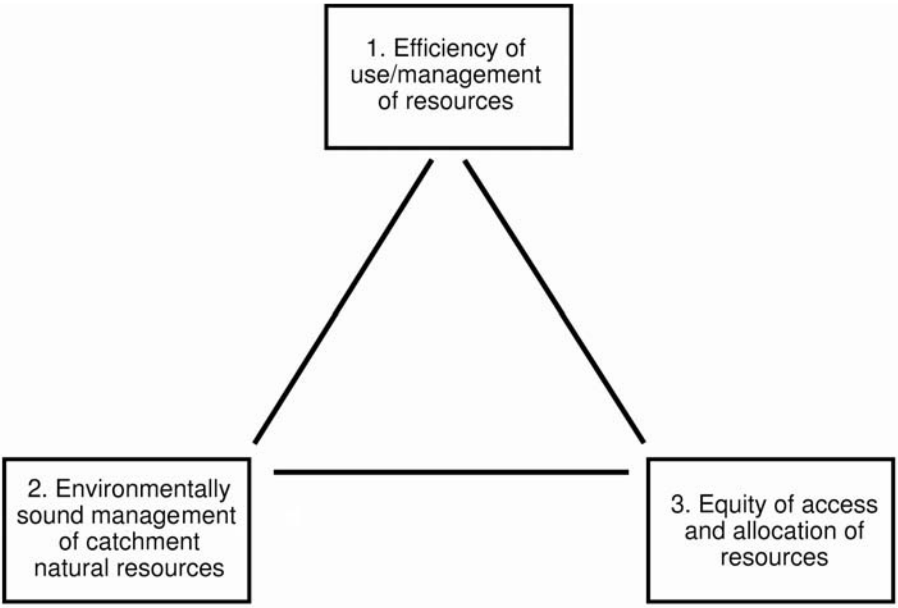


Figure 8.1 The sustainable development triangle for water (after Macdonald, 2001).

Table 8.1 The sustainability triangle for water: defining the axes

Axis	*Labels*
1	Optimum output per unit of water. 'Free' excessively used water for social and environmental objectives. Postpone period for exploitation of additional sources. Reduce pressure on scarce budgetary resources.
2	Define environmental requirements: 'definition of the environmental reserve'. Recognise instream functions as part of sustainable water resources management. Water quality crucial to avoid environmental degradation. Conservation of natural capital. Safeguards livelihood for large segment of population.
3	Define human need for water. Recognise that basic human need is prime social objective. Health benefits. Social justice and stability. Pre-condition for development and care for next generation.

After Macdonald (2001)

8.2 Science in the 'New Environmental Age' and the 'Risk Society'

The 'New Environmental Age' refers to that period of the late twentieth century when environmental crises began to receive media coverage and governments began to treat them at ministerial level (Nicholson, 1987); the 'Risk Society' (Beck, 1992; Mythen, 2004) is a much broader and more significant socio-political assessment of how the engine room of society treats all issues, with environment being included because of its major contribution to *manufactured risks*. The major aspects of relevance to our theme are summarised in Table 8.2.

The burden of this chapter is to explore the appropriateness of the knowledge base available to guide the conjunctive use of the land and water resources of large basins but, before this exploration, we need to address more general problems of the nature of *environmental sciences* and how they interact with the *institutions and organisations* whose critical role is now understood (i.e. from Chapter 7).

8.2.1 Science and the environment

A quotation from the IPCC (Mertz *et al.*, 2001) serves well to introduce an important dilemma:

> There are many uncertainties regarding the magnitude of future climate change, its consequences and the costs, benefits and implementation barriers of possible solutions. The impacts of climate change on ecosystems and humanity are *known with limited certainty*. The potential for an unspecified, low probability, but catastrophic turn of events haunts the problem.
>
> (Mertz *et al.*, 2001, p. 608, emphasis added)

Environmental sciences have fallen into the popular and political images built for the laboratory sciences. The short history of the environmental sciences has, however, shown them to be markedly different:

(a) They have tended to sound alarms about technology and economic development.
(b) Their results have been contentious, and public debate occurs between scientists with opposing results or interpretation.
(c) Environmental sciences lack the methodological rigour of the established sciences, being forced often into extensive modes of inquiry, and uncontrolled or at best statistically validated frameworks.
(d) Environmental science is willing to form alliances with 'vernacular science' or 'indigenous knowledge' systems.

Table 8.2 The Risk Society – a simple guide for watershed managers

Topic	*Interpretation*
'Towards a new modernity'	Beck's sub-title – provides the historical trajectory of risk: 'modernity' begins with the Industrial Revolution, and man-made risks begin to overtake natural disasters. The 'new modernity' refers to 'manufactured risks' deriving from globalised capitalism. These include, for example, SARS, BSE, CJD.
Societal dimensions	Choice, individualism and liberal democracy, but everywhere new constraints imposed by risk aversion.
Political repercussions	Dealing with uncertainty involves negotiating change. Science is placed in a new position of responsibility but increasing scrutiny; governance shifts emphasis to incorporate rival paradigmatic views of risk in an uncertain world. Technical experts attempt to put boundaries to risk discourses.
Geographical implications	There are no spatial or temporal limits – the local merges with the global (also has political, governance and institutional impacts) and the personal becomes the political.
Public participation	The public must demystify scientific output to argue back, and 'popular' decisions are made with openness, e.g. 'citizens' jury'.
Catchphrases	The logic of goods has become the logic of bads; social production of wealth has become social production of risks.

Compiled from Beck (1992) and Mythen (2004)

International civil society has become much more aware of the science–uncertainty–institutions–governance nexus through the problem of anthropogenic climate change (Chapter 6). It is the IPCC's view that the natural science approach to climate change renders its 'solutions' value-free and insensitive to the human dimension:

> In contrast, the human-centred sustainable development approach to environmental problems is more politically and geographically sensitive, but it is analytically vague. Sustainable development has not yet been able to translate its ideals into concrete objectives for problem solving and decision making.
>
> (Mertz *et al.*, 2001, p. 648)

'Analytically vague' is unfair, particularly because 'concrete objectives' is a phrase redolent of a military operation; even they are disastrous when not continually updated and vital information confirmed as events unfold! However, it must be admitted that the decision support offered in IWRM/IRBD is seldom designed to mitigate such a severe peril as climate change, nor responsible for harsh decisions to avoid 'runaway' change with global consequences.

8.2.2 Science and the 'Risk Society': the 'tools' obsession

Society increasingly attempts to cope with 'manufactured risks' by a tightening regulatory framework. The *regulatory machine* that has been relied on in most nation states, in the absence of a widespread consensus on *economic instruments*, to control pollution, promote conservation/restoration and govern the introduction of sustainable practices is heavily dependent on *scientific 'tools'*. Kondolf and Piégay (2003b) include in the category 'tools' concepts, theories, methods and techniques. However, to the 'mechanic' (operational environmental manager, rather than strategic planner) 'tools' are often configured as 'silver bullets' by which environmental regulation can be coerced, monitored for compliance and prosecuted for neglect or breach. Newson (in press) describes much of the operational business of sustainable river management as suspended between 'mantra', 'metric' and 'mania': Table 8.3 defines these terms (loosely) and indicates their regulatory significance. Without a legally defensible metric, the best influence of the mantra and the best efforts of the mania cannot make regulation succeed; if metrics are abused or fail, the concept behind them becomes distrusted by politicians and may be abandoned. Such may be the fate of some of the higher scientific ideals of the EU Water Framework Directive.

Table 8.3 The 3 Ms of regulatory system science, both command-and-control and incentive-based

3 Ms	*Distinguishing features*	*Regulatory impacts*
Mantra	Conceptual drivers from physical science and, increasingly, social science: often phrased as precautionary advice or evidence for best practice. Can go unchallenged in detail, as in 'geodiversity bespeaks biodiversity' and model outputs.	Regulators often informed by their own science professionals; innovation a public responsibility, especially if it reduces apparent risk. Regulators may challenge details and seek metrics lest 'the exception breaks the rule'.
Metric	Tools such as standards, legal limits, targets, improved instrumentation for compliance. Economics tools to set incentives.	Becomes associated with the mantra, especially by those regulated; poor tools can be legally challenged or circumvented.
Mania	Legacy of 'Think globally, act locally'. Now becomes vision: 'rivers of dreams' – the enthusiastic, organised and informed (but informal) sector often enshrined in traditional practices but a feature of, for example, fisheries management or river restoration by volunteers.	Cash-strapped institutions find partnerships needed to finance environmental improvement; community projects save on incentives and internalise risks by enthusiastically accepting ongoing responsibility. Regulatory metrics may be used sympathetically to promote local schemes.

After Newson (in press)

Emergency programmes of research and development (R&D) are set up to produce ‘the tools’. For example, dam removal has begun to gain ground as part of river restoration but also as part of the regulatory approach to dam safety. Graf (2002) illustrates an absence of appropriate ‘tools’ for predicting impacts and hence determining procedures: ‘Science does not provide the answers for problems that managers face, but it can provide estimates for the outcomes of the range of decisions that might be contemplated’ (p. 16). He goes on to say:

> To play an effective role in dam removal, science and its practitioners must be flexible. In applying adaptive management, decision makers choose a course of action and design it so that information is collected, results are monitored, and then adjustments are made accordingly to ultimately reach specific collective goals. *Adaptive science* must identify significant questions, seek to answer them, and then, in the light of that experience, redefine the questions in consultation with managers.
>
> (Graf, 2002, p. 19, emphasis in original)

Civic science (Lee, 1993) is an avowedly more ‘public in the way responsibilities are exercised’ yet also technical and open to learning by doing.

8.3 Uncertain ‘science speaks to power’

Mike Hulme, prominent UK climate change researcher, has written for newspaper readers, ‘The danger of a normal reading of science is that it assumes science can first find truth, then speak truth to power, and that truth-based policy will then follow’ (*Guardian*, 14 March 2007). He concludes by writing:

> What matters about climate change is not whether we can predict the future with some desired level of certainty and accuracy; it is whether we have sufficient foresight, supported by wisdom, to allow our perspective about the future, and our responsibility for it, to be altered.

It may seem discomforting to see the word ‘wisdom’ used by a scientist, but it pops up with reasonable frequency in, for example, deliberations about how the catchment management agencies should implement the Water Act in South Africa. It takes its place beyond ‘data’, ‘information’ and ‘knowledge’ along a bivariate plot linking systems understanding to societal implications. More simply, as defined by the late Miles Kington, ‘Knowledge is recognizing a tomato is a fruit; wisdom is not putting it in fruit salad.’

Collingridge and Reeve (1986) expressed early reservations about the role of science in relation to policy, rather than as a servant to technology. In a study which gives its title to this section, they unpick what they call ‘the myth of the power of science’ in relation to policy making, i.e. that ‘whatever information is needed to reduce uncertainty in making a particular policy choice, science can meet the challenge' (p. 2). They conclude that 'Contrary to the myth of the power of science there is a fundamental and profound mis-match between the needs of policy and the requirements for efficient research within science which forbids science any real influence on decision-making' (p. 5).

Policy making therefore becomes *incremental* rather than *fundamental*, and this aspect of the political filtering of research results is poorly appreciated by scientists, including the present author. Three years after the acceptance of a paper on the hydrological impacts of afforestation in the UK by Calder and Newson (1979) by the hydrological community, the Secretary of State for the Environment in the UK government made the following statement in Parliament: 'As regards afforestation, its percentage and its effect on catchment areas . . . I am advised there is a lack of clear scientific evidence' (*Hansard*, 21 March 1980). In later papers (Newson, 1990, 1991, 1992b), therefore, the author tried to put the knowledge base of hydrology into a policy context. These papers illustrated a slow but measurable policy readjustment to the original scientific research. By 2002 the UK government itself was promoting and accepting research (Calder *et al.*, 2002) which suggested negative impacts of lowland afforestation on both water quantity and water quality (see also Box 8.4).

The German *Vorsorgeprinzip* (precautionary principle) may be defined as taking integrated steps to protect the environment from degradation about whose precise operation and impact there is still scientific uncertainty. The Germans were coping with the death of forests, attributed to 'acid rain' and decided on action to reduce risks 'before the full "proof" of harm that could be serious or irreversible' (Harremoës *et al.*, 2002). Thus, land-use planning in river basins can be seen as precautionary, maintaining both quantity and quality of river flows and constituting a 'least regrets' positions in relation to the effects of, for example, predicted increases in hydrological extremes and other impacts of climatic change. Harremoës *et al.* (2002) also write of the *ignorance* in much research output (Table 8.4). There are other dimensions, too, such as complexity, indeterminacy, ambiguity and disagreement. Ignorance is, however, the source of 'inevitable surprises, or unpredicted effects' (p. 187). This is of particular significance to regulators: 'By their nature, complex, cumulative, synergistic or indirect effects in particular have traditionally been inadequately addressed in regulatory appraisal' (p. 187).

If, as in the case of IRBM, scientists wish to become involved in developing and expediting public policy, it is vital that they lose a characteristic naivety. Pielke (2006) discusses the motives which bring some scientists to 'politicize science' rather than to seek to extend the scope of decisions available to policy makers. That hydrologists are willing to do the latter is considered in detail by Schulze *et al.* (2004), who list the roles they play in implementing the 1998 Water Act in South Africa:

- 'honest broker' in institutional turf wars;

Table 8.4 Risk, uncertainty and ignorance: principal components of the dilemma in public policy and management

Situation	*State of knowledge*	*Actions/process*
Risk	'Known' impacts with 'known' probabilities.	Further investigations and actions to reduce risks (but also judgements over definition, acceptability).
Uncertainty	'Known' impacts but 'unknown' probabilities.	Precautionary prevention such as action to reduce exposure to hazards.
Ignorance	'Unknown' impacts and therefore 'unknown' probabilities.	Action taken to anticipate, identify and reduce the impact of 'surprises'. Use of the broadest possible sources of information, including long-term monitoring. 'Healthy humility' and 'open reflection' over the sufficiency of available science.

Modified from Harremoës *et al.* (2002)

- information provider;
- model developer for IWRM;
- local interpreter of processes;
- facilitator and communicator between stakeholder and policy maker;
- capacity builder.

Scientists can choose to become embedded in a water development application, a decision requiring a huge commitment of time, resources and support from their employers. However, this is perhaps the only way in which 'speaking to power' can be avoided. Whatever the relationship between the scientist and the river management problem, the accepted modern role for evidence is a supportive one: *decision support* frameworks, models and acronyms abound. Some river basin specialists have become actively involved in decision support tools, for example Clark and Richards (2002), who convert the uncertain predictions of a 'Delphi' panel of experts into options for addressing river bank erosion.

8.4 Uncertain science and land–water management: the early evidence and the 'catchment era'

The origin of the modern phase of 'catchment consciousness' is reputed by many writers to have been 'the Alpine Torrents' controversy (Glacken, 1956) of the nineteenth century in Europe. In 1797 a French engineer (Fabre) linked the sequence of damaging floods from rivers draining the Alps to deforestation of the headwaters. Fabre's work produced a series of studies in France which eventually evoked a policy response from the French government. It introduced a project of *reboisement* (reafforestation) during the nineteenth century (1860 and 1882). Alexander von Humboldt pronounced on the causative link between catchment mismanagement and environmental stress: ‘by felling the trees which cover the tops and sides of mountains, men in every climate prepare at once two calamities for future generations: want of fuel and scarcity of water’ (von Humboldt, 1852, quoted in Kittredge, [1948] 1973, p. 9).

A further profound influence at about this time was the landmark volume, *Man and Nature: Or Physical Geography as Modified by Human Action* by George Perkins Marsh ([1864] 1965). Marsh focused much of his factual reporting of deforestation on the Alpine zone of Europe, linking deforestation with both flood and drought; in places his observational data and bibliographic enquiries appear to yield contradictory evidence on the precise hydrological effects of a forest cover but concluded overwhelmingly that they were beneficial.

The Swiss established a paired catchment study in 1900 to investigate the effect of forest cover on runoff. They concluded there were almost entirely beneficial effects of tree cover – balancing the extremes of flow and attracting precipitation. The results were reported in the USA by Zon (1912), two years after the establishment of the Wagon Wheel Gap paired catchment experiment: ‘Accurate observations . . . *established with certainty* . . . [f]orests increase both the abundance and frequency of local precipitation over the areas they occupy’ (quoted by Kittredge, [1948] 1973, emphasis added).

Quantitative ‘evidence’ for policy making became more widespread after the systematic hydrological monitoring of a wide range of land uses in a wide range of climatic and physiographic conditions began during the International Hydrological Decade (1965–74). The Decade established a key distinction for scientists researching options in river basin management: between *representative* and *experimental* basins; the former seeks to represent the climate, geology or land use of the region of interest, and the latter involves a deliberate land-use change. Box 8.2 returns to important UK research areas to demonstrate these differences and the importance of relating hydrological impacts to a crop cycle, natural or managed.

The research and experimental basin network in the UK, designed to research the impacts of urbanisation, field drainage, fertiliser use and acidification as well as afforestation, typifies the era of such empiricism under relaxed conditions of funding and with no policy deadlines set for ‘the evidence’, there being no policy shell awaiting its incorporation (see Section 8.5.1). Catchment research was, however, criticised for its apparent lack of robust procedures: Burt and Walling (1984) claiming that ‘protracted attachment to the methodological directive “Go ye forth and measure” may well prove an invitation to waste time’ (p. 7).

Catchment research could hardly avoid a plethora of small-scale case studies, but by gaining in experimental control it too often encountered problems

Box 8.2 Catchment research in the UK to identify the impacts of commercial plantation forestry: a brief summary

Frank Law's (1956) astonishing revelation about the 'extra' evaporation from plantation conifers, compared to semi-natural moorland vegetation in the UK uplands, led to calls for an expansion of government research in hydrology; it was also supported more purposefully in universities, particularly in geography, where the fieldwork tradition supported enthusiastic empiricism. A 'rash' of catchment studies broke out in the UK, particularly in the *uplands*, in the late 1960s and early 1970s, with further extensions into the 1980s. We focus on three here: Plynlimon (Central Wales), Coalburn (North Pennines) and Balquhidder (Perthshire, Scotland). The size of these catchments varies from 10.55 square kilometres (the Wye at Plynlimon) to 1.5 square kilometres (Coalburn).

Plynlimon began as a tandem catchment study, representative of mature coniferous plantation forest (the Severn catchment) and open rough pasture/moorland (the Wye catchment). In recent years the Severn catchment has become experimental with controlled felling in two sub-catchments. By the late 1970s it was clear that evaporative losses from the forested Severn were double those from the Wye. Other aspects of hydrological regime, floods and droughts, were more difficult to separate; this was mainly a water balance discrepancy attributable to the *interception* process.

At Coalburn, experimental catchment status obtained from the start, as an open, peaty moorland was *ploughed, drained and planted* with conifers in the early 1970s; monitoring has been continuous since, and the catchment is shortly due for felling. Coalburn filled in what Plynlimon had been unable to decipher: the impact of various stages of the crop cycle and of various forms of management. Coalburn has proved that forestry cannot, in hydrological terms, be considered simply as a land cover, because its impacts on runoff and evaporation vary between the phases of ground preparation, crop establishment, and maturity (closure of the canopy); Plynlimon added the role of an ageing plantation (less evaporation) and the recovery of water yields after felling, a fact confirmed at Balquhidder.

Balquhidder added yet more dimensions. Another tandem representative basin study to begin with, here again the forested catchment has been partly harvested. However, Balquhidder's main role has been to illuminate the contrast between plantation forestry and *heather*-dominated (short scrub) moorland under conditions of reliable, deep winter *snow* cover and a *die-back* (no transpiration) in grasses at high altitude. The surprise initial findings were that the 'control' ('moorland') catchment yielded less runoff than its forested neighbour. Process studies which followed proved *inter alia* that a sheltered forest canopy evaporates less than one which is well ventilated, heather intercepts and evaporates. Additionally, the forested catchment had more deep drift deposits from which low flow yields were reasonably high.

Thus, paired catchment studies can produce misleading results without a full dissection of their relevant processes and small-scale geographical characteristics; this makes good catchment research expensive. The facts that crop hydrological impacts *vary with time* and that some (such as ploughing and drainage of blanket peat) are long-lasting mean that a commitment must be made to monitoring for decades (UK upland tree crops are harvested at between 40 and 70 years of age; one can add a decade for pre-calibration and another decade for recovery from harvesting).

The small size of the representative and experimental areas means that the impacts may be regarded as very localised in the headwaters and in fact may be so, but without scaling-up studies such as that by Archer (2003) we will remain in ignorance about the downstream decay of headwater impacts (see also Chapter 3). Despite considerable improvements to the sophistication of the 'routine' hydrometric network in most countries, its data are seldom used for research even though river managers could look for at least vindication of an effect first isolated by researchers. The research catchment is still the more likely venue for a true experiment, i.e. manipulation of a control such as land use, and has increasing value as a monitoring device as the duration of its records grows and circumstances in policy (and now climate) change.

of relevance. Yet science wanted the scale even smaller! Reynolds and Leyton (1967) were very clear: 'Watershed experiments cannot provide understanding of the physical processes, for which plot studies must be conducted' (quoted by Ward, 1971, p. 131). Reynolds and Leyton do not specify the location for plot studies but clearly there is much to be gained from a *nested* approach to scales of study (plots within catchments); this hierarchical approach was to be central to the UK Institute of Hydrology's (now Centre for Ecology and Hydrology) Plynlimon research catchments (Kirby *et al.*, 1992) and to the later LOCAR and CHASM programmes.

8.5 Uncertain science and land–water management: where now?

This review is heavily dominated by *forest* impacts but perhaps this is inevitable; in Chapter 3 we gathered that forest hydrology is dogged by myths of universal impacts. Catchment research is gradually taking on a much more extensive role, for several reasons: environmental contexts vitally determine land-use impacts (Chapter 3), international cooperation is seen as vital as regulatory systems become coordinated, and lastly our intensive study of processes (e.g. within research and experimental basins) has been deemed less important by a financially strapped scientific establishment. Many of our original research basins are no longer monitored, but new ones have developed as part of, for example, the Euromediterranean Network or via EurAqua.

We have now moved to an era dominated by the analytical or mathematical model (see Box 8.3). Yet, it is claimed, these models are too seldom questioned, 'get off' on their own elegance, are opaque to stakeholders relying on their predictions and fail to directly address 'wicked problems' in their many dimensions (Pilkey and Pilkey-Jarvis, 2007). These authors specifically address modelling in environmental science (including changing sea level and fisheries) but do not include land-use hydrology in the firing line.

In many cases large measures of ignorance affect the confidence any audience can put in catchment-scale models of runoff and water quality. Hydrologists may assume 'that the dominant processes are understood and that catchments, rivers and estuaries are equilibrium systems' (Harris and Heathwaite, 2005) but this can be disproven with intensive monitoring. To extend sufficient intensity of monitoring to gain knowledge and improve prediction requires deployment of innovative technologies: regulation of, for example, diffuse pollution sources can thus reduce its uncertainty and make metrics more robust.

Box 8.3 Hydrological models: an alternative to catchment research or means to extrapolate its findings?

Beven (2001) provides a primer in hydrological modelling which he introduces by listing the five main steps: perceptual (selection of processes to model), conceptual (how to represent them mathematically), procedural (coding for the computer), calibration (comparing with real records) and validation (putting it to predictive test).

In mathematical hydrological models of whole catchments, the traditional incorporation of a land-use effect is via a tank concept, one which has also proved useful as a hardware model for educational purposes (Figure 8.2). The parameters of such a model therefore scale the size of the storages in the hydrological cascade from canopy to channel and the catchment is simply seen as a 'lumped' system of these tanks (Blackie and Eeles, 1985). The interception store is particularly amenable to this treatment, but overall there is, of course, the need to *fit the model* to an actual flow record so as to set the parameters.

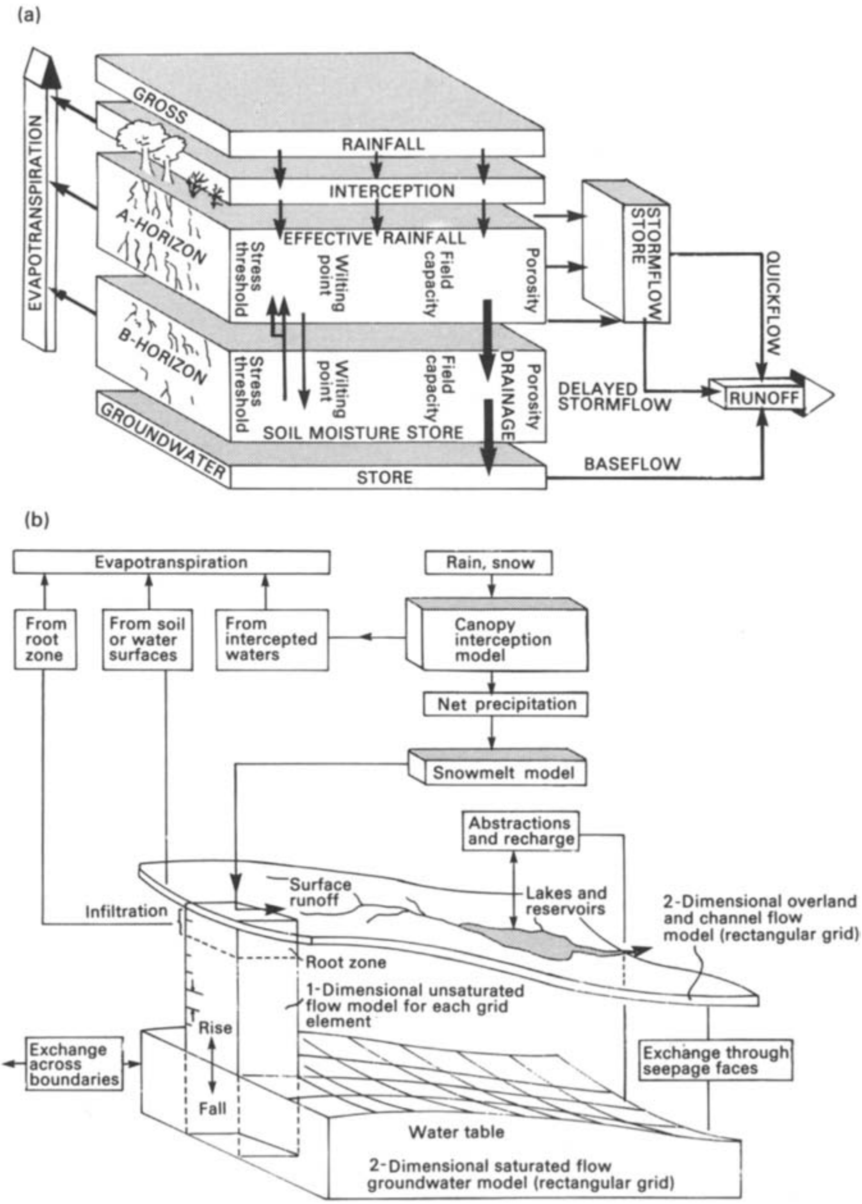


Figure 8.2 Deterministic hydrological models, (a) lumped and (b) distributed: an alternative to catchment research?

By contrast, distributed models are more frequently physically based (Beven, 1985); their parameters are the variables determining the operation of process equations which determine the routeing of rainfall to runoff. Distributed models are therefore useful to land-use hydrology and particularly to catchment experiments because they incorporate a detailed knowledge of actual catchment behaviour and can operate in data-sparse environments and on land-use impacts whose main interest may be in their spatial organisation: seldom will afforestation, or urbanisation, be the 'lumped phenomenon' predicted by 'lumped' models. Beven (2001) remarks that lumped models have much to offer the study of land-use change, being 'parametrically simpler'.

8.5.1 Translating the evidence from land-use hydrology into policy frameworks

We have no opportunity to investigate the translation into the nineteenth-century French policy of *reboisement* (reafforestation) of the observations by many of changes in the flow of Alpine rivers. Kittredge ([1948] 1973) lists the many books and papers published in Europe prior to the policy decision. However, the telling work, according to Kittredge, was not by an environmentalist but by the engineer Surell, who in 1841 published a book confirming the observations of his predecessor Fabre (see Glacken, 1956). We may therefore conclude that almost half a century of influential, official persuasion was necessary before policies relating to land were changed. It is also important to note that the agent of that change was the French government's Forest Department; Kittredge refers to the department as being given 'the mission of controlling the torrents'. It is interesting to note that in neighbouring nations with a problem of flood-prone Alpine rivers the approach to control was more direct and structural (Vischer, 1989).

The gauntlet of responsibility for managing land in relation to the aims of flow regulation passed quickly to the USA, where the 1902 *Forest Reserve Manual* listed the aims of forest reserves as 'to furnish timber' but also 'to regulate the flow of water'. The Wagon Wheel Gap catchment studies in Colorado did not begin until 1909, so this indicates a simple acceptance on faith of the European conclusion. The Weeks Law of 1911 provided the crucial right to acquire land for afforestation 'for the protection of the watershed of navigable streams' and to 'appoint a commission for the acquisition of lands for the purpose of conserving the navigability of navigable rivers' (Kittredge, [1948] 1973, p. 13).

What became more perplexing to the decision maker towards the end of the twentieth century and after the Millennium is the paradoxical appearance of some of the scientific guidance from land-use hydrology. For example, 'forests' can both exacerbate flooding and temper it: scientifically perfectly understandable but no fodder to the sanctioned discourse of politics. The archetypal politician might demand 'a simple answer'; the scientist cannot and should not oblige, whereupon the politician pronounces 'insufficient evidence'. O'Riordan (1976) suggests that 'Where problems pose solutions which challenge the dominant values and rules of political consensus, substantial power may be directed simply at keeping this challenge out of the political arena.' O'Riordan finds society's fears of rationality predictable; as a direct result, 'policy making is basically a political process'. At a later stage one can detect that society 'feels a policy coming on'.

We return to the particular case of policies incorporating precautionary hydrological evidence in the UK in Section 8.6, but it is first useful to look at the current top agenda item in seeking policy guidance from hydrologists, geomorphologists and ecologists: the Water Framework Directive.

8.5.2 Equipping the Water Framework Directive with appropriate evidence-based tools

The prime current example of the dilemmas described here currently lies with implementation of the EU Water Framework Directive: 'one of the most complex challenges that scientific and policy-making communities are facing', according to Quevauviller *et al.* (2005). The European Commission therefore initiated a common implementation strategy (CIS) for the WFD in order to share experiences and best practice, avoid duplication and limit the risk of bad application (regulation); a pilot river basins network was drawn up, and some of the data gathered are discussed below.

The task of implementation places a huge burden on individual nations to interrogate freshwater science for the best evidence and select available and potential 'tools'. All this was required in advance of knowing a precise definition of good ecological status, the central metric for compliance of all EU waters. By 2006 the UK Technical Advisory Group (TAG) for implementing the WFD was able to review, for public consultation:

- biological elements: aquatic flora, phytoplankton, benthic invertebrates, fish;
- hydromorphological elements: flow, residence time (lakes), connection to groundwater, currents/waves (coasts), depth and width variations, substrate, structure of riparian/shore/intertidal zone;
- physico-chemical elements: transparency, thermal conditions, dissolved oxygen, salinity, acidification, nutrients, specific pollutants.

There are thus very profound issues of the strength of the scientific evidence and the configuration of the resulting regulatory tools. The legal salvation may be, however, the monitoring programmes designed to accompany the first-round definitions, typologies and boundaries; in an iterative policy there is always room for (agreed) improvements, and in this way the WFD may sow some seeds of adaptive management (see Chapter 9).

8.6 Implementation: land-use controls in river basins – the case of UK forestry and farming

To develop an influential position with regard to land-use planning, those concerned with river basin management have a tough problem. It may be styled as a series of gaps between knowledge and applications (Figure 8.3). Since most research is done on small research catchments, the prediction gap is that between such small entities and the larger areas for which practical measures are needed. To be prescriptive, however, a wide range of these larger units must be addressed – the extrapolative technique must therefore have comprehensive scope and the models must be robust. Finally, a policy gap may exist between the boundaries of those agencies (e.g. local councils in the UK) with land-use planning powers and the outline of the river basin unit.

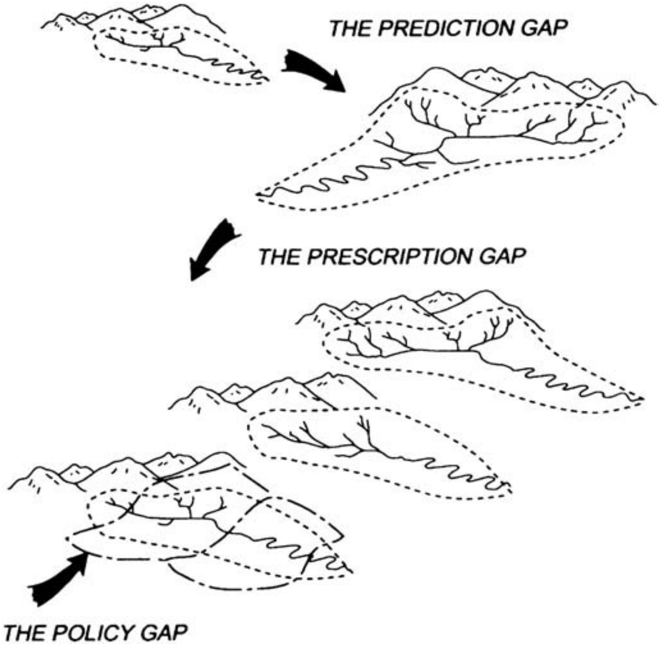


Figure 8.3 Gaps which threaten the application of catchment research to catchment management planning.

There are two essential prerequisites of policy information before investigating the uptake of hydrological guidance in land use and land management in Britain:

(a) Rural land-use policy is not achieved directly but by market interventions for produce or incentives offered by the EU Common Agricultural Policy.
(b) Outside towns there is little land-use planning, exceptions being national parks and land for nature conservation.

Thus, until the arrival of the Water Framework Directive and its river basin district plans, UK river managers could not turn precautionary hydrological evidence to promote land-use controls unless the government forestry and agriculture agencies were prepared to take action (mainly fiscal action via grant control) or the planning process for towns incorporated similar evidence. Movement has evolved rapidly on both fronts, and both the NRA's catchment management plans and the Environment Agency's LEAPs were able to use indicative preferences for precautionary land use in many catchments, particularly in headwaters (see also Newson, 1988, 1990).

For at least 40 years the water industry gave a cautious welcome to conifer plantations on catchment areas. Newson (1986) reviews the history of attitudes within the water industry and how research results, principally those of Law (1956), eventually impinged on decision making (see also Box 8.4). In the last 20 years, however, legislative support for land-use control in the UK has grown, principally in other contexts (e.g. to reduce nitrate pollution from agriculture). It is now possible to consider protection zones and environmental quality standards (for certain pollutants). In addition, and in contrast, voluntary guidelines for foresters have been published to reduce conflict. These standards (Forestry Commission, 1988, 1991, 1993, 2003) are used directly by the industry. They are also likely to be used by forest developers facing the new legal requirement in the UK for an environmental assessment on new plantations larger than 200 hectares.

Box 8.4 A short history of the controversial acceptance of hydrological guidance on the impacts of commercial upland plantation forestry in the UK

Prefacing the 'era of trees on catchments', the Gathering Grounds Committee (Ministry of Health, 1948) decided that whilst trees did not attract rainfall they did protect upland reservoir catchments against erosion. The Committee reached this conclusion on the basis of a trawl of the qualitative opinions of experts, much of the information coming from abroad. Much of it was inappropriate, but several well-known reservoirs became surrounded by conifers in an effort to blanket them off from human and livestock influences.

Law's (1956) results, which 'proved' that trees 'use' more water than rough moorland, did not lead to a change of policy but to an intensification of research (see Box 8.2). Indeed, there was no public policy to change, catchment area land use being mainly decided by individual water suppliers who desired to own whole catchment areas in order to prevent public access and agricultural improvement. In 1979 the results of the important Plynlimon (mid-Wales) catchment experiments were published, confirming and extending Law's adverse conclusions about the *reduction of water yields* when the uplands are covered by mature conifer plantations (Calder and Newson, 1979). In the late 1970s the outlook for timber production (Forestry Commission, 1979) suggested that Scotland would bear the brunt of new planting. Already the Scottish local councils and hydro-electric boards were identifying local hydrological problems in connection with afforestation. By the 1980s the water quality dimension was becoming much more important to water industry perceptions of land use and land management as *acidification* and *eutrophication* were identified within forested catchments (see Youngman and Lack, 1981 and Chapter 3). Issues not strictly related to water supply, such as fisheries, also began to surface (Harriman, 1978), and none of these research results was favourable to forestry, partly through the pervasive role of acidification.

Acidification launched the political process by which upland afforestation became affected by policies of *allocation* and *accommodation*. In terms of allocation, the UK government virtually abandoned further upland afforestation subsidies in England and Wales, especially in areas where 'critical loads' of acid deposition are exceeded. Later, the issues of reduced water resources 'headroom' and eutrophication of groundwater extended this policy to lowland forests. Meanwhile an accommodation of interests between upland foresters and water suppliers was successfully attempted through the best practice advice contained in the *Forests and Water Guidelines* volumes, four of which appeared between 1988 and 2003. These act as a blueprint and, if followed, a legal protection for forestry management in relation to streams throughout the crop cycle.

Into the twenty-first century, the drive to 'reafforest' Britain is more muted and coordinated with other land-use policies; there has been a switch to the lowlands as the focal point for 'community forests' rather than commercial timber production and 'wood security'.

There have been two major routes to policy implementation:

(a) The *allocation* option, whereby a 'keep-off' attitude to catchment areas may be followed by the water industry, armed with maps of sensitive areas. A refinement of this approach might be to plan catchment land use rationally on the basis of land capability assessments and hydrological predictions.
(b) The *accommodation* option, whereby land is allocated by a combination of 'free market' forces and a technical dialogue between the forest and water industries. Both water and timber are harvested from the same land, but both industries accept that higher costs may be involved, e.g. for greater care in preparing ground for afforestation, for leaving large strips of land unplanted or for higher levels of water treatment from upland sources.

An alternative 'sharp end' classification for policy options would be *command-and-control* versus *incentive-based*; the latter has become popular in European and American agriculture as governments seek ways to maintain rural profitability yet achieve environmental objectives. A third style: education can also be observed in the production of *guidelines to good practice* (see Figure 8.5).

8.7 Broadening horizons: new knowledge – people speak to science

As full an assessment as possible is required as a prelude to integrated management, and it behoves scientists of all complexions to clarify their role in critical resource allocation (Falkenmark *et al.*, 2004). Consider, for example, the information needs for an environmental flow allocation in Australia (Hillman and Brierley, 2002). Four core types of information – a gross compression – are listed by the authors: the current state of the river and changes from its natural regime, ecological impacts of various flow parameters and indices, information on social, economic, political and cultural realities, and operational information ('metrics') required to implement the outcomes. In the Australian case study, stakeholders criticised academic inputs for being both repetitive and rhetorical – in not addressing outcomes. As Hillman and Brierley put it, 'The use of scientific information should incorporate local knowledge without compromising quality, credibility and independence' (p. 625).

We need to be aware of the nature and role of what ordinary citizens have as knowledge about river management and, more importantly, what they *count* as knowledge about the problem. O'Riordan and Rayner (1991) have elevated this knowledge to the status of 'vernacular science', but it is more commonly referred to as 'indigenous knowledge' (see also Chapter 6). We appear, therefore, to have a ready-made holism in indigenous knowledge, one which, unlike academic knowledge, does not suffer interdisciplinary tensions. This dimension makes popular consensus imperative in both the developed and the developing world.

The ecosystem concept is only new to science; to traditional societies it was implicit (Berkes *et al.*, 1998), especially in terms of watersheds. Adams (1992) gives a concise general definition of the value of indigenous knowledge by writing that 'African land users have often had (and still have) a better understanding than anyone else of what can and cannot be done in their environment' (p. 37). Adams further emphasises the ability of indigenous knowledge to be responsive to changing conditions, which is why he prefers the term to 'traditional'. This knowledge is not restricted to the developing world: it is available for the asking in countries like Sweden, where Olsson and Folke (2001) became impressed with the way in which local strategies based on experience boost the resilience of a catchment-scale ecosystem.

8.8 'Walk your watershed': catchment health – a case for acupuncture?

A T-shirt and folder from the Water Environment Federation in the USA commands the beholder to 'Walk your watershed'; the folder tells me how to organise a 'watershed festival'. Perhaps the most graphic examples of a new relationship between science and society in the field of water management come from 'collaborative approaches to watershed management' (Sabatier *et al.*, 2005). As Brierley *et al.* (2006) put it, 'Grounded and authentic applications recognize explicitly the complexity of interactions across an array of biophysical and social scales' (p. 131). There are several contextual points to be gathered from the success of this movement across the world:

- Since IWRM has little statutory basis in most nations, links to land-use plans are easier to negotiate in ring-fenced projects (Carter *et al.*, 2005; Mitchell, 2005).
- It represents a distinctive contribution to social learning (see Chapter 9) and is often a spontaneous demonstration of public participation.
- It reduces the impact on risk taking of scientific uncertainties associated with land-use hydrology and instream habitats whilst maximising the role of indigenous knowledge.
- It represents a 'mania' of enthusiasm and motivation, promoting vision (Newson, in press).

It also makes up for shortcomings by 'stiff' officialdom; Falkenmark (1996) denotes 'hydroconservatism' amongst agencies, resulting from indifference due to reductionist ideas of water, poor general understanding of the complexity of water issues, fragmented and inflexible administrative structures and inter-cultural difficulties in development work. There is no doubt that the stakeholder-driven agenda has taken root in the USA after decades of institutional obfuscation.

Under such circumstances it is not surprising to find a plethora of grassroots partnerships being built to circumvent blockages in minds, bodies and budgets. Everard (2004) maps 25 such projects in England and Wales and develops the detail of nine of them. Other examples include the Mersey Basin Campaign in north-west England, the Tennessee Valley's Clean Water Initiative (Ungate, 1996) and the 'river contract' system in Belgium (Mormont, 1996). In Queensland, Australia, catchment care groups are part of the non-statutory basis of integrated catchment management, even though the Minister for Primary Industries retains the right to appoint the public representatives to the core management boards (Johnson *et al.*, 1996). These and others put local catchment management and river restoration projects into the realm of 'civic science' (Lee, 1993).

Many of the organisations promoting 'mania' have sufficient expertise to muster an impressive portion of the mantra too (e.g. the rivers trusts). Everard (2004) takes a positive view of small-scale ventures because their costs and benefits become much easier to make economically accountable using the methods described by those 'paying for restoration' (Holl and Howarth, 2000). Everard and Capper (2004) have drawn attention, for the UK, to the differences between institutional capacity to address system-wide issues of river protection through statute law and the effectiveness of common law as used by catchment protection groups, e.g. the Anglers' Conservation Association. Common law is often stronger, because it encompasses specific principles such as nuisance which can be judged on a scientific (or other evidential) basis over long distances and time periods. By contrast, the administration of statute laws can involve heavy reliance on 'procedures' (Doppelt *et al.*, 1993), public expenditure, custom and practice.

Perhaps justifiably recognised as the 'senior' player in catchment-scale grassroots campaigns in the UK, the Mersey Basin Campaign (MBC) prides itself on optimising the whole range of inputs that it is essential to mobilise for a severely damaged basin, from regional arms of national government, through local authorities, to commerce, volunteers and schools (Figure 8.4). The original aim of the MBC was to improve water quality in a degraded industrial landscape and thereby enhance riparian land values to the extent that urban regeneration occurred; it thus shares very little with rural schemes centred on fishery improvements to enhance tourism, but its challenges were harder. Despite an involvement by 'big players', Wood *et al.* (1999) conclude that MBC's impact 'has been made at the local level using the principles of partnership to establish a sense of ownership amongst diverse elements of the community, and nurturing the recognition of common interest' (p. 353).

Nearby in north-west England, there are highly valued rural landscapes and freshwater ecosystems whose protection and restoration involve both

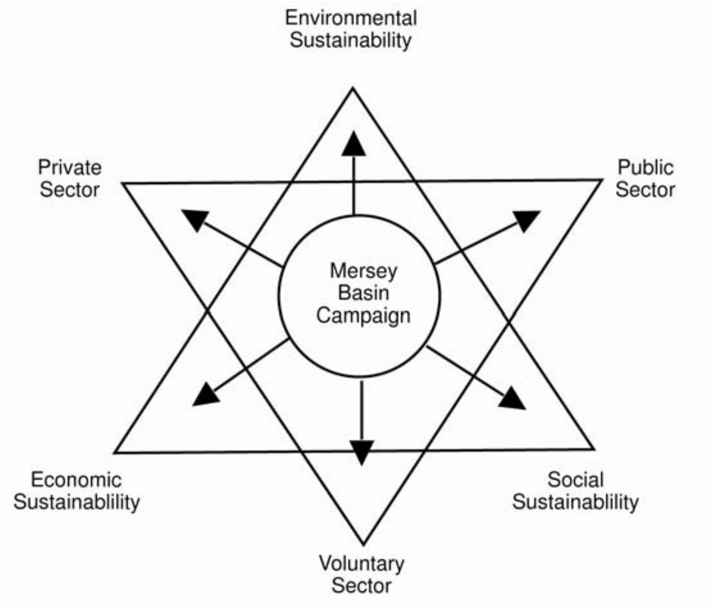


Figure 8.4 The Mersey Basin Campaign and its key players.

instream and catchment management (Makin *et al.*, 2004). Here again, local mobilisation of effort and the creative use of nationally available funds to the rural sector, identified and assured by facilitators, have brought about conflict resolution and 'win–win' outcomes for all parties. Makin *et al.*, however, make a plea for science-based tools to reveal the hydro-ecological and land-use hydrological parameters amenable to local management.

8.8.1 Placing the needles, getting 'more bangs per buck'

There are now very clear reasons why *small-scale catchment management actions* by agencies, individuals and communities serve the national interest. The UK government (Defra, 2004) is alarmed that, after spending £20 billion in just over a decade to 'clean up' point sources of pollution, more than 20 UK rivers are at severe risk of failing the standards of the Habitats Directive and a very high proportion of water bodies are at risk of failing the Water Framework Directive's demand for 'good ecological quality'. The main cause is diffuse pollution by oils and hydrocarbons, pesticides, veterinary medicines, silt, organic waste, faecal pathogens, nitrogen and phosphorus (Defra, 2002a).

There have long been calls for a landscape-scale approach to understanding the pathways followed by pollutants from diffuse sources (Haycock and

Muscutt, 1995), but the universal prescription of riparian buffer zones is increasingly questioned. Where an important rural land-use agency takes a landscape-scale approach there are proven benefits. For example, 20 years of applications of the Forestry Commission's *Forests and Water Guidelines* (Forestry Commission, 1988, 1993, 2003), including careful matching of machinery to site conditions and the retention of riparian buffer areas (Figure 8.5), have created a marked reduction in diffuse pollution to sensitive upland aquatic habitats (Nisbet, 2001).

Two grassroots catchment projects in the UK are of note because they address diffuse pollution impacts on public water supply in addition to ecosystem and fisheries concerns. The River Dee in north-east Scotland is subject to acidification of its mountainous headwaters but also to agricultural and forestry impacts lower down, on the outskirts of the city of Aberdeen, which is experiencing rapid growth in water demand. In one of the latter subcatchments, Tarland Burn, a local landowner has prompted a community programme (facilitated by a local research hydrologist) to address reforms in the way all their activities impact on the stream. The early successes gained in this way spread to a '3 Dee Vision', whose catchment management approaches became part of a three-year comparative EU research programme (Walker and Langan, 2004). In north-west England the regional water supply company, United Utilities, has embarked on a sustainable catchment management programme (SCaMP), which has the joint purpose of increasing

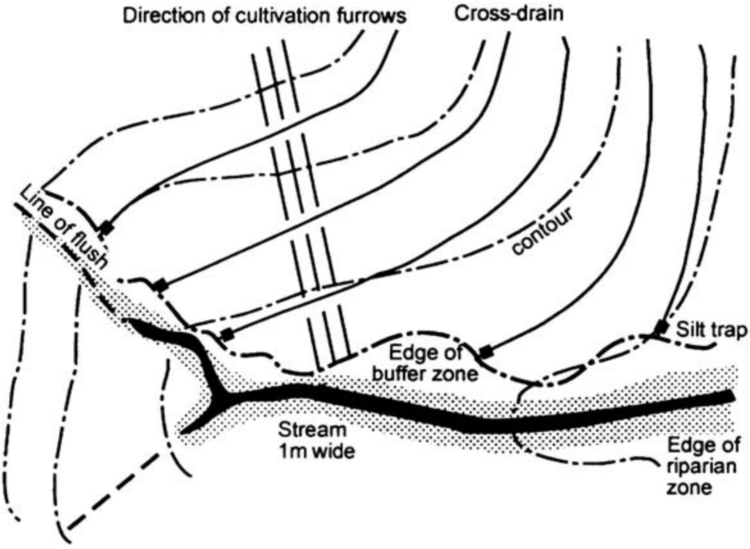


Figure 8.5 Guidance on land-use management for catchment protection: cultivation furrows, cross-drains and buffer zones (after Forestry Commission, 1993).

biodiversity, especially in protected areas, and reducing pollution of raw water. United Utilities is also a major landowner (57,500 hectares) and thus has control of, for example, farm rentals. Nevertheless, it seeks gradual improvements to land use and management and a very broadly based stakeholder platform. Perversely, for the future scope of such schemes, the official water industry regulator will not allow United Utilities to finance water quality improvements through catchment management (but will do so, for example, for sewage treatment).

Part of the SCaMP programme involves blocking moorland drains, a feature of agricultural ambition for the uplands during two world wars. The disproportionate impact of such features on the runoff and water quality of headwater catchments has been revealed by a number of hydrological experiments. McDonald *et al.* (2003) show how the Upper Wharfedale Best Practice Project instituted drain blockage in locations, pinpointed by a predictive model, which would yield most benefits downstream. It is this optimisation of benefit–cost (not formally assessed in these cases) by progressively tackling small zones of the river basin that has inspired the author to use the term ‘catchment acupuncture’. To put it on a firmer theoretical base requires an expansion of studies of hydrological connectivity (Bracken and Croke, 2007) and a return to the concepts revealed by those investigating runoff processes in the 1970s (see Chapter 3). Whether or not this approach has promise as a compromise between private and public actions within a model of upstream–downstream dependencies will depend on large-scale public policy developments like cooperative agreements (Brouwer *et al.*, 2003) and on careful linkages between policy instruments and the scale at which effectiveness is sought, farm, stream or landscape (Cunningham and Sinclair, 2005). There are also challenges to forge interdisciplinary knowledge bases built around, for example, diffuse pollution models which can target ‘hot-spots’ and the stakeholder platforms to negotiate and promote responses ‘on the ground’ (Donaldson *et al.*, 2005; Lane *et al.*, 2006).

Chapter 9

Adaptive land and water management

Through participation and social learning to hydropolitical decisions

There is no doubt that the Millennium Development Goals and constant media references to a 'world water crisis' have lured many from a strategic, large-scale, long-term policy into an emergency, focused (often urban) panic. However, the focus continues to move, e.g. following the large-scale strategic thinking of the *Comprehensive Assessment of Water Management in Agriculture*, which emphasises that *poverty is a rural issue* and that *rural societies feed the world.*

9.1 'Big themes' for future land and water development

Hillman and Brierley (2002) suggest that complacency over integrated river basin management is misplaced:

> While identifying and gathering the key types of information for river management is itself a major task, integrating these components is arguably an even bigger challenge. *Significant technical and institutional barriers stand in the way of developing a practical approach to adaptive and ecosystem-based management.*
>
> (Hillman and Brierley, 2002, p. 624, emphasis added)

Land use and management have strong rivals for the attention of river managers: existing 'plumbing' in river basins already brings about fundamental changes to the flow and water quality of up to two-thirds of the world's rivers (Chapters 3 and 6). This immediately facilitates the traditional engineering approach to river management in which structural measures come to be preferred because of the degree and certainty of control they offer and because, to the public, they demonstrate 'action'.

In our second edition, the work of the 'Swedish school' of river management, notably that of Malin Falkenmark, was beginning to set a *hydrodemographic* context for basin development (Figure 9.1). Falkenmark (1986) developed a 'carrying capacity' model for human water consumption which

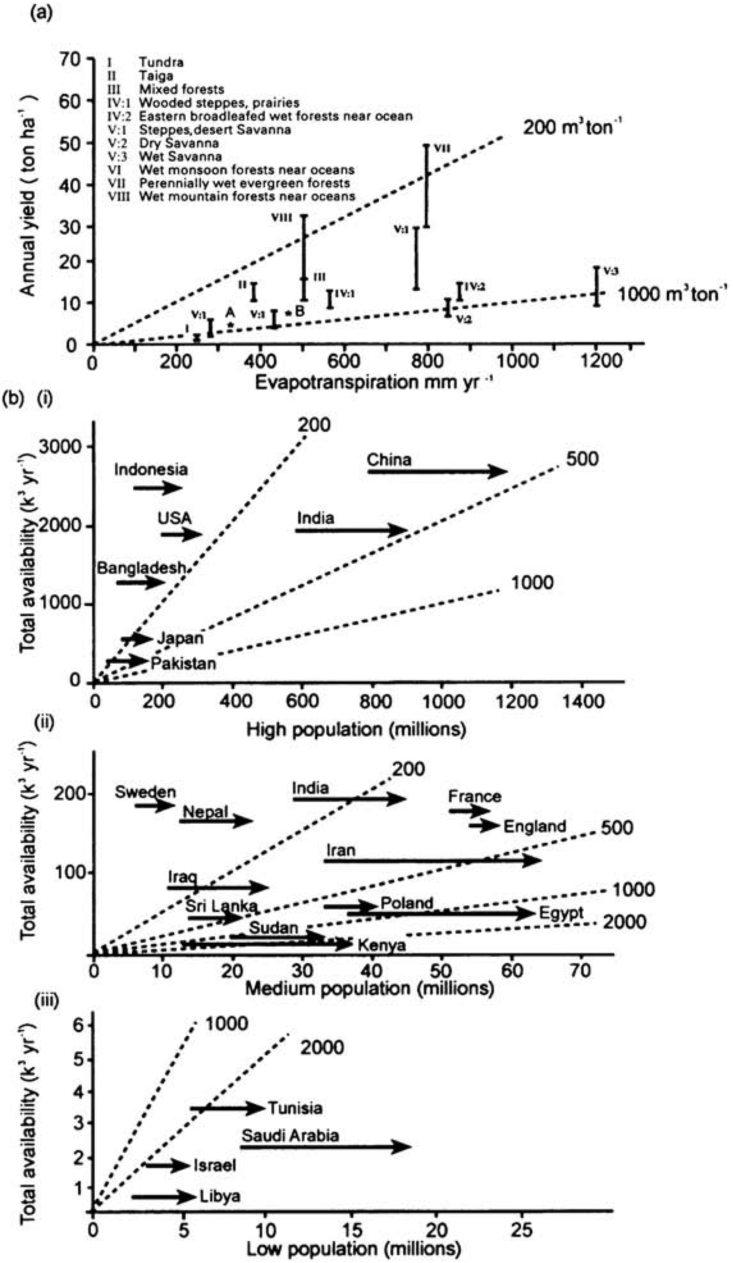


Figure 9.1 Carrying capacity arguments for water use (after Falkenmark, 1986):

(a) Vegetation and water use
(b) Human water use (500 people per unit represents a deferred problem, 1,000 indicates current stress)

links biomass production (in terms of its water needs per tonne of dry matter) with human gross need for water. She used the basic unit of a million cubic metres per year as a guide to the populations which can be supported. Falkenmark's early analysis, however, lacked a quantitative assessment of the *biological requirements* for water.

The Stockholm International Water Institute (SIWI) remains at the forefront of sustainability issues in hydrology. Their focus is now much more one of humans *in* the ecosystem (see Section 9.3 in the second edition); the term 'hydrosolidarity' has been introduced to indicate the vital interaction between human security and ecological security (SIWI and IWRA, 1999; SIWI and UNDP, 2002). Spatially, the message translates as 'upstream/downstream hydrosolidarity'. Falkenmark (2002) emphasises the concept of *resilience*; if human society can recognise and encourage resilient ecosystems, the goods and services those ecosystems provide will assist the resilience of human society in coping with change, climatic, demographic and political. The major barriers to these ideas are that the current 'sanctioned discourse' of water resource politics is of unreformed resource exploitation, untainted by demand management, and that systems of governance in many nations simply cannot promote them. Falkenmark is honest to remark that 'the strategy referred to under the concept catchment-based ecosystem approach continues to remain rather dizzy'. Others have advocated a freer format for expression of hydrosolidarity, whilst retaining the upstream–downstream ethos. Some have promoted 'problemsheds' as an alternative to watersheds; Molden (2002) uses the term 'hydronomic zones' (*hydro* – water, *nomus* – management). The principles are similar: it promotes global feasibility to link territories with similar water management problems, e.g. diffuse pollution, widespread soil erosion, ecological damage by large dams. The central question in hydronomic zones is 'Where does this water go after each use?' Molden suggests six types of hydronomic zone:

- water source zones;
- water recapture zones;
- regulated recapture zones;
- final use zones;
- stagnation zones;
- environmentally sensitive zones.

We saw something of this selective, prioritised, smaller-scale approach to land–water management at the end of Chapter 8. The *headwaters* of basins are vital and likely to be grossly impacted by climate change where they occupy mountainous zones. Even where they do not, a major threat to freshwater systems is now more fully understood, if not appreciated – the large dam. There has also been progress in gaining protection for impacts that get worse nearer to the channel, e.g. point-source pollution in the developed world, respect for the *riparian zone as a functional buffer*, growing respect for *wetlands*, but as yet only a widespread debate about the full *floodplain*. All these issues come under the heading 'ecosystem services' (Box 9.1), but as yet there is little demonstrable progress in utilising economic values for them in the grand political schemes of things which rule river basins.

Since successful actions and outcomes appear to derive from a scaled approach to practical management, is there not a message inherent for the governance of all water-related problems?

Box 9.1 The value and loss of spontaneous regulation in developed river basins

Central to the concepts of 'hydrosolidarity' and 'resilience' is a notion of valuation for those goods and services provided to human society by the non-human components of ecosystems (Table 9.1). In the identification of 'hydronomic zones' we expect to protect sources of these goods and services but they are very easily lost during conventional land and water development, as in the UK (Table 9.2).

Table 9.1 Benefits humans derive from (intact) freshwater ecosystems

Direct use of surface waters and groundwaters
Preparation of food/drink
Hygiene, waste disposal
Livestock production
Hydropower
Cooling
Manufacturing
Fire fighting
Products harvested from healthy freshwater ecosystems
Fish and wildlife
Riparian products
Wetland products
Streambed minerals and materials
Services provided by healthy freshwater ecosystems
Recreation (fishing, hunting, boating, swimming)
Transportation of goods
Water storage/flood control
Nutrient deposition/waste purification
Habitat for biological diversity
Climatic moderation
Buffering of polluted inputs
Aesthetics and mental health

Source: After Naiman *et al.* (1995)

Table 9.2 Loss of spontaneous regulation functions in river basins: the UK

60.9% of all agricultural land in the UK is drained
35,000 km of river channel in England and Wales are maintained for flood defence
2,361 ha of lowland raised mire lost in England and Scotland, 1948–78
3,370 km^2 of East Anglian fens lost, 1637–1984
10–20% increase of arable agriculture on lowland floodplains, 1948–78
One-third of all land-use change in England 1985–6 was rural to urban
Between 1945 and 1990 the urban area in England grew by 58%

9.2 Scale-sensitive governance, information flows and social learning

There is no 'one-size-fits-all' model for land, water and development; the biggest cause of failures in the past has been this mentality shared by developed-world technocrats and developing-world power brokers. The river basin unit cannot call upon all the elements of a successful integrated, sustainable and adaptive form of environmental management. Allan (1995) removes the rigidity of our thinking on scale by adopting the American term 'problemshed'. Taking a long, hard look at Figure 9.2, we might reflect on how many elements of the basin-scale 'big picture' have thoroughly legitimate processes and outcomes at other scales!

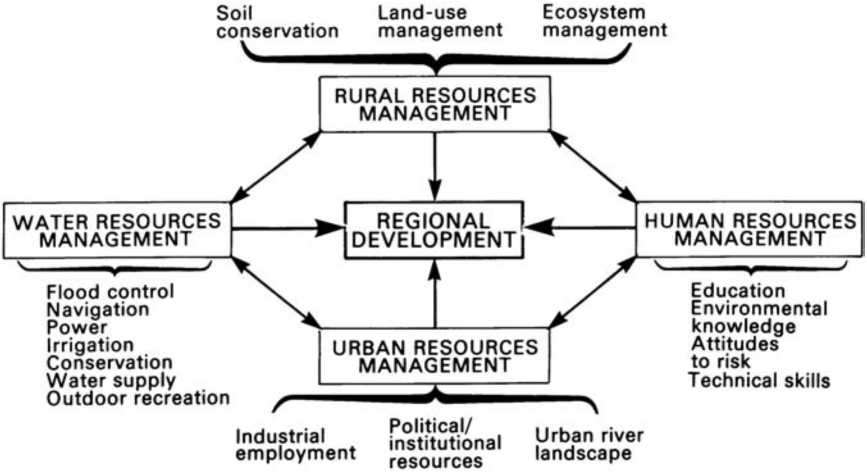


Figure 9.2 The complex of projects involved in river basin development.

The reasons for inherent geographical variability of options for river basin (or 'problemshed') management include:

(a) Differences in *scale*. In successful river basin management the flow of information is critical (see Section 9.3) and so scale does not merely become a boundary condition to physical and chemical processes in rivers but a central institutional issue.
(b) Differences in *trajectory*. Here we may include changes through time in water needs, the development process, climatic controls and political controls. Successful river basin management will be the result of considering a range of options to suit the often unique combination of these variables for each basin.
(c) Differences in the *environmental capacity and resilience of the system* to be developed, in turn leading to different relative needs to manage demand for that capacity. Our ignorance of the particular circumstances of dryland environments is a critical barrier to their sustainable development (Magalhaes, 1994).
(d) Differences in *human capacity*, ranging from systems of governance to education, funding for knowledge creation, communications and available GDP.

Scale plays a *vital part in governance* and interlinked hierarchical water management *institutions and organisations*. The bureaucratic niches in the socio-political hierarchy can be seen to be a positive (offering effective good scale niches) or negative (often scale insensitive) influence on sustainable management. The ethos of thinking globally but acting locally was well established (e.g. through Agenda 21 and Local Agenda 21, Thames 21, etc.) long before globalisation of the capitalist system introduced a political piquancy to scales of governance. There have been prominent proponents of intermediate or meso-scales for environmental policy and management, such as ecoregions (Gore, 1992); Aberley (1993) brings together statements which emphasise their obvious environmental focus: for example, 'ecoregional boundaries stand forth as convergent thresholds welcoming us "home" '. O'Riordan (2004) suggests that 'the region will become an increasingly important focus for study of sustainability politics'.

Governance is defined by Hooper (2005) in the context of IRBM as 'a decision process involving multiple players at different *levels* – individual water users, government agencies, private sector interests, NGOs and lobby groups and those marginalized because of poverty or accessibility'. Effective governance in the water sector is not 'linear, prescriptive and logical' but tends to be 'adaptive and messy'. Hooper selects just three from the hierarchy of scales involved to illustrate scale-sensitive water governance (Table 9.3(a); see also Figure 5.12). The National Academy of Science also selects three sizes of river basin to indicate the scale at which optimum results are most

Table 9.3(a) Dominant scales for IRBM

	Macro-level	*Meso-level*	*Micro-level*
Map scale	>1:1,000,000	1:100,000–1:500,000	1:1,000–1:10,000
Level of decision making	National.	Regional.	Local and individual.
River basin organisation	E.g. international commission.	E.g. inter-state commission or large basin district.	Local land and water management group or catchment forum.
IRBM document	International agreement.	River basin management plan.	Storm water management plan, farm water plan.

After Hooper (2005)

Table 9.3(b) Common scales for watershed management issues

Issue	*Small basins 2,500 km^2*	*Intermediate basins 2,500–25,000 km^2*	*Larger basins >25,000 km^2*
Regulatory thresholds			✓
Reservoir system management			✓
Goal, objective and policy development	✓	✓	✓
Hydrological modelling	✓	✓	✓
Management point-source pollution	✓	✓	✓
Public education	✓	✓	✓
Floodplain management	✓	✓	
Management diffuse pollution	✓	✓	
Participatory planning	✓	✓	
Stream bank stabilisation	✓	✓	
Wetland management	✓	✓	
Land-use planning and zoning	✓	✓	
Flood control works	✓		
Irrigation management	✓		

Modified from National Research Council (1999)

likely for 23 issues; a selection is shown in Table 9.3(b). It is the geographer's privilege to pick out the scale elements of a scientific, political or administrative problem. Gamble and Meentemeyer (1996) have recently reiterated that any remedies for the currently unsustainable use of the Ganges and Brahmaputra must come from the explicit use of scale in both research and applications. Molle (2007) also uses empirical research from the Chao Phraya River in Thailand as the basis for a scale analysis of the critical hydropolitical issues in managing the basin.

Perhaps the most fundamental geographical case study of *scales* (both space *and* time) for sustainable watershed development is that by Thomas and

Adams (1997) of the Hadejia-Jama'are wetlands and the Komodugu Yobe basin in Nigeria. They firstly underline the uncertainties involved in hypothesising time and space boundaries: intergenerational inequality, future values, environmental change and ecosystem/administrative spaces and their interaction and feedback. Despite these, an intensive interdisciplinary investigation of the wetland and river basin system reveals both the relevance of scale and how scale perspectives profoundly influence the actors in the sustainability drama. Communication between scale perspectives presents major challenges and opportunities for conflict resolution; the authors attempt to represent these on bivariate plots of time and space.

If scale sensitivity for land and water management is best captured through the experience of stakeholders, are there ways in which this experience can rival the 'normal science' route through 'research and development'?

9.2.1 What is social learning? How can it help?

In a recent attempt to define social learning and its roles, Keen *et al.* (2005) suggest that social learning is necessary because social change is necessary if society is going to adequately address environmental challenges.

Social learning is necessarily broad and encompasses many of the other dimensions of sustainable governance: systems orientation, integration, negotiation and participation amongst them. Andrew and Robottom (2005) conclude from case studies that, *inter alia*, environmental and sustainability issues:

- are complex in structure;
- express themselves within specific contexts;
- involve a wide range of stakeholders;
- need a politicised perspective to be resolved;
- require negotiation and reconciliation – usually difficult and challenging processes.

Social learning is seen as a vital component of new institutional and organisational structures accompanying 'start again' legislation like the EU Water Framework Directive (WFD). The WFD lays out its requirements for public participation in preambles, articles and annexes, without ever being too specific, except in connection with river basin management plans (Videira *et al.*, 2007). The EU ADVISOR project reported by Videira *et al.* set out to deliver a toolkit for the conduct of integrated and participatory planning. The EU-sponsored SLIM project (Social Learning for the Integrated Management and sustainable use of water at the catchment scale) has recently been carried out at the UK Open University (Ison *et al.*, 2007). Within a context of learning theories (Blackmore, 2007) and using case studies, some from the UK (Collins *et al.*, 2007), it advocates social learning practices as helping us to:

- recognise and reframe our mental models;
- see issues through fresh eyes;
- resolve social dilemmas;
- define and articulate what we value;
- discover a shared purpose;
- see through conflicting views to a shared vision for the common good.

SLIM has a simple basic model which it then applies to case studies (Figure 9.3). It relates changes to practices and understanding for each issue by locking the issue into four domains: institutions and policies, stakeholding, facilitation and ecological constraints. The 'big picture' can then be warped to show the realpolitik of a given contentious matter of catchment management. SLIM identified numerous situations where 'current traditional policy initiatives' were failing; commonly these are characterised by complexity, connectivity, uncertainty, multiple perspectives and conflict. Whilst integration may be possible simple stakeholder involvement, shared concerns only become explicit within 'collaborative knowing', i.e. social learning. SLIM suggests that goals for projects using such visionary processes should be modified to become a series of intermediary objects for designing (IOD) and intermediary concepts for designing (ICD).

Another European review, covering ten large river basins (Mostert *et al.*, 2007), concludes that clarity about the role of the stakeholders is vital, providing *ab initio* a commitment to *information as the currency of the process*. Confidentiality too often becomes an issue when foreshortening and curtailing the participation. Yet more EU research, under the HamoniCOP programme (Pahl-Wostl, 2006), aims to integrate the potential of ICT tools and

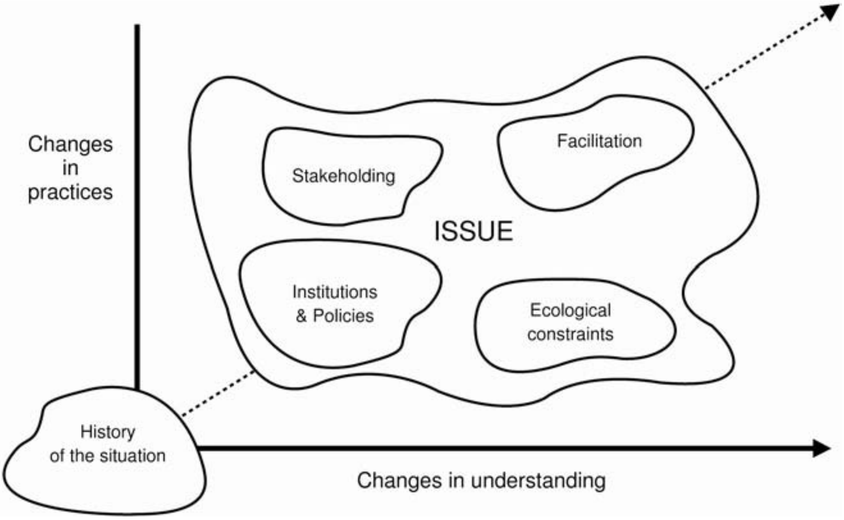


Figure 9.3 The conceptual framework for analysis by the SLIM project on social learning.

models to aid information exchange for river basin management within the WFD regulations.

Petts (2007) sounds a realistic warning about how far social learning penetrates into the institutions which govern water management; individual experts may gain significantly from processes of, for example, planning river restoration, but their enthusiasm may remain marginal to the authorities for which they work.

9.3 Experiences of participation: stakeholders and 'Joe Public'

Social learning can make public participation a process in governance, but too often participation is simply structural. Arguably, the biggest formal boost to frameworks for public participation came with environmental impact assessment procedures in the late 1960s. Their rapid growth may represent societal processes at work, as we abandon the 'hegemony of the rationalist deference to science and experts' (Weston, 2004). Delli Priscoli (2004) suggests that five areas of growing concern specifically to the water field are promoting interest in participation: ethics, civic culture, tension between science and politics, tensions between boundaries, and the need for more and better conflict management.

In introducing a long-overdue review of 'multi-stakeholder platforms' as a vehicle for IWRM/IRBM, Warner (2007) suggests that water managers are at last conforming with the normative experience of all public management which has to address 'wicked' problems of governance, rather than working smoothly through 'engineerability'. The transition from technocracy to democracy involved a rediscovery of civil society, replacing state-led and market-led water management which, on their own, have failed. 'Collaborative management' is an increasingly common term within IWRM/IRBM (Margerum and Whitall, 2004; Ferreyra and Beard, 2007; Watson, 2007).

Appraisals of collaborative management of rivers, employing multi-stakeholder platforms, now try to critique their particular example. There are even deconstructions of the 'tyranny' of participation (Cooke and Kothari, 2001); these authors write that the chapters in their edited volume 'confirm that tyranny is both a real and potential consequence of participatory development, counter-intuitive and contrary to its rhetoric of empowerment though this may be' (p. 3).

Seeking to reflect lessons from the increasing levels of uptake for 'integrating citizens in adaptive management', Shindler and Cheek (1999) derived six propositions to improve the effectiveness of the process from their qualitative case studies:

- It is open and inclusive.
- It is built on skilled leadership and interactive forums.

- It involves innovative and flexible methods.
- Involvement is early and continuous.
- Efforts result in action.
- It seeks to build trust between participants.

A later North American overview study of 37 watershed partnerships by Leach and Pelkey (2001) identified 210 lessons learned in 28 thematic groups, of which adequate funding, interpersonal trust and committed participants featured strongly. Margerum and Whitall (2004) focus on the role of a technical tool to promote collaboration – an ecosystem management decision-support model – which, however, proved insufficiently clear for its outputs to be 'owned' by all participants. Conflicts over what constitutes watershed health (Rogue basin, south-west Oregon) were not resolved satisfactorily; extra time and resources are required for conflict resolution and to avoid the temptation to 'push on' without it. From the same region, Ferreyra and Beard (2007) move from narrative evaluation to indicators of outcome (taking care to separate out*comes* from out*puts*, because stakeholders sign up to actions, not words).

Newson (2007) takes a slightly different analytical route; his experience of multi-stakeholder platforms includes a success, a neutral case and a failure. The key points of the success story (the Upper Wharfedale Project) included the experience in 'having a voice' of the local community (in a highly pressured National Park, tourist location) and an information platform (quality of life capital: QoLC) used as a focus for vision creation (Newson and Chalk, 2004). QoLC permits an early data-sharing environment in setting down the attributes of local environment, scales of value, substitutability and management issues. The role of information, its generation and exchange amongst stakeholders is now frequently the focus for reflective reviews of participation. Creighton (2004) remarks that 'inside every [successful] public participation program is a good public information program' (p. 385). I have added the word 'successful', without which the sentence is clearly untrue! *Information is contested* and plays an important part in power structures (Moreyra and Wegerich, 2006). Nevertheless, other supports are necessary but not sufficient: Newson and Chalk also emphasise the vital need for financial resource deployment, visible outcomes, an influential personal catalyst and continuity. Facilitation of the process of stakeholder participation is clearly vital and may be a relevant metaphor for research (McClintock *et al.*, 2003), thus placing the information hub and the catalyst activity together in one person or a small group.

Warner (2007) suggests that stakeholders are 'individuals, groups or institutions that are concerned with or have an interest in water resources and their management'. Herein lies the danger of exclusion for 'Joe Public', the hypothetical 'man in the street' who has a democratic right to be involved but may remain oblivious of the process by which decisions are being made.

Realistically, Lee (1993) identified 'Majority rule by the minority that care', an 'approximation to democracy'. In the cognate field of biodiversity planning, Evans (2004) notes the tendency of pre-existing actors to form 'steering groups', simultaneously enabling and constraining the process. Some analysts see even the watershed unit chosen for IWRM/IRBM multi-stakeholder platforms as excluding many potential participants (Moreyra and Wegerich, 2006). 'Place (and scale) is a social construction that feeds the ends of those whose definition counts' (p. 639).

9.3.1 Rhetoric and reality

The dangers of the rhetoric of participation triumphing over the reality are constant. Despite a duty to consult on river basin district plans under the EU Water Framework Directive, many fear a low-level choice will be made by member states from the menu listing the strength of stakeholder representation. Article 14 of the directive refers only to 'active involvement', 'access to information' and consultation on draft river basin management plans. The Environment Agency has bemoaned the constraints of the WFD timetable for its efforts to create an efficient stakeholder platform in the Ribble Pilot River Basin Project; time is of the essence in the evolution of the new opportunities within a command-and-control tradition. Watson and Howe (2006) appear to raise 'two cheers' for the Ribble Project and offer five lessons from its stakeholder mapping and visioning workshops, including the need for balanced representation, the importance of information and facilitation, focus on the future and the costs of an effective platform. Errors were also conspicuous when legislation enforced public participation in allocating water in Australia (Tan, 2006), including notable failures to build capacity amongst participants.

Such dangers also stalk the development process. In Ghana, Poolman and van de Giesen (2006) report failures to gain the benefits ascribed to participation which ought, under the best conditions, work:

- to ensure design reflects the real priorities of beneficiaries;
- to ensure feasibility from people's viewpoint;
- to ensure the relevance of intervention;
- to ensure sustainability beyond the project period;
- to ensure the project is reaching and listening to the voices of people it targets;
- to increase ownership and therefore motivation;
- to provide early warning of problems.

The answer it seems, one with general relevance, is to conduct a *stakeholder analysis* before the establishment of the platform, featuring a systems analysis of the decision framework so as to tease out who should participate, to what end and how.

South Africa's National Water Act (NWA) has launched a variety of projects to encourage the kind of participation vital in a new democracy in which very many 'wicked' problems attend both land and water management. Van Wilgen *et al.* (2003) conclude that it is often vital to facilitate stakeholder interaction amongst themselves before getting round to the technical issues for decision. Also reviewing parts of the NWA process in South Africa, Simpungwe *et al.* (2007) conclude that, if the state initiates multi-stakeholder platforms through the enactment of the law, participants suffer limitations which it requires a range of empowerment techniques to overcome.

Communications have a vital role in participation, notably in the developing world; Bessette (2006) assembles a whole volume devoted to participatory development communication. Contributors consider the roles of radio, TV, electronic communication and even mobile phones as a development tool. However, it should not be assumed that consultation is possible under all political conditions. Nations undergoing rapid development are often one-party states with major regional problems of opposition, even civil war.

9.4 The cauldron of hydropolitics and the spell of economics

> Water still symbolizes such values as opportunity, security and self-determination. Water represents these values less because the water itself has economic value than because control over it signals social organization and political power. . . . Strong communities are able to hold on to their water and put it to work.
>
> (Ingram, 1990, p. 5)

According to Bouguerra (2006), there is an Arab proverb which invokes 'a curse on science that is of no use to men'. Water, says Bouguerra, is first and foremost a political-ethical issue. It is hard to enthuse scientists about politics, with the result that we experience grave difficulties when 'science speaks to power' (Chapter 8). O'Riordan (2004) laments the situation with these words (p. 239): 'This is the next phase of environmental science: interlocking scientific analysis to political and social contexts so that a more politicized science emerges. The notion of "politicization" should be regarded as positive, not frightening or threatening.'

Perhaps part of the explanation for the 'stand-off' between science and politics lies in the fact that the politician stands by power accrued by election whilst the scientist stands by 'truth' established by peer review (Price, 1965 and Figure 9.4). Both, however, experience conflict, but the politician sees it as a reason to negotiate a settlement or to establish a 'sanctioned discourse', i.e. negotiated 'truth'. Lee's (1993) experience of politics in river basins suggests to him that the environment is inevitably contested, since one person's access to or use of a place incurs a cost which may be displaced across space,

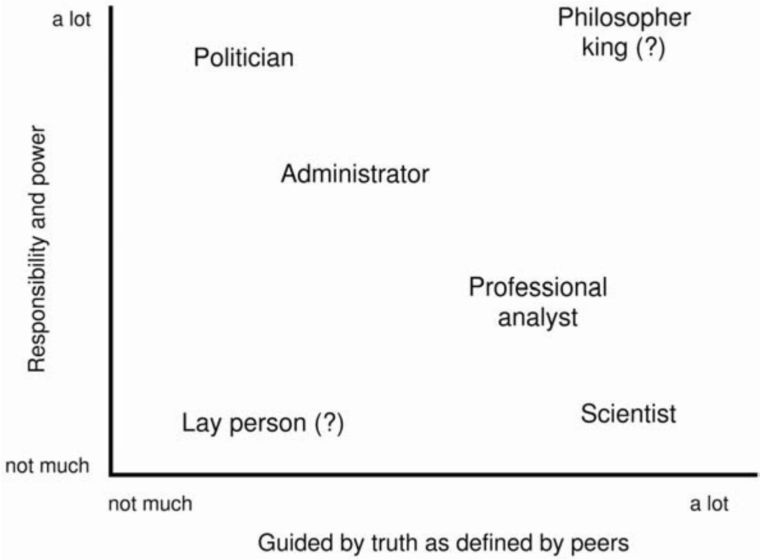


Figure 9.4 Comparing science and politics (after Price, 1965; Lee, 1993).

time and culture to be borne by others. Lee warns that policy is often made and implemented within a sub-field of politics: not the stuff of elections or visible accountability but the field of lobbying, often by 'the minority that cares'.

A coherent field of *hydropolitics* has only recently emerged. It has blossomed from an initial notion of 'water wars' and thus a preoccupation with scarcity (Ohlsson, 1995) to embrace (Turton, 2002):

- water and conflict;
- water and the environment;
- water and security;
- water, society and culture.

Mollinga (2001) ranks the politics of water by scale, from state and inter-state 'hydropolitics', through the politics of water resource policy to 'the everyday politics of water use (the day-to-day contestation of water resource use)' – the way local relations of power shape and are shaped by water use. Mollinga enters a theoretical debate over the degree to which political decisions over water use represent rational choice or are best described by cultural attitudes or institutional positioning; his case study of irrigation in South India indicates the power of the latter. Just like these ingrained elements of political structure, the commodification of water has a long history (Page, 2005). Despite evoking outrage in relation to water as a human right, Page's view is that demystifying the role of water as a commodity is a prelude to better understanding the capital, financial challenge of supplying it.

9.4.1 Simple economic instruments: pricing

Without leaving the fold of hydropolitics, but turning to economics, debate about the incorporation of economics in the whole field of water management tends to centre on the power nexus of globalisation, the role of private capital, corruption, market monopoly and so on (Holland, 2005), whereas the promotion of 'hydrosolidarity' requires something of an intellectual revolution to create a new *environmental economics* (see Section 9.4.2).

There is considerable current rivalry (arranged largely along exhumed, traditional left–right political lines) between regulatory and economic approaches to environmental management. Authors such as Winpenny (1994) appear to advocate comprehensive adoption of *fiscal measures* in river basin management, and he roundly criticises the biophysical approach to regulatory basin frameworks as an intellectual luxury. Merrett (2005) goes further in wanting to establish a variant of the land phase of the hydrological cycle, the 'hydrosocial balance', using 21 terms to establish total use; the geographical unit can be any for which appropriate data exist or can be estimated or modelled. However, there remains the issue of pricing, and the list of water prices tabled by Calder (2005a) indicates a 400-fold range, together with plentiful 'zeros'. 'Who charges' is as relevant as 'what they charge': the connection between private capital and domestic water supply is inevitable (see Chapter 5) given that many World Bank loans for water projects call directly for privatisation (Holland, 2005). However, Rodriguez (2004) wants a separation between an image of 'ownership' for water – implying the politics of commodification – and the vital need for financial support for improving the welfare provided by secure water supplies. Water scarcity and ill-health act as disincentives to the business sector as well as their customers (WBCSD, 2007).

Pricing water has obvious advantages for demand management, as with the newest Coke vending machine which raises the price in line with air temperature! But there are convincing arguments against this 'classical' economic approach: 'Faced with those who know the price of everything and the value of nothing, it seems useful to show at the outset that water is not an ordinary element, still less a commodity' (Bouguerra, 2006, p. 10). 'The market – in the case of water, at least – is not a panacea, as we can see from the shortages, accidents, price rises and assorted scandals that followed complete privatization of the sector in Britain' (p. 98).

Resource pricing (including the cost of pollution control and water purification) can, however, be seen as a key element for driving integrated management. The transition to realistic pricing is a special challenge for developing economies which have favoured heavily subsidised water services. The Kolkata

Municipal Corporation in India serves 4.5 million residents with water which, until recently, was virtually free at the point of delivery. According to Majumdar and Gupta (2007), however, the supply is intermittent, pressure is inadequate, there is excess leakage, energy costs are high and there is an over-reliance on groundwater. Charges, based on property taxes, have recently been introduced, to a generally favourable public reaction. The authors remind us that the costs of a poor supply to any household can be considerable – time wasted in supply cuts, home purification processes and the high costs of ill-health make consumers willing to support a small charge, particularly if the basic allowance remains free to favour the poor. This level of feasibility for domestic water charging and these levels of benefit are not universal: Arntzen (1995) notes that in Botswana the impediments to the use of economic instruments include a significant non-market economy, limited expertise and immediate welfare problems for the communities served.

Perry (2001) paints a less sanguine picture for volumetric charges in irrigated agriculture, a sector badly in need of demand management: in Iran they would have very little impact on farmers' choice of crop or choice of irrigation technology. Substantial price rises or volumetric restrictions would not be politically feasible, and less drastic measures would simply increase the costs of administering the irrigation services. There are also problems in most cultures with a 'freedom to farm' political ethic, reducing the scope for government intervention and prolonging a bounded rationality in economic decision making by agriculture (Supalla, 2003).

9.4.2 Paying for ecosystem services: but what are they worth?

Green (2003) is keen to clarify the role of environmental economics in decisions:

- to simplify the nature of the choice to a level that we can comprehend;
- to enable us to understand the key elements of that choice; and
- to communicate that understanding to all of the stakeholders so as to form a framework in which they can debate, argue and negotiate their concerns.

If a normative policy for sustainable management of water is to be 'hydrosolidarity', ecosystem services will need to enter the world of economic valuation: few other opportunities exist to 'count'. Salzman *et al.* (2001) refer to 'the single greatest failing of modern environmental law and its greatest challenge today – the inadequate protection of ecosystems and the services they provide' (p. 310). They add that 'ecologists, economists and lawyers have only recently begun systematically examining the extent and implications of these services' valuable contributions to social welfare'.

The global ecosystem valuation by Costanza *et al.* (1997) has already led to practical outcomes of this way of thinking – the protection of New York's water supply catchments (Pires, 2004). In another example from the USA, Loomis *et al.* (2003) report that more than US$100 million worth of water (valued by the market and by non-market methods) has recently changed from irrigation uses into environmental uses. However, market and governmental failures continue to result in ecosystem degradation, despite the several options both of approach (Table 9.4(a)) and of valuation technique (Table 9.4(b)); the major stumbling block appears to be that the 'sanctioned discourse' of global politics (or capitalism) has not yet accepted the inclusion of these elements of economic life.

The concept now has sufficient kudos to find itself promoted by the World Bank in an informative review shared with IUCN and the Nature Conservancy (2005), respected voices of practical conservation ecology. Their report summarises the concepts behind ecosystem service values, approaches to valuation and case studies, including how values might be used in cost–benefit analyses. Further detailed analysis of the techniques in economic valuation of the environment can be found in Garrod and Willis (1999).

Reporting a year later than the World Bank, the International Institute for Sustainable Development (IISD) (Duraiappah, 2007) carried the sombre news from the Millennium Ecosystem Assessment that nearly two-thirds of the 'provisioning, regulating, supporting and cultural services provided by

Table 9.4(a) Approaches to valuation of ecosystem goods and services

Approach	*Why do we do it?*	*How do we do it?*
Determining the total value of the current flow of benefits from an ecosystem	To understand the contribution that ecosystems make to society.	Identify all mutually compatible services provided; measure the quantity of each service provided; multiply by the value of each service.
Determining the net benefits of an intervention that alters ecosystem conditions	To assess whether the intervention is economically worthwhile.	Measure how the quantity of each service would change as a result of the intervention (cf. without it); multiply by the marginal value of each service.
Examining how the costs and benefits of an ecosystem (or an intervention) are distributed	To identify winners and losers for ethical and practical reasons.	Identify relevant stakeholder groups; determine which specific services they use and the value of those services to that group (or changes from intervention).
Identifying sources of finance for protection, conservation, restoration	To help make ecosystem conservation financially self-sustaining.	Identify groups that receive large benefit flows from which funds could be extracted.

Table 9.4(b) Economic valuation methods applicable to ecosystem services

Methodology	*Approach*	*Applications*	*Data required*	*Limitations*
Revealed preference methods:				
Production function	Trace impact on produce of change in ecosystem services.	Any impact affecting farming, industry, etc.	Net value of produce foregone under impact.	Before and after data often lacking.
Health costs, human capital	Morbidity and mortality impacts of ecosystem change.	E.g. air or water pollution with impacts on human health.	Dose-response functions; cost of illness, value of life.	Functions and costs not easily yielded by toxicology or actuarial calculation.
Replacement, relocation costs	Cost of replacing the lost goods or services.	Any loss of goods or services.	Extent of loss and cost of replacement.	Tends to overestimate actual values.
Travel costs	Derive demand curve from survey data.	Recreation or amenity best suited.	Survey to collect monetary and time costs.	Hard to index multiple destinations.
Hedonic pricing	Extract prices of goods that include goods and services.	Air quality, scenery, cultural benefits.	Prices and characteristics of goods.	Requires large amounts of data and sensitive to specification.
Stated preference methods:				
Contingent valuation	Ask respondents their willingness to pay for preferred option.	Any service.	Survey that presents scenarios and alternatives.	Many potential sources of bias.
Choice modelling	Ask respondents for preferred option from alternatives with particular attributes.	Any service.	Survey of respondents.	Analysis of data generated is complex.
Other methods:				
Benefits transfer	Use results from one scenario in a different context.	Any for which comparable studies exist.	Valuation at another similar site.	Similarity can be deceptive and results spurious.

nature upon which human well-being is dependent are in decline worldwide' (p. 1). Moreover, these losses constitute a threat to the achievement and sustainability of the Millennium Development Goals. The IISD report develops the challenges to valuation posed by the fact that many services are public goods and therefore not marketed by incorporation in property rights. It also warns that if markets for ecosystem services (MES) can be established by valuation we must ensure that they do not marginalise those too poor to participate.

Despite the pioneering example of New York's water supply catchment management (Chapter 4), the inclusion of ecosystem goods and services as costed benefits in economic decision-support tools like cost–benefit analysis remains rare and contentious. A frequently quoted example of a valuation of river ecosystem *goods* concerns the Hadejia-Nguru wetlands conservation project in Nigeria. Here a comparison was made by economists who calculated values for agricultural, fuel wood and fish production from the Hadejia-Jama'are floodplain as a comparison with a potentially damaging upstream Kano River irrigation project. Over all periods for calculating discounted values the floodplain 'won' by around 60 per cent extra income per hectare.

More contentious than this market pricing of goods is the necessarily indirect valuation of *services* (see Pearce, 2000). In early 1998 there was a celebrated attempt by the Environment Agency in England to restrict abstraction of groundwater naturally feeding the River Kennet by quoting 'non-use' values of £13.2 million for the disputed water. The Agency calculated the figure via population data for a radius of 60 kilometres from the river and contingent valuation data derived from other willingness-to-pay studies involving rivers, mainly that of the Darent (Garrod and Willis, 1996), where *non-use values* had 'carried the day' and the extent of public affection for 'natural' rivers had become apparent. At a public inquiry held into the abstractors' appeal against reduced volumes of abstraction, the government-appointed inspector ruled that the non-use benefits of the River Kennet were nearer to £0.3 million. The use of such valuations in decision support was badly damaged, as was the use of an instream flow incremental methodology (IFIM) 'environmental flows' model. The economic problems of valuing river flows are discussed, with examples of the derived sums, by Ozdemiroglu and Mourato (2000).

The focal point for choices which might be greatly assisted by environmental economics is clearly 'hydrosolidarity', particularly in the light of fundamental allocation of resources between the needs of human and non-human biota and the whole field of watershed management. 'Land stewardship through watershed management' (Ffolliott *et al.*, 2002) demands that we have less uncertain guidance on land-use hydrology but also that, for example, upstream communities can receive financial incentives to manage land in less intensive ways, or incorporate 'best practice', to benefit downstream beneficiaries (FAO, 2002). However, to believe Galaz (2005) is to put upstream–downstream relations firmly in the arena of politics and conflict resolution. We are thus back where we started in this section!

9.5 Formalities of adaptive management

Mitchell (1997) provides an effective compression of the principles and history of 'adaptive environmental management', also known as 'adaptive resource management' (Rogers *et al.*, 2000). It is now 30 years since Holling (1978) perceived that the environment raised new problems for civil society: policies lacked a rationale for coping with the 'uncertain, the unexpected and the unknown'.

Folke (2002) predicates the need for adaptive management of all natural resources on the twofold fundamental error underpinning past policies – the assumption of a linear, controllable response by ecosystems to human exploitation and the separation of action into human and ecosystem components. Table 9.5 summarises the categories of change seen as desirable by Folke, who goes on: 'Management for resilience enhances the likelihood of sustaining development in a world of transformations where the future is unpredictable and surprise is likely' (p. 33). *Resilience* has become a major theme of the Swedish International Water Institute (SIWI); Moberg and Galaz (2005) further advance the concept, citing water as the 'bloodstream of the biosphere' and promoting 'social resilience' – our capacity to absorb or even benefit from perturbations. 'Adaptive co-management sees resource management as a continuous learning-by-doing process that recognises public participation and collaborative learning' (p. 7).

There have been other, more measured and less comprehensive promotions of adaptive management, paying more attention to the realpolitik of the current management situation. Clark (2002) enters the mind-set of the river manager attempting sustainable plans and actions: the key-note is uncertainty, and this is especially troubling to those trained in conventional science and engineering approaches. However, the requirement for change should not be daunting. As engineers like Henry Petroski (1982, 2006) have argued, failure

Table 9.5 Changes in perception required by natural resource management

From	*To*
Assume stability, control change.	Accept change, manage for resilience.
Predictability, optimal control.	Uncertainty, risk spreading, insurance.
Managing resources for increased yield.	Managing diversity for coping with change.
Technological change solves resource scarcity.	Adaptive co-management builds resilience.
Society and nature separated.	Social–ecological co-evolution.

After Folke (2002)

is implicit in engineering design, although a fallen bridge can be rebuilt with improvements, whilst an ecosystem cannot. As Clark puts it, it is 'choosing to adjust to changing circumstances rather than attempting to hold the system in its existing state'.

Newson and Clark (2008) emphasise the irony that river restoration works best at scales (e.g. the catchment) for which we have least certainty over methods and outcomes. The presence of new disciplines and new interdisciplinarities increases the uncertainty; for example, ecologists and geomorphologists alike stress the rarity of stable endpoints and the rich possibilities of different suites of processes leading to identical morphologies and communities (and vice versa: one process having multiple outcomes!). The authors are realistic enough to admit that 'certain' actions remain socially desirable in circumstances such as regulation – evidence-based policies. However, they see uncertainty and adaptation as becoming civilising elements of coping with change: 'change is the only stability' is their concluding slogan. Of course, a major implication is that science must respond by adopting 'smart' systems of ecosystem and resource monitoring; there are signs that this approach is slowly emerging from river restoration (Florsheim *et al.*, 2006). Monitoring can serve two other vital functions in participatory management – prolonging community interest/involvement and keeping information flowing across the centre of the stakeholder platform.

The responsibilities of science in relation to society have been referred to many times in this volume, e.g. in Chapters 7 and 8. Lee (1993) used his long experience of coping with 'wicked' problems in the Columbia basin of the USA to rationalise science as a 'compass' by which society may navigate and politics as a 'gyroscope' by which it can allocate (decide). He takes the view that policies are experiments – a vital point of overlap capable of promoting adaptive management. 'Bounded conflict' becomes a vital role for the political system, the responsibility of governance structures and institutions – the conflict in which Lee participated was that between dams (power generation) and the salmon fishery in the Pacific North-West region. His view is that adaptive management is 'needed if scientific uncertainty is not to thwart socially timely action'. Lee is able to list the institutional factors affecting adaptive management as:

- There is a mandate to take action in the face of uncertainty.
- Decision makers are aware that they are experimenting anyway.
- Decision makers care about improving outcomes over biological timescales.
- Preservation of pristine environments is no longer an option, and human intervention cannot produce desired outcomes predictably.
- Resources are sufficient to measure ecosystem-scale behaviour.
- Theory, models and field methods are available to estimate and infer ecosystem-scale behaviour.

Table 9.6 Leadership style and organisational structure/culture in conventional bureaucracies and adaptive organisations

Issue	*Conventional bureaucracies*	*Adptive organisations*
Leadership style	Primarily command-and-control. Transactional.	Primarily to coordinate and facilitate. Generative.
Structure	Functional hierarchies. Vertical communication. Work *for*. . .	Dynamic teams. Horizontal dialogue. Work *with* . . .
Culture	Thought at top, action at bottom. Collect data, manage information. Follow rules and regulations. Culture of blame for error. Rather make no decision than wrong one. View uncertainty, complexity and change as threats.	Common purpose through collaborative goal setting. Act as a hub for knowledge. Driven by vision and values. Learn and adapt. Apply new knowledge to better decisions. Seek opportunities for learning and improvement.

Modified from Rogers *et al.* (2000)

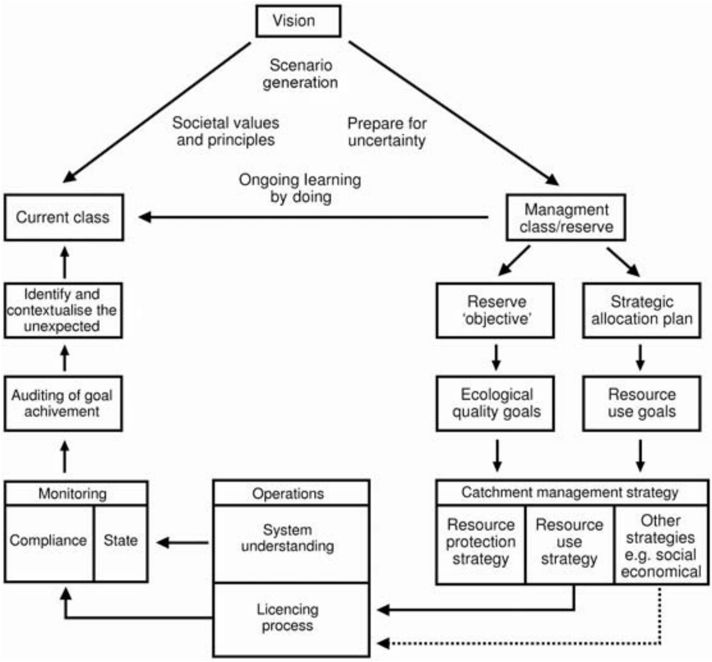


Figure 9.5 Strategic adaptive management of water resources (after Rogers *et al.*, 2000).

- Hypotheses can be formulated.
- Organisational culture encourages learning from experience.
- There is sufficient stability to measure long-term outcomes; institutional patience is essential.

Maybe it is this last condition which would prove politically intractable during rapid economic development. Rogers *et al.* (2000) review the huge institutional and organisational challenges facing the catchment management agencies configured by the 1998 National Water Act in South Africa. Despite the fresh start provided by the Act, a tradition of command-and-control approaches to environmental issues (Table 9.6) renders adaptive resource management subordinate to, for example, the 'tyranny of modelling'. Another variant (strategic adaptive management) is advocated to build a partnership between science, management and society (Figure 9.5).

Postscript

Globalised water – will poverty, trade and energy issues override basin-scale management?

Can we learn from the past? In the case of the Aral Sea we have been forced to a costly humility by the magnitude of the 40-year environmental and social disaster and definitive unsustainability (Chapter 1, but see 'The Aral Sea – righting the wrongs?', page 363).

Can we learn from the future? For the remainder of the Anthropocene, all we are entitled to expect is surprises! Perhaps two major trajectories for humankind can be identified: *technocentric* and *ecocentric* (O'Riordan, 1977), but this doesn't rule out compromise between these extremes, and we have identified upward 'creep' in the strength of sustainability being considered by policy makers as contingency in the face of change. In the context of the material between these covers, it will be interesting to observe whether the *global drivers* which currently concern us: poverty, trade, energy (which combine to increase the risk of war, famine and damaging environmental change), begin to control policy at the river basin scale. Given that very large basins have such great importance, particularly in terms of water stress, policies designed to mitigate or alleviate human welfare may well squeeze out the prevailing 'hydrocentricity'. The soundest political context for an ecocentric or hybrid response to these problems is in terms of the goods and services provided by *intact ecosystems*; of the services to human society, 'resilience' is perhaps the most valuable, but it needs costing in terms that politicians will understand. Another vital responsibility of those promoting the rights of non-human biota (the ecosystem) and habitats is to ensure that ecosystem management has all the qualities we deem essential in good water supply and sanitation for humans. We have seen that ecosystem management, particularly under conditions of rapid environmental change, is characterised by high levels of uncertainty but that these can be mitigated to some extent by adaptive management. However, much of *ecosystem management* is currently founded on ignorance, not uncertainty, and there remains a significant role for 'normal science' to light small candles in the darkness.

Poverty, water poverty and trading out water stress

IWRM meets poverty: what is the outcome? Some of the answers already ventured appear back in Chapter 5, and the precautionary principle appears to characterise most of them, particularly if the agendas become the longer-term ILWRM or IRBM. It may well be that IWRM is enjoying a 'last fling' via the very powerful advocacy of the Global Water Partnership (see Chapter 1), whose policy guidance 'toolbox' is described by some as sanctimonious, by others as driven by the capitalist 'water mafia', but by most professionals as a distillation of the sanctioned discourse amongst their ranks. After all, if the 'world water crisis' is in fact one of mismanagement, enlightened best practice is a reasonable attempt at a remedy, one that the toolbox is careful to make appropriate to local circumstances. The Global Water Partnership's definition is that IWRM 'is a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems'. In turn, the United Nations Environment Programme, which has produced a decade of global integrated environmental assessments, has in its latest report stated that 'practical implementation of Integrated Water Resource Management (IWRM) at the basin scale, including consideration of conjunctive groundwater aquifers and downstream coastal areas, is a key response to freshwater scarcity'. The key question remains, are there other responses – from outwith the water profession?

Turton *et al.* (2003) suggest that we need 'decision-making capacities beyond those of the hydrology, agriculture and engineering communities', within what I described in Chapter 9 as the cauldron of hydropolitics. Whilst these authors take a more theoretical approach than the inductively derived IWRM, the social theory they employ matches with both 'humans in the ecosystem' and 'the ecosystem approach' described at many points above. The *adaptive capacity of a nation or region* links the mobilisation of social resources to existing natural capital to ensure adequate resource availability. The 'precautionary development trajectory' harmonises the improvement in standards of living (alternatively, the Human Development Index) with moderate depletion of environmental resources to keep within 'the sustainability box'. The poverty dimension is not ignored: 'How, why and where the "poverty reduction" goal is placed within the hierarchy of food and water decision-making will impact on the policy options pursued.' Whilst food security (partly achievable by trade in 'virtual water' – see the following section) appears paramount to poverty alleviation, Turton *et al.* suggest that a better understanding of the household water economy might suggest that 'more water for agriculture' is not the answer, however much rural households are key to poverty in many developing nations. The theoretical framework is applied to case studies in the Middle East and Africa, North and South. Rather than a toolbox, the authors venture an as-yet conceptual model which allows consideration of a range of policy options which can be tailored to national macro-economic circumstances with poverty alleviation as an optional final filter; trade in food via 'virtual water' is one of the options.

Returning to IWRM, it is unashamedly ventured as the panacea for poverty alleviation by 'the water sector' (Ahmad, 2003), yet justified by the management failures which precipitate water 'crisis'. Ahmad makes an attempt to ask 'Who are the poor?' and assesses 'Why the poor are poor'. The answers seem to fall into the analytical picture framed by Turton *et al.* (2003): ongoing socio-economic and political processes locally but, more generally, unfavourable trade, protectionist agricultural policies by developed nations, high debt burdens and low foreign direct investment.

Writing of the 'water–poverty interface', Ahmad features livelihood, health and hazardous extreme impacts of badly managed water systems as contributors to poverty. He carefully balances anthropogenic and natural symptoms: allocation, especially for food growing and during rapid urbanisation, but also ecological unsustainability and climate change.

Another angle on the water–poverty interface is provided by the recent development of a Water Poverty Index (WPI) (Lawrence *et al.*, 2002); the main components of this index are resources, access, capacity, use and environment. Each component is indexed by several variables, for example access is defined by clean drinking water, sanitation and irrigation (as a percentage of the population in need). The capacity component relates better to the multidimensional concept of poverty now seen as useful by international agencies – it includes income, education, infant mortality and income distribution. Mapping the Water Poverty Index, Lawrence *et al.* depict very clearly the dire state of Africa and South Asia (mostly 'severe' and 'high' respectively). A retrospective account of the successes, failures and future data demands of the WPI is provided by Sullivan and Meigh (2007); the integration of data from different disciplines at different scales faced by the indicator approach neatly encompasses many of the scientific, social and institutional dilemmas covered in this book.

Will 'virtual water' work?

At the time of writing, Hoekstra and Chapagain (2008) have published the largest accessible account of the world trade in 'virtual water', under the title *Globalization of Water*. They claim that:

> We are convinced that many of today's water problems cannot be solved at river basin level, because they are inextricably bound up with the processes that determine where in the world agricultural and industrial production take place and with the written and unwritten rules of global trade.
>
> (Hoekstra and Chapagain, 2008, p. xi)

Given that most authors consider food security and trade are serious component causes of poverty and that poverty is inextricably linked to environmental degradation, can strategies based around 'virtual water' alleviate both water stress (to human and non-human biota) and poverty? Turton *et al.* (2003) see benefits because 'broad-based ideas such as "virtual water" allow decision-makers to understand the existence of different macro-options'. However, elsewhere 'virtual water' excites deep controversy. Allan (2003), usually cited as the propagator of the concept 'in about 1993', has suggested that alternative terms like 'embedded water' may be more meaningful for the cognoscenti, but they have no popular impact. Hoekstra and Chapagain also consider 'embodied' and 'shadow' water.

Water is embedded in commodities by their growth or manufacture, and some, like fruit, carry high proportions of water when traded. Trade, therefore, can completely obscure a national water 'footprint'. The concept in fact combines well with those of 'green water' and with the import and export of sustainability (in which one partner sells products made unsustainably to another which wishes, thereby, to preserve a sustainability record). The controversy arises, it seems, because of the metaphorical nature of the term. Merrett (2003a, 2003b) suggests that the debate needs nothing more than the term 'water requirements' (principally of agricultural commodities); he also refutes the impression given in publications by Allan that crop water travels with the crop when traded. If 'virtual water' becomes a strategy for trading out poverty and water stress, it will increase the economic hegemony of the developed world (already impressive via the World Trade Organization, World Bank and International Monetary Fund).

Water and energy: fuelling desalination, hydro-electricity and irrigating biofuels!

Students in a Newcastle classroom are generally surprised and slightly confused at being told that the biggest component of cost in a glass of water is energy. This fact arises from both the costs of pumping within the relatively luxurious supply and waste pipe networks in the UK and the fact that environmental costs are not yet fully included.

Technocentric students are also underwhelmed by the 'world water crisis' when *'the answer surely is desalination'*. The technology of removing salt from water is, of course, naturally based: evaporate the water or filter out the salt. However, the energy costs of doing so, in order to produce the volumes currently demanded for most uses, for most population densities are prohibitive. Since the first industrial desalination plant in 1881, progress has been very slow. An energy-rich nation such as the United States built its first large-scale plant in 2003 (two more are planned), and London recently scrapped plans for a plant because of the carbon footprint of the energy required and the brine waste product from the process. From a very different perspective, an experiment is going on in Gujarat, India, to produce small volumes of safe drinking water from a reverse osmosis desalination plant powered by oxen; the capacity is around 500 litres per hour. Until, following classical economics, we run so short that water prices rise (perhaps because of fully costed environmental damage from, from example, large dams) it will remain the privilege of regions with large solar power potential to desalinate – and then perhaps to benefit one economic sector: horticulture. 'Sea-water greenhouses' are becoming a popular feasibility development in, for example, Tenerife and Abu Dhabi. However, even in solar-rich countries like Saudi Arabia, other, less energy-intensive means of improving water collection, e.g. from fog, are forging further ahead (Gandhidasan and Abualhamayel, 2007). When compared with the volumes achievable by demand management, irrigation efficiency and surface water management, the contribution from desalination is likely to figure more in the finance and technology sections of newspapers than as a newsworthy contribution to environmental sustainability.

The water–energy link is reversed in two thematic areas: *hydro-electric power* generation and the growth, using 'green water', of *biofuel crops*. Hydro-electric power is often seen as a 'green' alternative to fossil fuel combustion, providing plentiful renewable electric power with a very low carbon footprint. Hydro-electric power stations can also respond quickly to demand peaks and troughs, though the necessity to alter water release volumes from dams powering turbines to be this flexible leads to drastic departures from 'environmental flows'. Currently, 19 per cent of world energy needs are supplied by hydro-power (World Commission on Dams, 2000); 78 per cent of the world hydro-power potential is yet untapped (Majot, 1997). The first water turbines were used to boost the power of water mills in 1832; 50 years later the first hydro-power station was built (McCully, 2001). McCully has long been warning that the large-scale modern equivalent has few of the environmental advantages usually claimed by dam builders: 'Hydropower, however, is not only socially and environmentally destructive but is also far from being as "climate friendly" as its proponents allege.' As a result of the flooding of potential carbon sinks by reservoir development and the carbon dioxide and methane emissions from drowned vegetation, some hydro-power plants (notably in tropical basins) can exceed the emissions of 'greenhouse' gases of coal- and gas-fired plants. This finding is the more worrying because installing a new hydro-power plant constitutes a 'clean development mechanism' under the Kyoto Protocol. McCully also has concerns that hydro-power is not as cheap as proponents claim and that many completed stations hardly reach half the output designed into their generation plant; the World Commission on Dams (2000) has a detailed survey of performance.

There are, however, many advocates of small-scale hydro-power, akin to the local energy generation provided by water mills and making far less impact on the physical characteristics of the rivers driving the turbines: environmental flow regimes are largely maintained by an off-stream turbine. However, for those nations without alternative energy sources, only large plants (often strings of them on the same river, as in Canada) will suffice to power industry, commerce and urbanisation: 24 nations are more than 90 per cent dependent. Examples include the Three Gorges dam in China and a proposal for one on the Congo (Grand Inga) with double its capacity, capable of supplying 500 million Africans. Africa's hydro-electric power is massively under-developed, but capacity under construction increases by 25 per cent per year at present. Brazil's economic development is also hydro-powered: hence its attention to dam projects in the Amazon basin, some of which already have a proven record of greenhouse gas pollution (e.g. Balbina).

Hydro-power has one obvious disadvantage: its vulnerability to drought. At the time of writing, China's 15 per cent power dependency on hydro-power has been drastically cut back because of low river flows. This vulnerability can be total on small streams which dry up quickly: a disadvantage with 'small', 'mini', 'micro' and 'pico' scales promoted as alternatives to large dams by Majot (1997); however, another alternative also advocated by these authors – demand management – seems the most promising way forward for all forms of energy production.

Another technocentric hope for an extended renewable energy source towards the end of the Anthropocene is biofuel: on 18 December 2007, George W. Bush put his presidential signature on a bill to increase fivefold the biofuel production of the USA by 2022. Ethanol is thought by many to be the mass transport and heating fuel of the future, rescuing the American Midwest from agricultural depression, yet releasing possibly as little as 25 per cent more energy than is used in its production from corn. Into the bargain, a 'rush' into biofuels will intensify land use, scrapping such habitat conservation measures as 'set-aside' and threatening food reserves. In our context, however, it is the water demand by biofuel cropping and conversion that makes a major impact on levels of water stress and the balance between human and non-human (ecosystem) demands. Varis (2007) reminds us that to produce 1 kilogram of biofuel crop typically requires 200 kilograms of water; put another way, 25 cubic metres of evaporated water might be required to produce one gigajoule of energy. Thus, global and regional assessments of renewable energy strategies must include the impact on available water resources; like hydro-power, biofuel is not a miracle technocentric solution to an acknowledged critical problem.

The carbon flux of river systems, both particulate and dissolved, has long been acknowledged as a prime energy source to freshwater ecosystems; however, it is changing, partly because of land-use changes but partly through climate variability. Worrall and Burt (2007) collate dissolved organic carbon (DOC) data from 315 rivers from across Britain; almost three-quarters, mainly those with peaty headwaters, show an increase in recent years, but there is no consistent causal signal, e.g. climate or pollution. Increasing DOC in rivers has been identified in many parts of the northern hemisphere, and there is sufficient concern to protect 'locked-up' carbon that some organisations want the trend reversed as part of climate protection. The Westcountry Rivers Trust in the UK has claimed that anthropogenic climate change can be partly mitigated by wise catchment management: 'improved ecosystem function' in local rivers constitutes in their view a new approach to voluntary carbon offsetting (Westcountry Rivers Trust, 2007). This brings us nicely to our final dilemma: the vital role of the ecosystem approach for sustainable, adaptive river management.

The ultimate challenge: ecosystem management under uncertainty, ignorance and surprises

It is fair to say that, if IWRM presents itself as the global water professionals' model for sustainability, it does so under a seemingly technocentrist banner without much troubling the prevailing capitalist economic model. This neglects the emerging consensus, possibly restricted to ecocentrists like the author, that sustainability demands new starting points, amongst them a reconciliation of *economy* and *ecology*. Points of entry to this start 'area' include the concept of humans *in* the ecosystem and its corollary of fully costed ecosystem goods and services. In return, surely, it is the responsibility of the relevant sciences – whilst adopting the role of science in the 'Risk Society' – to assist in as rational and efficient a system of ecosystem management as is possible under uncertainty and even ignorance.

Jewitt (2001) puts the position as boldly as this:

> there is the danger that traditional command and control approaches to management of the water resources system will continue to be applied under the banner of IWRM. Achieving the sustainable use of water resources and thus the maintenance of ecosystem services requires a rediscovery of the hydrological cycle and the water resources system.

He follows Rogers and Biggs (1999), also from South Africa and also writing from the perspective of the practicalities of managing the ecological reserve of water under the National Water Act (Chapter 5); additionally these authors have the enlightened example of river management in the Kruger National Park behind them, a powerful endorsement of the more conceptual writings of the Swedish International Water Institute. The vital role of 'green water' is picked up by Jewitt: 'IWRM must therefore consider the management of the land portion of the water resources system as critical to its success.' He claims that water resources must not be exploited beyond the point where resilience is lost, and resilience depends on 'maintaining a certain base level of ecological integrity and function'.

Here, then, is the final 'wicked problem' of the book: Jewitt's 'certain base level' is in fact a very uncertain base level, yet until it is estimated and selected using tools derived from science but sanctioned by politics we cannot even share fresh water between society and ecosystems however much we promote, nay protest, the need (Falkenmark, 2003a; Wallace *et al.*, 2003). As Falkenmark concludes, 'the overall problematique boils down to finding ways of meeting at the same time immediate societal needs through proper management of ecosystem services, and long-term ecosystem needs to secure social and economic development'. Wallace *et al.* stress the practical needs to put physical quantities and social values on human and aquatic ecosystem requirements; both papers select the catchment scale as the basis for action.

The work by Rockström and Gordon (2001) is often quoted as a 'big bid' for the 'green water' used by the world's ecosystems: they depend on 90 per cent of the terrestrial return flow of 'green water' to the atmosphere, leaving human society with a dire responsibility to use its water efficiently. They make an elegant conclusion that 'Water conventionally perceived as unused and invisible is, on our human dominated planet, to a large extent already in use for ecosystem support and services to social and economic development'. *Water resource management cannot, therefore, be separated from ecosystem management* and freshwater ecosystem processes cannot be researched without including 'hydromorphology'; this represents a profound change to the establishment 'normal' science which has produced IWRM. In fact, of course, the larger dimensions of the 'fluvial hydrosystem' (Chapter 2) and the incorporation of land-use hydrology require that a landscape approach is taken in this reconfiguration of research and development (Roux *et al.*, 2002). Only in this way can the 'ignorance' aspect of sustainability science be addressed. No index of sustainability, however specific to land and water (e.g. Chaves and Alipaz, 2007), can succeed at present except to assist in, for example, gross international comparisons.

And what of the primary benefit humans can expect? We can illustrate the flows of ecosystem goods and services to human society, the beneficial impacts on poverty alleviation and a kind of cultural serenity induced by living within safely set environmental limits, but resilience is the master benefit, yet the hardest with which to convince people. 'It's all in the mind' suggests a caption in Moberg and Galaz (2005), but if we can capture a meaning as rich as 'immune system' or 'ability to cope' we start to pull in the political model of Turton *et al.* and match it to adaptive management strategies to cope with uncertain futures. As Moberg and Galaz suggest, 'there is now a move towards a perspective that strives for sustaining and enhancing the capacity of both human and natural systems to cope with, adapt to, and shape change'.

The second edition concluded with a call for a new water ethic. Whilst Acreman (2001) warns that this may be a luxury afforded by those who have already achieved economic and social security, let's have another try! Tabara and Pahl-Wostl (2007) have stated that 'Sustainability demands, above all, a cultural transition in the form of an emerging sustainability culture that views humans as an inextricable part of making their own social-ecological system.' Bouguerra (2006) has suggested 'the renunciation of egotistic positions, since water and the water cycle are the common denominator joining together human beings on Earth', to which we would add that water is 'the bloodstream of the biosphere' (Ripl, 2003) and, taken together, this justifies the single-word ethical mantra: 'hydrosolidarity'.

The Aral Sea – righting the wrongs?

> One of the most severe manmade environmental and ecological disasters of all time was created during the last decades of the 20th Century due to the lack of consciousness regarding the consequences of the integrated effects of widespread deforestation and water withdrawal for irrigation.
>
> (Ehlin, 2000)

The Aral Sea Basin Programme (ASBP):

- the result of interstate agreements to set up new regional institutions;
- objectives: to stabilise the environment, improve the management of international waters;
- to build the capacity of regional institutions.

Biggest component projects (World Bank/Global Environment Facility):

- water and salt management;
- public awareness;
- dam and reservoir management;
- transboundary monitoring;
- wetland restoration;
- water supply and sanitation;
- hydrometeorological monitoring;
- water and energy;
- ecological research;
- human rehabilitation.

Goals to be reached by 2025:

- There is sufficient water for a 'bright future' given cooperative use and greater irrigation efficiency.
- Knowledge on land and water-related socio-economic factors in the region is insufficient and must be improved.
- The largest environmental problem to tackle is soil salinity.

- Industry and tourism to be expanded – they use less and permit ‘virtual’ water imports.
- Restoration of the Sea itself to pre-1960 levels/extent is impossible.
- High initial expenditure is needed for long-term economic benefits.

(Sources contained in SIWI, RSAS and UNIFEM, 2000)

References

Abate, Z. (1994) *Water Resources Development in Ethiopia*, Reading: Ithaca Press.

Aberley, D. (1993) *Boundaries of Home: Mapping for Local Empowerment*, Gabriola Island, BC: New Society Publishers.

Abu-Maila, Y. S. (1991) 'Water resource issues in the Gaza Strip', *Area*, 23(3), 209–16.

Abu-Zeid, M. and O'Neil, M. (2007) 'Foreword', *Water Resources Development*, 23(2), 205–7.

Achet, S. H. and Fleming, B. (2006) 'A watershed management framework for mountain areas: lessons from 25 years of watershed conservation in Nepal', *Journal of Environmental Planning and Management*, 49(5), 675–94.

Ackroyd, P. (2007) *Thames: Sacred River*, London: Chatto & Windus.

Acreman, M. (2001) 'Ethical aspects of water and ecosystems', *Water Policy*, 3, 257–65.

Acreman, M. and Dunbar, M. J. (2004) 'Defining environmental flow requirements – a review', *Hydrology and Earth Systems Sciences*, 8(5), 861–76.

Adams, B. and Foster, S. S. D. (1992) 'Land-surface zoning for groundwater protection', *Journal of the Institution of Water and Environmental Management*, 6, 312–20.

Adams, W. A., Perrow, M. R. and Carpenter, A. (2004) 'Conservatives and champions: river managers and the river restoration discourse in the United Kingdom', *Environment and Planning A*, 36, 1929–42.

Adams, W. M. (1985) 'River basin planning in Nigeria', *Applied Geography*, 5, 297–308.

Adams, W. M. (1992) *Wasting the Rain: Rivers, People and Planning in Africa*, London: Earthscan.

Adams, W. M., Portanski, T. and Sutton, J. E. G. (1994) 'Indigenous farmer-managed irrigation in Soiyo, Tanzania', *Geographical Journal*, 160(1), 17–32.

Adel, M. M. (2002) 'Man-made climatic changes in the Ganges basin', *International Journal of Climatology*, 22, 993–1016.

Aeschbacher, J., Liniger, H. and Weingartner, R. (2005) 'River water shortage in a highland–lowland system', *Mountain Research and Development*, 25(2), 155–62.

Agarwal, A., Kimondo, J., Moreno, G. and Tinker, J. (1980) *Water, Sanitation, Health – For All? Prospects for the International Drinking Water Supply and Sanitation Decade, 1981–90*, London: Earthscan.

Agnew, C. (2002) 'Drought, desertification and desiccation: the need for further analysis', *Geography*, 87(3), 256–67.

Ahmad, Q. K. (2003) 'Towards poverty alleviation: the water sector perspectives', *Water Resources Development*, 19(2), 263–77.

Ahmed, S. (1990) 'Cleaning the River Ganga: rhetoric and reality', *Ambio*, 19(1), 42–5.

Akpabio, E. M., Watson, N. M., Ite, U. E. and Ukpong, I. E. (2007) 'Integrated water resources management in the Cross River basin, Nigeria', *Water Resources Development*, 23(4), 691–708.

Alabaster, J. S. (1972) 'Suspended solids and fisheries', *Proceedings of the Royal Society of London, Series B*, 180, 395–406.

Alcamo, J. *et al.* (2003) *Millennium Ecosystem Assessment: A Framework for Assessment – Ecosystems and Human Well-being*, Washington, DC: Island Press.

Al-Ibrahim, A. A. (1990) 'Water use in Saudi Arabia: problems and policy implications', *Journal of Water Resource Planning and Management*, 116(3), 375–88.

Al-Ibrahim, A. A. (1991) 'Excessive use of groundwater resources in Saudi Arabia: impacts and policy options, *Ambio*, 20(1), 34–7.

Al Jayyousi, O. (2007) 'Water as a human right: towards civil society globalization', *Water Resources Development*, 23(2): 329–39.

Allan, J. A. (1992) 'Fortunately there are substitutes for water: otherwise our hydropolitical futures would be impossible', in *Proceedings of the Conference on Priorities for Water Resources Allocation and Management*, London: Overseas Development Administration, 13–26.

Allan, J. A. (1995) 'The political economy of water: reasons for optimism but long term caution', in J. A. Allan (ed.), *Water, Peace and the Middle East: Negotiating Resources in the Jordan Basin*, London: Tauris, 75–117.

Allan, J. A. (2003) 'Virtual water – the water, food and trade nexus: useful concept or misleading metaphor?', *Water International*, 28(1), 4–11.

Allan, J. A. and Karshenas, M. (1996) 'Managing environmental capital: the case of water in Israel, Jordan, the West Bank and Gaza, 1947 to 1995', in J. A. Allan (ed.), *Water, Peace and the Middle East: Negotiating Resources in the Jordan Basin*, London: Tauris, 121–33.

Allen, R. G., Gichniki, F. N. and Rosenzweig, C. (1991) CO_2-enhanced climatic changes and irrigation water requirements', *Journal of Water Resource Planning and Management*, 117(2), 157–78.

Alvares, C. and Billorey, R. (1988) *Damming the Narmada: India's Greatest Planned Environmental Disaster*, Penang, Malaysia: Third World Network/APPEN.

Amoros, C., Roux, A. L., Raygrobellet, J. L., Brayard, J. P. and Paton, G. (1987) 'A method for applied ecological studies of fluvial hydrosystems', *Regulated Rivers: Research and Management*, 1(1), 17–36.

Andrew, J. and Robottom, I. (2005) 'Communities' self-determination: whose interests count?', in M. Keen, V. A. Brown and R. Dyball (eds), *Social Learning in Environmental Management: Towards a Sustainable Future*, London: Earthscan, 63–77.

Annin, P. (2006) *The Great Lakes Water Wars*, Washington, DC: Island Press.

Archer, D. (2003) 'Scale effects on the hydrological impact of upland afforestation and drainage using indices of flow variability: the River Irthing, England', *Hydrology and Earth System Sciences*, 7(3): 325–38.

Archer, D. R. and Williams, G. (1995) *Resolving Conflicts between Sustainable Energy and Water Resources in the Regulation of the River Tyne, England*, IAHS Publication 231, Wallingford, Oxon: International Association of Hydrological Sciences, 3–14.

Arnell, N. W. and Reynard, N. S. (1996) 'The effects of climate change due to global warming on river flows in Great Britain', *Journal of Hydrology*, 183, 397–424.

Arnell, N. W. and Delaney, E. K. (2006) 'Adapting to climate change: public water supply in England and Wales', *Climate Change*, 78, 227–55.

Arnell, N. W., Jenkins, A. and George, D. G. (1994) *The Implications of Climate Change for the National Rivers Authority*, London: HMSO.

Arntzen, J. (1995) 'Economic instruments for sustainable resource management: the case of Botswana's water resources', *Ambio*, 24(6), 335–42.

Arthington, A. H. and Pusey, B. J. (2003) 'Flow restoration and protection in Australian rivers', *River Research and Applications*, 19, 377–95.

Arthington, A. H., Bunn, S. E., Poff, N. L. and Naiman, R. J. (2006) 'The challenge of providing environmental flow rules to sustain river ecosystems', *Ecological Applications*, 16(4), 1311–18.

Arya, S. L., Agnihotri, Y. and Samra, J. S. (1994) 'Watershed management: changes in animal population structure, income and cattle migration, Shiwaliks, India', *Ambio*, 23(7), 446–50.

Ashton, P. J. (2002) 'Avoiding conflicts over Africa's water resources', *Ambio*, 31(3), 236–42.

Ashton, P. (2004) 'Water and development: a Southern African perspective', in J. Trottier and P. Slack (eds), *Managing Water Resources Past and Present: The Linacre Lectures, 2002*, Oxford: Oxford University Press, 149–74.

Association of British Insurers (ABI) (2005) *Making Communities Sustainable: Managing Flood Risk in the Government's Growth Areas*, London: ABI.

Atkinson, T. C. (1978) 'Techniques for measuring subsurface flow on hillslopes', in M. J. Kirkby (ed.), *Hillslope Hydrology*, Chichester: Wiley, 73–120.

Babbitt, B. (2000) 'A new course for water policy', *World Rivers Review*, February, 10–13.

Bagader, A. A., El-Sabbagh, A. T. E., Al-Glayand, M. A. and Samarrai, M. Y. I. (1994) *Environmental Protection in Islam*, Gland, Switzerland: IUCN.

Bagnold, R. A. (1977) 'Bedload transport by natural rivers', *Water Resources Research*, 13, 302–12.

Baird, A. J. and Wilby, R. L. (1999) *Eco-hydrology: Plants and Water in Terrestrial and Aquatic Ecosystems*, London: Routledge.

Baldock, D. (1984) *Wetland Drainage in Europe: The Effects of Agricultural Policy in Four EEC Countries*, London: IEEP/IIED.

Balling, R. C. and Goodrich, G. B. (2007) 'Analysis of drought determinants for the Colorado River basin', *Climatic Change*, 82: 179–94.

Bandyopadhyay, J. (1987) *The Indian Drought 1987–88: The Ecological Causes of Water Crisis – What to Do*, Penang, Malaysia: Third World Science Movement.

Bandyopadhyay, J. and Gyawali, D. (1994) 'Himalayan water resources: ecological and political aspects of management', *Mountain Research and Development*, 14(1), 1–24.

Barnett, T., Malone, R., Pennell, W., Stammer, D. and Washington, W. (2004) 'The effects of climate change on water resources in the West: introduction and overview', *Climatic Change*, 62, 1–11.

Barrow, C. (1987) *Water Resources and Agricultural Development in the Tropics*, Harlow: Longman.

Barrow, C. J. (1999) *Alternative Irrigation: The Promise of Runoff Agriculture*, London: Earthscan.

Batchelor, C. H., Rama Mohan Rao, M. S. and Manohar, S. (2003) 'Watershed development: a solution to water shortages in semi-arid India or part of the problem?', *Land Use and Water Resources Research*, 3, 1–10.

Batchelor, M. and Brown, K. (eds) (1992) *Buddhism and Ecology*, London: Cassell.

Bates, S. F., Getches, D. H., Macdonnell, L. J. and Wilkinson, C. F. (1993) *Searching out the Headwaters: Change and Rediscovery in Western Water Policy*, Washington, DC: Island Press.

Bathurst, J. C., Benson, I. A., Valentine, E. M. and Nalluri, C. (2002) 'Overbank sediment deposition patterns for straight and meandering flume channels', *Earth Surface Processes and Landforms*, 27, 659–65.

Beaumont, P. (1989) *Environmental Management and Development in Drylands*, London: Routledge.

Beck, U. (1992) *Risk Society: Towards a New Modernity*, London: Sage.

Bennett, J. (2003) 'Opportunities for increasing water productivity of CGIAR crops through plant breeding and molecular biology', in J. W. Kijne, R. Barker and D. Molden (eds), *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, Wallingford, Oxon: CABI Publishing, 103–26.

Beresford, Q., Bekle, H., Phillips, H. and Mulcock, J. (2001) *The Salinity Crisis: Landscapes, Communities and Politics*, Crawley, WA: University of Western Australia Press.

Berkes, F., Kislalioglu, M., Folke, C. and Gadgil, M. (1998) 'Exploring the basic ecological unit: ecosystem-like concepts in traditional societies', *Ecosystems*, 1, 409–15.

Bessette, G. (2006) *People, Land and Water: Participatory Development Communication for Natural Resource Management*, London: Earthscan.

Beukman, R. (2002) *Revisiting Local Water Management in Southern Africa*, Ottawa: International Development Research Centre, Policy Workshop on Local Water Management.

Beven, K. (1985) 'Distributed models', in M. G. Anderson and T. P. Burt (eds), *Hydrological Forecasting*, Chichester: Wiley, 405–35.

Beven, K. J. (2001) *Rainfall-Runoff Modelling: The Primer*, Chichester: Wiley.

Beven, K., Heathwaite, L., Haygarth, P., Walling, D., Brazier, R. and Withers, P. (2005) 'On the concept of delivery of sediment and nutrients to stream channels', *Hydrological Processes*, 19, 551–6.

Bewket, W. (2002) 'Land cover dynamics since the 1950s in Chemoga watershed, Blue Nile basin, Ethiopia', *Mountain Research and Development*, 22(3), 263–9.

Binnie, G. M. (1981) *Early Victorian Water Engineers*, London: Thomas Telford.

Binnie, G. M. (1987) *Early Dam Builders in Britain*, London: Thomas Telford.

Binns, T. (1998) 'Geography and development in the "new" South Africa', *Geography*, 83(1), 3–14.

Bissio, B. (ed.) (1988) *Third World Guide*, Montevideo: Third World Editors.

Biswas, A. K. (1967) 'Hydrologic engineering prior to 600 BC', *Proceedings of the American Society of Civil Engineers Journal, Hydraulics Division*, HY5, 118–31.

Biswas, A. K. (1993) 'Land resources for sustainable agricultural development in Egypt', *Ambio*, 22(8), 556–60.

Biswas, A. K. (2004) 'Integrated water resources management: a reassessment', *Water International*, 29(2), 248–56.

Biswas, A. K. (2005) 'An assessment of future global water issues', *Water Resources Development*, 21(2), 229–37.

Biswas, A. K., Jayatilaka, R. and Tortajada, C. (2005) 'Social perceptions of the impacts of Colombo water supply projects', *Ambio*, 34(8), 639–44.

Black, P. E. (1982) *Conservation of Water and Related Land Resources*, Westport, CT: Praeger.

Blackie, J. R. and Eeles, C. W. O. (1985) 'Lumped catchment models', in M. G. Anderson and T. P. Burt (eds), *Hydrological Forecasting*, Chichester: Wiley, 311–45.

Blackie, J. R. and Robinson, M. (2007) 'Development of catchment research, with particular attention to Plynlimon and its forerunner, the East African catchments', *Hydrology and Earth System Science*, 11(1), 26–43.

Blackie, J. R., Edwards, K. A. and Clarke, R. T. (eds) (1979) 'Hydrological research in East Africa', *East African Agriculture and Forestry Journal*, Special Issue 43.

Blackmore, C. (2007) 'What kinds of knowledge, knowing and learning are required for addressing resource dilemmas? A theoretical view', *Environmental Science and Policy*, 10, 512–25.

Blaikie, P. (1985) *The Political Economy of Soil Erosion in Developing Countries*, Harlow: Longman.

Blomquist, W., Calbick, K. S. and Dinar, A. (2005) *Institutional and Policy Analysis of River Basin Management: The Fraser Basin, Canada*, Policy Research Working Paper 3525, Washington, DC: World Bank.

Blood, E. R. (2003) 'Regional water strategies', in M. M. Holland, E. R. Blood and L. R. Shaffer (eds), *Achieving Sustainable Freshwater Systems: A Web of Connections*, Washington, DC: Island Press, 251–82.

Boardman, J. (1990) *Soil Erosion in Britain: Costs, Attitudes and Policies*, Social Audit Paper 1, Brighton: Education Network for Environment and Development.

Boardman, J. (2006) 'Soil erosion science: reflections on the limitations of current approaches', *Catena*, 68, 73–86.

Boardman, J., Dearing, J. A. and Foster, I. D. L. (1990) 'Soil erosion studies: some assessments', in J. Boardman, I. D. L. Foster and J. A. Dearing (eds), *Soil Erosion on Agricultural Land*, Chichester: Wiley, 659–72.

Boardman, J., Evans, R. and Ford, J. (2003) 'Muddy floods on the South Downs, southern England: problem and response', *Environmental Science and Policy*, 6(1), 411–19.

Bonell, M. and Balek, J. (1993) 'Recent scientific developments and research needs in hydrological processes of the humid tropics', in M. Bonell, M. M. Hufschmidt and J. S. Gladwell (eds), *Hydrology and Water Management in the Humid Tropics*, Cambridge: Cambridge University Press, 167–260.

Bonell, M. and Bruijnzeel, L. A. (eds) (2005) *Forests, Water and People in the Humid Tropics*, Cambridge: Cambridge University Press.

Bonell, M., Hufschmidt, M. M. and Gladwell, J. S. (1993) *Hydrology and Water Management in the Humid Tropics*, Cambridge: Cambridge University Press.

Bonnett, A. (2008) *What Is Geography?*, London: Sage.

Boon, P. J. (1987) 'The influence of Kielder Water on Trichopteran (caddisfly) populations in the River North Tyne (northern England)', *Regulated Rivers: Research and Management*, 1, 95–109.

Boon, P. J. (1992) 'Essential elements in the case for river conservation', in P. J. Boon, P. Calow and G. E. Petts (eds), *River Conservation and Management*, Chichester: Wiley, 11–33.

Bosch, J. M. and Hewlett, J. D. (1982) 'A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration', *Journal of Hydrology*, 55, 3–23.

Botterill, L. C. (2003) 'Government responses to drought in Australia', in L. C. Botterill and M. Fisher (eds), *Beyond Drought: People, Policy and Perspectives*, Collingwood, Victoria: CSIRO Press, 49–65.

Bouguerra, L. (2006) *Water under Threat*, London: Zed Books.

Bowden, W. B., Fenemor, A. and Deans, N. (2004) 'Integrated water and catchment research for the public good: the Motueka–Tasman Bay initiative, New Zealand', *Water Resources Development*, 20(3), 311–23.

Bowman, J. A. (1990) 'Ground-water-management areas in the United States', *Journal of Water Resources Planning and Management*, ASCE, 116(4), 484–502.

Bowonder, B. and Ramana, K. V. (1987) 'Environmental degradation and economic development: a case study of a marginally productive area', *Applied Geography*, 7, 301–15.

Bracken, L. and Croke, J. (2007) 'The concept of hydrological connectivity and its contribution to understanding runoff-dominated geomorphic systems', *Hydrological Processes*, 21, 1749–63.

Bradley, D. C. and Ormerod, S. J. (2001) 'Community persistence among stream invertebrates tracks the North Atlantic Oscillation', *Journal of Animal Ecology*, 70, 987–96.

Braga, B. P. F. (2001) 'Integrated urban water resources management: a challenge into the 21st century', *Water Resources Development*, 17(4), 581–99.

Bramley, M. E. and Bowker, P. M. (2002) 'Improving local flood protection to property', *Civil Engineering*, 150, 49–54.

Brammer, H. (1990a) 'Floods in Bangladesh I: geographical background to the 1987 and 1988 floods', *Geographical Journal*, 156(1), 12–22.

Brammer, H. (1990b) 'Floods in Bangladesh II: flood mitigation and environmental aspects', *Geographical Journal*, 156(2), 158–65.

Bratt, G. (1995) *The Bisses of Valais: Man-Made Watercourses in Switzerland*, Gerrards Cross, Bucks.: Guy Bratt.

Brayshaw, A. C., Frostick, L. E. and Reid, I. (1983) 'The hydrodynamics of particle clusters and sediment entrainment in coarse alluvial channels', *Sedimentology*, 30, 137–43.

Breckwoldt, R., Boden, R. and Andrew, J. (2004) *The Darling*, Canberra: Murray–Darling Basin Commission.

Breuilly, E. and Palmer, M. (eds) (1992) *Christianity and Ecology*, London: Cassell.

Brichieri-Colombi, J. S. (2004) 'Hydrocentricity: a limited approach to achieving food and water security', *Water International*, 29(3), 318–28.

Brierley, G. J. and Murn, C. P. (1997) 'European impacts on downstream sediment transfer and bank erosion in Cobargo catchment, New South Wales, Australia', *Catena*, 31, 119–36.

Brierley, G. J. and Fryirs, K. (2000) 'River styles, a geomorphic approach to catchment characterization: implications for river rehabilitation in Bega catchment, New South Wales, Australia', *Environmental Management*, 25, 661–79.

Brierley, G. J. and Fryirs, K. A. (2005) *Geomorphology and River Management: Applications of the River Styles Framework*, Oxford: Blackwell.

Brierley, G., Hillman, M. and Fryirs, K. (2006) 'Knowing your place: an Australasian perspective on catchment-framed approaches to river repair', *Australian Geographer*, 37(2), 131–45.

British Ecological Society (1990) *River Water Quality*, Ecological Issues 1, London: British Ecological Society.

Brizga, S. and Finlayson, B. (eds) (2000) *River Management: The Australasian Experience*, Chichester: Wiley.

Brookes, A. (1992) 'Recovery and restoration of some engineered British river channels', in P. J. Boon, P. Calow and G. E. Petts (eds), *River Conservation and Management*, Chichester: Wiley, 337–52.

Brookes, A. (1995a) 'Challenges and objectives for geomorphology in UK river management', *Earth Surface Processes and Landforms*, 20, 593–610.

Brookes, A. (1995b) 'River channel restoration: theory and practice', in A. Gurnell and G. Petts (eds), *Changing River Channels*, Chichester: Wiley, 369–88.

Brookes, A. and Gregory, K. J. (1988) 'Channelization, river engineering and geomorphology', in J. M. Hooke (ed.), *Geomorphology in Environmental Planning*, Chichester: Wiley, 145–67.

Brookes, A. and Shields, F. F. (1996) *River Channel Restoration: Guiding Principles for Sustainable Projects*, Chichester: Wiley.

Brooks, D. B. (2007) 'Human rights to water in North Africa and the Middle East: what is new and what is not; what is important and what is not', *Water Resources Development*, 23(2), 227–41.

Brooks, K. N. and Tayaa, M. (2003) 'Planning and managing soil and water resources in drylands: role of watershed management', *Arid Lands Newsletter*, 52, University of Arizona.

Brouwer, F., Heinz, I. and Zabel, T. (2003) *Governance of Water-Related Conflicts in Agriculture: New Directions in Agri-Environmental and Water Policies in the EU*, Dordrecht: Kluwer.

Brown, A. G. (1987) 'Long-term sediment storage in the Severn and Wye catchments', in K. J. Gregory, J. Lewin and J. B. Thomas (eds), *Palaeohydrology in Practice*, Chichester: Wiley.

Brown, A. G. (2002) 'Learning from the past: palaeohydrology and palaeoecology', *Freshwater Biology*, 47, 817–29.

Brown, A. G. and Quine, T. A. (eds) (1999) *Fluvial Processes and Environmental Change*, Chichester: Wiley.

Brown, B. W. and Shelton, R. A. (1983) 'Fifty years of operation of the TVA reservoir system', in G. G. Green and E. E. Eiker (eds), *Accomplishments and Impacts of Reservoirs*, New York: ASCE, 138–51.

Brown, T. and Harper, D. (1999) 'Sustainability in the context of tropical catchments', in D. Harper and T. Brown (eds), *The Sustainable Management of Tropical Catchments*, Chichester: Wiley, 3–17.

Bruch, C., Nakayama, M., Troell, J., Goldman, L. and Maruma Mrema, E. (2007) 'Assessing the assessments: improving methodologies for impact assessment in transboundary watercourses', *Water Resources Development*, 23(3), 390–410.

Bruijnzeel, L. A. (1993) *Land-Use and Hydrology in Warm Humid Regions: Where Do We Stand?*, Publication 216, Wallingford, Oxon: International Association of Hydrological Sciences, 1–34.

Bruijnzeel, L. A. (2004) 'Hydrological functions of tropical forests: not seeing the soil for the trees?', *Agriculture, Ecosystems and Environment*, 104, 185–228.

Brune, G. M. (1958) 'Trap efficiency of reservoirs', *American Geophysical Union Transactions*, 34(3), 407–17.

Bull, L. J. and Kirkby, M. J. (eds) (2002) *Dryland Rivers: Hydrology and Geomorphology of Semi-Arid Channels*, Chichester: Wiley.

Bullock, J. and Darwish, A. (1993) *Water Wars: Coming Conflicts in the Middle East*, London: Gollancz.

Burby, R. J. (2001) 'Flood insurance and floodplain management: the US experience', *Global Environmental Change*, B3 (3–4), 111–22.

Burt, T. P. and Walling, D. E. (1984) 'Catchment experiments in fluvial geomorphology: a review of objectives and methodology', in T. P. Burt and D. E. Walling (eds), *Catchment Experiments in Fluvial Geomorphology*, Norwich: Geo Books, 3–18.

Burt, T. P. and Horton, B. P. (2006) 'Inter-decadal variability in daily rainfall at Durham (UK) since the 1850s', *International Journal of Climatology*, 27, 945–56.

Burton, L. (1991) *American Indian Rights and the Limits of Law*, Lawrence: University Press of Kansas.

Calder, I. R. (1990) *Evaporation in the Uplands*, Chichester: Wiley.

Calder, I. R. (1994) *Eucalyptus: Water and Sustainability*, ODA Forestry Series 6, London: Overseas Development Administration.

Calder, I. R. (2002) 'Forests and hydrological services: reconciling public and science perceptions', *Land Use and Water Resources Research*, 2, 1–12.

Calder, I. R. (2005a) *Blue Revolution: Integrated Land and Water Resource Management*, 2nd edn, London: Earthscan.

Calder, I. R. (2005b) 'Integrated land and water resources management', in M. Anderson (ed.), *Encyclopedia of Hydrological Sciences*, Chichester: Wiley.

Calder, I. R. and Newson, M. D. (1979) 'Land use and upland water resources in Britain: a strategic look', *Water Resources Bulletin*, 15(6), 1628–39.

Calder, I. R. and Aylward, B. (2006) 'Forests and floods: moving to an evidence-based approach to watershed and integrated flood management', *Water International*, 31(1): 87–99.

Calder, I. R., Hall, R. L. and Adlard, P. G. (1992) *Growth and Water Use of Forest Plantations*, Chichester: Wiley.

Calder, I. R., Rosier, P. T. W., Prasanna, K. T. and Parameswarappa, S. (1997) 'Eucalyptus water use greater than rainfall input: a possible explanation from southern India', *Hydrology and Earth System Sciences*, 1(2): 249–56.

Calder, I. R., Reid, I., Nisbet, T., Armstrong, A., Green, J. C. and Parkin, G. (2002) 'Study of the potential impacts on water resources of proposed afforestation', Defra contracts CWO 633-I and 633-II, Loughborough University.

Calow, P. and Petts, G. E. (eds) (1992) *The Rivers Handbook*, Vol. I, Oxford: Blackwell.

Calow, P. and Petts, G. E. (eds) (1994) *The Rivers Handbook*, Vol. II, Oxford: Blackwell.

Canter, L. (1985) *Environmental Impact of Water Resources Projects*, Chelsea, MI: Lewis Publishers.

Carter, J. G. (2007) 'Spatial planning, water and the Water Framework Directive: insights from theory and practice', *Geographical Journal*, 173(4), 330–42.

Carter, N., Kreutzweiser, R. D. and de Loe, R. C. (2005) 'Closing the circle: linking land use planning and water management at the local level', *Land Use Policy*, 22, 115–27.

Carter, R. (1992) 'Small-scale irrigation in sub-Saharan Africa: a balanced view', in *Priorities for Water Resource Allocation and Management*, Proceedings of the Conference, London: Overseas Development Administration, 103–16.

Carter, R. C. and Howsam, P. (1994) 'Sustainable use of groundwater for small-scale irrigation, with special reference to sub-Saharan Africa', *Land Use Policy*, 11(4), 275–85.

Carter, R. C. and Howsam, P. (1999) 'The impact and sustainability of community water supply and sanitation programmes in developing countries', *Water and Environment Journal*, 13, 292–6.

Cashman, A. (2006) 'A watery form of sustainability', *Water and Environment Journal*, 20, 2–6.

Cech, T. V. (2003) *Principles of Water Resources: History, Development, Management and Policy*, New York: Wiley.

Center for Watershed Protection (CWP) (2003) *Impacts of Impervious Cover on Aquatic Ecosystems*, Ellicott City, MD: CWP.

Central Water Planning Unit (CWPU) (1979) *River Regulation Losses in England and Wales*, Reading: CWPU.

Centre for Ecology and Hydrology (CEH) (1999) *The Flood Estimation Handbook*, Wallingford, Oxon: CEH.

Chakraborty, R. (2004) 'Sharing of river waters among India and its neighbours in the 21st century: war or peace?', *Water International*, 29(2), 201–8.

Chambers, R. (1988) *Managing Canal Irrigation: Practical Analysis from South Asia*, Cambridge: Cambridge University Press.

Chandler, W. V. (1984) *The Myth of the TVA Conservation and Development in the Tennessee Valley, 1933–1983*, Cambridge, MA: Ballinger.

Charlesworth, S. M., Harker, E. and Rickard, S. (2003) 'A review of sustainable drainage systems (SuDS)', *Geography*, 88(2), 99–107.

Charlton, F. C., Brown, P. M. and Benson, R. W. (1978) *The Hydraulic Geometry of Some Gravel Rivers in Britain*, Report IT180, Wallingford, Oxon: Hydraulics Research.

Chatterji, M. (2002) 'Introduction', in M. Chatterji, S. Arlosoroff and G. Guha, *Conflict Management of Water Resources*, Aldershot: Ashgate, 3–46.

Chaves, H. M. L. and Alipaz, S. (2007) 'An integrated indicator based on basin hydrology, environment, life and policy: the Watershed Sustainability Index', *Water Resource Management*, 21, 883–95.

Chenoweth, J. (2004) 'Changing ownership structures in the water supply and sanitation sector', *Water International*, 29(2), 138–47.

Cheru, F. and Bradford, C. (eds) (2005) *The Millennium Development Goals: Raising the Resources to Tackle World Poverty*, London: Zed Books.

Chessman, B. C., Fryirs, K. A. and Brierley, G. J. (2006) 'Linking geomorphic character, behaviour and condition to fluvial biodiversity: implications for river management', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 16, 267–88.

Chettri, R. and Bowonder, B. (1983) 'Siltation in Nizamsagar reservoir: environmental management issues', *Applied Geography*, 3, 193–204.

Chomitz, K. M. and Kumari, K. (1996) *The Domestic Benefits of Tropical Forests: A Critical Review Emphasizing Hydrological Functions*, Policy Research Working Paper 1601, Washington, DC: World Bank.

CIRIA (2000) *Sustainable Urban Drainage Systems: Design Manual for England and Wales*, Report C522, London: CIRIA.

CIRIA (2001) *Sustainable Urban Drainage Systems: Best Practice Manual*, Report C523, London: CIRIA.

Clark, M. J. (2002) 'Dealing with uncertainty: adaptive approaches to sustainable river management', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 12, 347–63.

Clark, M. J. and Richards, K. J. (2002) 'Supporting complex decisions for sustainable river management in England and Wales', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 12, 471–83.

Clarke, R. (1991) *Water: The International Crisis*, London: Earthscan.

Clarke, R. and King, J. (2004) *The Atlas of Water: Mapping the World's Most Critical Resource*, London: Earthscan.

Clarke, S. J., Bruce-Burgess, L. and Wharton, G. (2003) 'Linking form and function: towards an eco-hydromorphic approach to sustainable river restoration', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 12, 347–63.

Clayton, A. M. H. and Ratcliffe, N. J. (1996) *Sustainability: A Systems Approach*, London: Earthscan.

Cleaver, F. and Franks, T. (2005) *Water Governance and Poverty: A Framework for Analysis*, BCID Research Paper 13, Bradford: Bradford Centre for International Development, University of Bradford.

Clifford, N. J., Harmar, O. P., Harvey, G. and Petts, G. E. (2006) 'Physical habitat, eco-hydraulics and river design: a review and re-evaluation of some popular concepts and methods', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 16, 389–408.

Colborn, T. E., Davidson, A., Green, S. N., Hodge, R. A., Jackson, C. I. and Liroff, R. A. (1990) *Great Lakes, Great Legacy?*, Washington, DC: Conservation Foundation, and Ottawa, Ontario: Institute for Research on Public Policy.

Collingridge, D. and Reeve, C. (1986) *Science Speaks to Power*, London: Francis Pinter.

Collins, K., Blackmore, C., Morris, D. and Watson, D. (2007) 'A systematic approach to managing multiple perspectives and stakeholding in water catchments: some findings from three UK case studies', *Environmental Science and Policy*, 10, 564–74.

Collins, R. O. (1990) *The Waters of the Nile, Hydropolitics and the Jonglei Canal 1900–1988*, Oxford: Clarendon Press.

Collins, R. O. (2006) 'Negotiations and exploitation of the Nile waters at the end of the Millennium', *Water International*, 31(1), 116–26.

Conacher, A. J., Combes, P. L., Smith, P. A. and McLellan, R. L. (1983a) 'Evaluation of throughflow interceptors for controlling secondary soil and water salinity in dryland agricultural areas of southwestern Australia: I. Questionnaire surveys', *Applied Geography*, 3, 29–44.

Conacher, A. J., Combes, P. L., Smith, P. A. and McLellan, R. L. (1983b) 'Evaluation of throughflow interceptors for controlling secondary soil and water salinity in dryland agricultural areas of southwestern Australia: II. Hydrological study', *Applied Geography*, 3, 115–32.

Conley, A. H. (1989) 'The value of high-technology for managing intersectoral and international sharing of inadequate water resources in a developing region of Africa', in *Water '89: Water Decade and Beyond*, Bangkok: World Water, 1–7.

Conley, A. H. (1996) 'A synoptic view of water resources in Southern Africa', Southern African Society of Aquatic Scientists, Victoria Falls Conference.

Conway, V. M. and Millar, A. (1960) 'The hydrology of some small peat covered catchments in the North Pennines', *Journal of the Institution of Water Engineers*, 14, 415–24.

Cook, H. and Williamson, T. (eds) (2007) *Water Meadows: History, Ecology and Conservation*, Macclesfield: Windgather Press.

Cooke, A. (1973) *America*, London: BBC Publications.

Cooke, B. and Kothari, U. (2001) 'The case for participation as tyranny', in B. Cooke and U. Kothari (eds), *Participation: The New Tyranny*, London: Zed Books, 1–15.

Cosgrove, W. J. and Rijsberman, F. R. (2000) *World Water Vision: Making Water Everybody's Business*, London: Earthscan.

Costanza, R., d'Arge, R., de Groot, R., Faber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neil, R. V. and Parvelo, J. (1997) 'The value of the world's ecosystems and natural capital', *Nature*, 387, 253–60.

Costanza, R., Graunlich, L., Steffen, W., Crumley, C., Dearing, J., Hibbard, K., Leemans, R., Redman, C. and Schimel, D. (2007) 'Sustainability of collapse: what can we learn from integrating the history of humans and the rest of nature?', *Ambio*, 36(7), 522–7.

Crabb, P. (1991) 'Resolving conflicts in the Murray–Darling basin', in J. W. Handmer, A. H. J. Dorcey and D. I. Smith (eds), *Negotiating Water: Conflict Resolution in Australian Water Management*, Canberra: CRES, Australian National University.

Creighton, J. L. (2004) 'Designing effective public participation programmes: a US perspective', *Water International*, 29(3): 384–91.

Crow, B. (1995) *Sharing the Ganges: The Politics and Technology of River Development*, London: Sage.

Crutzen, P. J. (2002) 'Geology of mankind: the Anthropocene', *Nature*, 415, 23.

Cullen, P. W., Norris, R. H., Resh, V. H., Reynoldson, T. B., Rosenberg, D. M. and Barbour, M. T. (1999) 'Collaboration in scientific research: a critical need for freshwater ecology', *Freshwater Biology*, 42: 131–42.

Cunningham, N. and Sinclair, D. (2005) 'Policy instrument choice and diffuse source pollution', *Journal of Environmental Law*, 17(1), 51–81.

Curtis, A., Britton, A. and Sobels, J. (1999) 'Landcare networks in Australia: state-sponsored participation through local organisations', *Journal of Environmental Planning and Management*, 42(1), 5–21.

Custers, P. (1992) 'Banking on a flood-free future? Flood mismanagement in Bangladesh', *Ecologist*, 22(5), 241–7.

Darby, H. C. (1983) *The Changing Fenland*, Cambridge: Cambridge University Press.

Darby, S. and Sear, D. A. (eds) (2008) *River Restoration: Managing the Uncertainty in Restoring Physical Habitat*, Chichester: Wiley.

Darian, S. G. (1978) *The Ganges in Myth and History*, Honolulu: University of Hawaii Press.

Das Gupta, A., Singh Babel, M., Albert, X. and Mark, O. (2005) 'Water sector of Bangladesh in the context of integrated water resources management: a review', *Water Resources Development*, 21(2): 385–98.

Datta, S. K. and Virgo, K. J. (1998) 'Towards sustainable watershed development through people's participation: lessons from the Lesser Himalaya, Uttar Pradesh, India', *Mountain Research and Development*, 18(3), 213–33.

Davies, B. and Day, J. (1998) *Vanishing Waters*, Cape Town: University of Cape Town Press.

Davis, W. M. (1899) 'The geographical cycle', *Geographical Journal*, 14, 481–504.

Day, J. C. (1985) 'Canadian interbasin diversions: inquiry on federal water policy', Research Paper 6, Simon Fraser University, BC.

Deakin, R. (1999) *Waterlog: A Swimmer's Journey through Britain*, London: Chatto & Windus.

Decamps, H. and Naiman, R. J. (1990) 'Towards an ecotone perspective', in R. J. Naiman and H. Decamps (eds), *The Ecology and Management of Aquatic–Terrestrial Ecotones*, Carnforth, Lancs.: Parthenon Publishing, 1–5.

Decamps, H., Fortune, M. and Gazelle, F. (1989) 'Historical changes of the Garonne River, southern France', in G. E. Petts (ed.), *Historical Change of Large Alluvial Rivers: Western Europe*, Chichester: Wiley, 249–67.

Delli Priscoli, J. D. (1989) 'Public involvement, conflict management: means to EQ and social objectives', *Journal of Water Resource Planning and Management*, Proceedings of the American Society of Civil Engineers, 115(1), 31–42.

Delli Priscoli, J. (2004) 'What is public participation in water resources management and why is it important?', *Water International*, 29(2), 221–7.

Department for Environment, Food and Rural Affairs (Defra) (2002a) *The Government's Strategic Review of Diffuse Water Pollution from Agriculture in England: Agriculture and Water – A Diffuse Pollution Review*, London: Defra.

Department for Environment, Food and Rural Affairs (2002b) *Directing the Flow: Priorities for Future Water Policy*, London: Defra.

Department for Environment, Food and Rural Affairs (2004) *Mapping the Problem: Risks of Diffuse Water Pollution from Agriculture*, London: Defra.

Department for Environment, Food and Rural Affairs/Environment Agency (EA) (2006) *Analysis of Historical Data Sets to Look for Impacts of Land Use and Management Change on Flood Generation*, Inception Report FD2120, London: Defra/EA.

Department of Water Affairs (1986) *Management of the Water Resources of the Republic of South Africa*, Pretoria: Department of Water Affairs.

Department of Water Affairs and Forestry (DWAF) (1994) *Water Supply and Sanitation Policy: An Indivisible National Asset*, White Paper, Cape Town: DWAF.

Department of Water Affairs and Forestry (2002a) *A Guide to the National Water Act*, Pretoria: DWAF.

Department of Water Affairs and Forestry (2002b) *Water Management Institutions Overview*, Pretoria: DWAF.

Desalegn, C. E., Babel, M. S., Das Gupta, A., Seleshi, B. A. and Merrey, D. (2006) 'Farmers' perception of water management under drought conditions in the Upper Awash basin, Ethiopia', *Water Resources Development*, 22(4), 589–602.

de Voto, B. (1953) *The Journals of Lewis and Clark*, Boston, MA: Houghton Mifflin.

Dhruva Narayana, V. V. (1987) 'Downstream impacts of soil conservation in the Himalayan region', *Mountain Research and Development*, 7(3), 287–98.

Döckel, J. A. M. (2006) 'The possibility of trade in water use entitlements in South Africa under the National Water Act of 1998', in S. Perret, S. Farolfi and R. Hassan (eds), *Water Governance for Sustainable Development*, London: Earthscan, 35–54.

Dodds, A. A., Fisher, P. J., Paull, A. J. and Sears, J. R. (1993) 'Developing an appropriate wastewater management strategy for Sydney's future urban development', *Water Science and Technology*, 27(1), 19–29.

Dollar, E. S. J. and Rowntree, K. M. (1995) 'Hydroclimatic trends, sediment sources and geomorphic response in the Bell River catchment, eastern Cape Drakensberg, South Africa', *South African Geographical Journal*, 77(1), 21–32.

Dollar, E. S. J., James, C. S., Rogers, K. H. and Thoms, M. C. (2007) 'A framework for interdisciplinary understanding of rivers as ecosystems', *Geomorphology*, 89, 147–62.

Donaldson, A., Heathwaite, L., Lane, S., Ward, N. and Whatmore, S. (2005) *Holistic Approaches to Understanding Diffuse Land Management Issues: A Framework for Interdisciplinary Working*, Discussion Paper Series 2, Newcastle: Centre for Rural Economy, Newcastle University.

Doornkamp, J. C., Gregory, K. J. and Burn, A. S. (1980) *Atlas of Drought in Britain 1975–76*, London: Institute of British Geographers.

Doppelt, B., Scurlock, M., Frissell, C. and Karr, J. (1993) *Entering the Watershed: A New Approach to Save America's River Ecosystems*, Washington, DC: Island Press.

Douglas, E. M., Githui, F. W., Mtafya, A. R., Green, P. A., Glidden, S. J. and Vorosmarty, C. J. (2007) 'Characterizing water scarcity in Africa at different scales', *Journal of Environmental Management*.

Downing, T. E., Butterfield, R. E., Edmonds, B., Knox, J. W., Moss, S., Piper, B. S. and Weatherhead, E. K. (2003) *Climate Change and the Demand for Water*, Oxford: Stockholm Environment Institute.

Downs, P. W. and Gregory, K. J. (2004) *River Channel Management: Towards Sustainable Catchment Hydrosystems*, London: Arnold.

Downs, P. W., Gregory, K. J. and Brookes, A. (1991) 'How integrated is river basin management?', *Environmental Management*, 15(3), 299–309.

Dresner, S. (2002) *The Principles of Sustainability*, London: Earthscan.

Dresner, S. and Ekins, P. (2006) 'Design of environmentally and socially conscious water metering tariffs for the UK', *Journal of Environmental Planning and Management*, 49(6): 909–28.

Drèze, J., Samson, M. and Singh, S. (1997) *The Dam and the Nation: Displacement and Resettlement in the Narmada Valley*, Delhi: Oxford University Press.

Duda, A. M. (2003) 'Integrated management of land and water resources based on a collective approach to fragmented international conventions', *Philosophical Transactions of the Royal Society of London B*, 358, 2051–62.

Dugan, P. (1990) *Wetland Conservation: A Review of Current Issues and Required Action*, Gland, Switzerland: IUCN.

Duraiappah, A. K. (2007) *Markets for Ecosystems Services: A Potential Tool for Multilateral Environmental Agreements*, Winnipeg: International Institute for Sustainable Development.

Durance, I. and Ormerod, S. J. (2007) 'Climate change effects on upland stream macroinvertebrates over a 25-year period', *Global Change Biology*, 13, 942–57.

Dynesius, M. and Nilsson, C. (1994) 'Fragmentation and flow regulation of river systems in the northern third of the world', *Science*, 266, 753–62.

Dyson, M., Bergkamp, G. and Scanlon, J. (eds) (2003) *Flow: The Essentials of Environmental Flows*, Gland, Switzerland: IUCN.

Ebisemiju, F. S. (1989) 'The response of headwater stream channels to urbanization in the humid tropics', *Hydrological Processes*, 3, 237–53.

Eckholm, E. (1976) 'The politics of soil conservation', *Ecologist*, 6(2), 54–9.

Edwards, R. W. and Brooker, M. P. (1982) 'The ecology of the Wye', *Monographiae Biologicae*, 50, The Hague: Junk.

Ehlin, U. (2000) 'Water security: opportunity for development and cooperation in the Aral Sea area', in SIWI, RSAS and UNIFEM, *Water Security: Opportunity for Development and Cooperation in the Aral Sea Area*, Report 9, Stockholm: Stockholm International Water Institute, i–ii.

Entec (2006) *Running Water: Could This Be the UK's First Sustainable Sector?*, Leamington Spa: Entec.

Environment Agency (EA) (1996) *The Environment Agency and Sustainable Development*, London: Department of the Environment, Ministry of Agriculture, Fisheries and Food, Welsh Office.

Environment Agency (2002a) *Managing Water Abstraction: The Catchment Abstraction Management Process*, Bristol: EA.

Environment Agency (2002b) *The Water Framework Directive: Guiding Principles on the Technical Requirements*, Bristol: EA.

Environment Agency (2006) *Underground, Under Threat: The State of Groundwater in England and Wales*, Bristol: EA.

Environment Agency (2007) *Water Efficiency in the South East of England: Retrofitting Existing Homes*, Bristol: EA.

Environment Canada (1992) *State of Environment for the Lower Fraser River Basin*, SOE Report 92–1, Ottawa: Environment Canada.

Ericksen, N. J. (1986) *Creating Flood Disasters?*, Water and Soil Miscellaneous Publication 77, Wellington: National Water and Soil Conservation Authority.

Ericksen, N. J. (1990) 'New Zealand water planning and management: evolution or revolution?', in B. Mitchell (ed.), *Integrated Water Management*, London: Belhaven, 45–87.

Ericksen, N. J., Berke, P. R., Crawford, J. L. and Dixon, J. E. (2004) *Plan-Making for Sustainability: The New Zealand Experience*, Aldershot: Ashgate.

European Committee for Standardization (CEN) (2004) *European Standard EN14614*, Brussels: CEN.

Evans, J. (2004) 'What is local about local environmental governance? Observations from the local biodiversity action planning process', *Area*, 36(3), 270–9.

Evans, R. (2006) 'Curtailing water erosion of cultivated land: an example from north Norfolk, eastern England', *Earth Surface Processes and Landforms*, 31, 598–605.

Everard, M. (2004) 'Investing in sustainable catchments', *Science of the Total Environment*, 324(1–3), 1–24.

Everard, M. (ed.) (2005) *Water Meadows: 'Living Treasures in the English Landscape'*, Cardigan: Forrest.

Everard, M. and Capper, K. (2004) 'Common law and river conservation', *Environmental Law and Management*, 16(3), 31–5.

Evers, Y. D. (1995) 'Supporting local natural resource management institutions: experience gained and guiding principles', in D. Stiles (ed.), *Social Aspects of Sustainable Dryland Management*, Chichester: Wiley, 93–103.

Fahey, B. D. and Rowe, L. K. (1992) 'Land-use impacts', in M. P. Mosley (ed.), *Waters of New Zealand*, Wellington: New Zealand Hydrological Society, 265–84.

Fahim, H. M. (1981) *Dams, People and Development: The Aswan High Dam Case*, New York: Pergamon.

Falkenmark, M. (1986) 'Fresh water: time for a modified approach', *Ambio*, 15(4), 192–200.

Falkenmark, M. (1996) 'Stockholm Water Symposium, 1995: human dimensions of the water crisis', *Ambio*, 25(3), 216.

Falkenmark, M. (2001) 'The greatest water problem: the inability to link environmental security, water security and food security', *Water Resources Development*, 17(4), 539–54.

Falkenmark, M. (2002) *Human Security versus Ecological Security: Compatible or Non-Compatible Goals? Balancing Human Security and Ecological Security Interests in a Catchment – Towards Upstream/Downstream Hydrosolidarity*, Proceedings of SIWI Seminar, Stockholm, Report 17, Stockholm: Stockholm International Water Institute, 1–8.

Falkenmark, M. (2003) 'Freshwater as shared between society and ecosystems: from divided approaches to integrated challenges', *Philosophical Transactions of the Royal Society of London B*, 358, 2037–49.

Falkenmark, M. (2003b) 'Water cycle and people: water for feeding humanity', *Land Use and Water Resources Research*, 3, 3.1–3.4.

Falkenmark, M. and Chapman, T. (1989) *Comparative Hydrology: An Ecological Approach to Land and Water Resources*, Paris: UNESCO.

Falkenmark, M. and Rockström, J. (2004) *Balancing Water for Humans and Nature: The New Approach in Ecohydrology*, London: Earthscan.

Falkenmark, M. and Lannerstad, M. (2005) 'Consumptive water use to feed humanity: curing a blind spot', *Hydrology and Earth System Sciences*, 9, 15–28.

Falkenmark, M., Anderson, L., Castensson, R. and Sundblad, K. (1999) *Water: A Reflection of Land Use – Options for Counteracting Land and Water Mismanagement*, Stockholm: Swedish Natural Science Research Council.

Falkenmark, M., Gottschalk, L., Lundqvist, J. and Wouters, P. (2004) 'Towards integrated catchment management: increasing dialogue between scientists, policymakers and stakeholders', *Water Resources Development*, 20(3), 297–309.

Farley, K. A., Jobbágy, E. G. and Jackson, R. B. (2005) 'Effects of afforestation on water yield: a global synthesis with implications for policy', *Global Change Biology*, 11, 1565–76.

Faysse, N. (2004) *An Assessment of Small-Scale Users' Inclusion in Large-Scale Water User Associations of South Africa*, Research Report 84, Colombo: International Water Management Institute.

Feldman, D. L. (1991) *Water Resources Management: In Search of an Environmental Ethic*, Baltimore, MD: Johns Hopkins Press.

Fenemor, A. (1992) 'Water resource management in New Zealand', in M. P. Mosley (ed.), *Waters of New Zealand*, Wellington: New Zealand Hydrological Society, 365–79.

Ferguson, R. I. (1981) 'Channel form and channel changes', in J. Lewin (ed.), *British Rivers*, London: Allen & Unwin, 90–125.

Ferreyra, C. and Beard, P. (2007) 'Participatory evaluation of collaborative and integrated water management: insights from the field', *Journal of Environmental Planning and Management*, 50(2), 271–96.

Ffolliott, P. F., Baker, M. B., Edminster, C. B., Dillon, M. C. and Mora, K. L. (2002) *Land Stewardship through Watershed Management: Perspectives for the 21st Century*, New York: Kluwer.

Findlay, S. J. and Taylor, M. P. (2006) ‘Why rehabilitate urban river systems?’, *Area*, 38(3), 312–25.

Fleming, G. (ed.) (2002) *Flood Risk Management: Learning to Live with Rivers*, London: Thomas Telford.

Fletcher, K. M. (2003) ‘Wetland laws and policies: how we got to where we are today’, in M. M. Holland, E. R. Blood and L. R. Shaffer (eds), *Achieving Sustainable Freshwater Systems: A Web of Connections*, Washington, DC: Island Press, 43–63.

Florsheim, J. L., Mount, J. F. and Constantine, C. R. (2006) ‘A geomorphic monitoring and adaptive assessment framework to assess the effect of lowland floodplain river restoration on channel–floodplain sediment continuity’, *River Research and Applications*, 22, 353–75.

Flynn, S. and Chirwa, D. M. (2005) ‘The constitutional implications of commercialising water in South Africa’, in D. A. McDonald and G. Ruiters (eds), *The Age of Commodity: Water Privatization in Southern Africa*, London: Earthscan, 59–96.

Folke, C. (2002) *Entering Adaptive Management and Resilience into the Catchment Approach: Balancing Human Security and Ecological Security Interests in a Catchment – Towards Upstream/Downstream Hydrosolidarity*, Proceedings of SIWI Seminar, Stockholm, Report 17, Stockholm: Stockholm International Water Institute, 32–6.

Folke, C. (2003) ‘Freshwater for resilience: a shift in thinking’, *Philosophical Transactions of the Royal Society of London B*, 358, 2027–36.

Food and Agriculture Organization of the United Nations (FAO) (2002) *Land–Water Linkages in Rural Watersheds*, Land and Water Bulletin 9, Rome: FAO.

FAO/Center for International Forestry Research (CIFOR) (2005) *Forests and Floods: Drowning in Fiction or Thriving on Facts?*, RAP Publication 2005/03, Forest Perspectives 2, Bangkok: FAO/CIFOR.

Fookes, P. G. and Vaughan, P. R. (1986) *A Handbook of Engineering Geomorphology*, London: Surrey University Press.

Forestry Commission (1979) *The Wood Production Outlook in Britain*, Edinburgh: Forestry Commission.

Forestry Commission (1988) *Forests and Water Guidelines*, Edinburgh: Forestry Commission.

Forestry Commission (1991) *Forests and Water Guidelines*, 2nd edn, London: HMSO.

Forestry Commission (1993) *Forests and Water Guidelines*, 3rd edn, Edinburgh: Forestry Commission.

Forestry Commission (2003) *Forests and Water Guidelines*, 4th edn, Edinburgh: Forestry Commission.

Foster, D., Wood, A. and Griffiths, M. (2000) ‘The Water Framework Directive (2000/60/EC): an introduction’, Department of the Environment Northern Ireland workshop: Lakes assessment and the EC Water Framework Directive, 7–9 June, Enniskillen.

Foster, I. D. L., Dearing, J. A. and Grew, R. (1988) ‘Lake-catchments: an evaluation of their contribution to studies of sediment yield and delivery processes’, in M. P. Bordas and D. E. Walling (eds), *Sediment Budgets*, Publication 174, Wallingford, Oxon: International Association of Hydrological Sciences, 413–29.

Fowler, H. J. and Kilsby, C. G. (2003) ‘A regional frequency analysis of United

Kingdom extreme rainfall from 1961 to 2000', *International Journal of Climatology*, 23, 1313–34.

Franks, T. R. (1994) 'The green river in Bangladesh: the Lower Atrai basin', in C. Kirby and W. R. White (eds), *Integrated River Basin Development*, Chichester: Wiley, 367–76.

Frederiksen, H. D. (2003) 'The world water crisis: ramifications of politics trumping basic responsibilities of the international community', *Water Resources Development*, 19(4), 593–615.

Freestone, H. J. (1992) 'Hydrology and large water projects', in M. P. Mosley (ed.), *Waters of New Zealand*, Wellington: New Zealand Hydrological Society, 409–21.

Frey, F. W. (1993) 'The political context of conflict and cooperation over international river basins', *Water International*, 18, 54–68.

Frissell, C. A., Liss, W. J., Warren, C. E. and Hurley, M. D. (1986) 'A hierarchical framework for stream habitat classification: viewing streams in a watershed context', *Environmental Management*, 10, 199–214.

Fryirs, K. and Brierley, G. J. (1999) 'Slope–channel decoupling in Woluma catchment, New South Wales, Australia: the changing nature of sediment sources following European settlement', *Catena*, 35, 41–63.

Fryirs, K. A., Brierley, G. J., Preston, N. J. and Kasai, M. (2007a) 'Buffers, barriers and blankets: the (dis)connectivity of catchment-scale sediment cascades', *Catena*, 70, 49–67.

Fryirs, K. A., Brierley, G. J., Preston, N. J. and Spencer, J. (2007b) 'Catchment-scale (dis)connectivity in sediment flux in the upper Hunter catchment, New South Wales, Australia', *Geomorphology*, 84, 297–316.

Gadgil, M. and Guha, R. (1992) *This Fissured Land: An Ecological History of India*, Delhi: Oxford University Press.

Galaz, V. (2005) 'Socio-ecological resilience and social conflict: institutions and strategic adaptation in Swedish water management', *Ambio*, 34(7), 567–72.

Gamble, D. W. and Meentemeyer, V. (1996) 'The role of scale in research on the Himalaya–Ganges–Brahmaputra interaction', *Mountain Research and Development*, 16(2), 149–55.

Gandhidasan, P. and Abualhamayel, H. I. (2007) 'Fog collection as a source of fresh water supply in the Kingdom of Saudi Arabia', *Water and Environment Journal*, 21(1), 19–25.

Gandy, M. (1997) 'The making of a regulatory crisis: restructuring New York's water supply', *Transactions of the Institute of British Geographers*, NS22, 338–58.

Gangstad, E. O. (1990) *Natural Resource Management of Water and Land*, New York: Van Nostrand Reinhold.

Gardiner, J. L. (ed.) (1991) *River Projects and Conservation: A Manual for Holistic Appraisal*, Chichester: Wiley.

Gardiner, J., Thompson, K. and Newson, M. (1994) 'Integrated watershed/river catchment planning and management: a comparison of selected Canadian and United Kingdom experiences', *Journal of Environmental Planning and Management*, 37(1), 53–67.

Gardner, B. D. (2003) 'Weakening water rights and efficient transfers', *Water Resources Development*, 19(1), 7–19.

Gardner, R. A. M. and Gerrard, A. J. (2002) 'Relationships between runoff and land degradation on non-cultivated land in the Middle Hills of Nepal', *International Journal of Sustainable Development and World Ecology*, 9, 59–73.

Garner, A. (2006) 'Substance, desire and control: water in the New Forest', *Worldviews*, 10(2), 259–81.

Garrod, G. and Willis, K. G. (1996) 'Estimating the benefits of environmental enhancement: a case study of the River Darent', *Journal of Environmental Planning and Management*, 39(2), 189–203.

Garrod, G. and Willis, K. G. (1999) *Economic Valuation of the Environment: Methods and Case Studies*, Cheltenham: Edward Elgar.

George, R. J. (1990) 'Reclaiming sandplain seeps by intercepting perched groundwater with eucalypts', *Land Degradation and Rehabilitation*, 2, 13–25.

Gerrard, A. J. and Gardner, R. A. M. (2000) 'The nature and management implications of landsliding on irrigated terraces in the Middle Hills of Nepal', *International Journal of Sustainable Development and World Ecology*, 7, 229–36.

Ghassemi, F., Thomas, G. A. and Jakeman, A. J. (1988) 'Effect of groundwater interception and irrigation on salinity and piezometric levels in an aquifer', *Hydrological Processes*, 2, 369–82.

Gilbertson, D. D. (1986) 'Runoff (floodwater) farming and rural water supply in arid lands', *Applied Geography*, 6, 5–11.

Giles, H. and Brown, B. (1997) ' "And not a drop to drink": water and sanitation services to the urban poor in the developing world', *Geography*, 82(2), 97–109.

Gilmour, D. A., Bonell, M. and Cassells, D. S. (1987) 'The effects of forestation on soil hydraulic properties in the Middle Hills of Nepal: a preliminary assessment', *Mountain Research and Development*, 7(3), 239–49.

Giordano, M. A. and Wolf, A. T. (2002) 'The world's international freshwater agreements: historical developments and future opportunities', in *Atlas of International Freshwater Agreements*, Transboundary Freshwater Dispute Database, Corvallis: Oregon State University.

Giordano, M., Giordano, M. and Wolf, A. (2002) 'The geography of water conflict and cooperation: internal pressures and international manifestations', *Geographical Journal*, 168(4), 293–312.

Gippel, C. J. (2000) 'Managing regulated rivers for environmental values: selected case studies from southeastern Australia', in S. Brizga and B. Finlayson (eds), *River Management: The Australasian Experience*, Chichester: Wiley, 97–122.

Glacken, C. J. (1956) 'Changing ideas of the habitable world', in W. L. Thomas (ed.), *Man's Role in Changing the Face of the Earth*, Chicago, IL: University of Chicago Press, 70–92.

Glade, T. (2003) 'Landslide occurrence as a response to land use change: a review of evidence from New Zealand', *Catena*, 51, 297–314.

Gladwell, J. S. (1993) 'Urban water management problems in the humid tropics: some technical and non-technical considerations', in M. Bonell, M. M. Hufschmidt and J. S. Gladwell (eds), *Hydrology and Water Management in the Humid Tropics*, Cambridge: Cambridge University Press, 414–36.

Glantz, M. H., Rubenstein, A. Z. and Zonn, I. (1993) 'Tragedy in the Aral Sea basin: looking back to plan ahead?', *Global Environmental Change*, 3(2), 174–98.

Gleick, P. H. (1987) *Global Climatic Changes and Regional Hydrology: Impacts and Responses*, Publication 168, Wallingford, Oxon: International Association of Scientific Hydrology, 389–402.

Gleick, P. H. (ed.) (1993) *Water in Crisis*, Oxford: Oxford University Press.

Gleick, P. H. (1998–99 and biennially) *The World's Water*, Washington, DC: Island Press.

Gleick, P. H. (2006) *The World's Water, 2006–2007*, Washington, DC: Island Press.

Glennon, R. (2002) *Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters*, Washington, DC: Island Press.

Global Water Partnership (GWP) (2001) *Toolbox: Integrated Water Resources Management – Sharing Knowledge for Equitable, Efficient and Sustainable Water Resources Management*, Stockholm: GWP.

Goldsmith, E. and Hildyard, N. (eds) (1984) *The Social and Environmental Effects of Large Dams*, Vol. 1: *Overview*, Cornwall: Wadebridge Ecological Centre.

Goldsmith, E. and Hildyard, N. (eds) (1986) *The Social and Environmental Effects of Large Dams*, Vol. 2: *Case Studies*, Cornwall: Wadebridge Ecological Centre.

Gomez, B. and Church, M. (1989) 'An assessment of bed load sediment transport formulae for gravel bed rivers', *Water Resources Research*, 25(6), 1161–86.

Gore, A. (1992) *Earth in the Balance: Forging a New Common Purpose*, London: Earthscan.

Gore, J. A. (1985) *The Restoration of Rivers and Streams: Theories and Experience*, Stoneham, MA: Ann Arbor Science (Butterworth).

Gore, J. A., Layzer, J. B. and Russell, I. A. (1992) 'Non-traditional applications of instream flow techniques for conserving habitat of biota in the Sabie River of Southern Africa', in P. J. Boon, P. Calow and G. E. Petts (eds), *River Conservation and Management*, Chichester: Wiley, 161–77.

Graf, W. L. (1985) *The Colorado River: Instability and Basin Management*, Washington, DC: Association of American Geographers.

Graf, W. L. (1992) 'Science, public policy, and western American rivers', *Transactions of the Institute of British Geographers*, 17, 5–19.

Graf, W. L. (1999) 'Dam nation: a geographic census of American dams and their large-scale hydrologic impacts', *Water Resources Research*, 35(4), 1305–11.

Graf, W. (2002) 'Summary and perspective', in W. Graf (ed.), *Dam Removal Research: Status and Prospects*, Washington, DC: Heinz Center, 1–21.

Graf, W. L. (2003) *Dam Removal Research: Status and Prospects*, Washington, DC: Heinz Center.

Green, C. (2003) *Handbook of Water Economics: Principles and Practice*, Chichester: Wiley.

Green, C. and Penning-Rowsell, E. (2002) *Flood Risk and Insurance: Strategic Options for the Insurance Industry and for Government*, Enfield, Middx.: Flood Hazard Research Centre, Middlesex University.

Gregory, K. J. (ed.) (1977) *River Channel Changes*, Chichester: Wiley.

Gregory, K. J. (1995) 'Human activity and palaeohydrology', in K. J. Gregory, L. Starkel and V. R. Baker (eds), *Global Continental Palaeohydrology*, Chichester: Wiley, 151–72.

Grewal, S. S., Mital, S. P. and Singh, G. (1990) 'Rehabilitation of degraded lands in the Himalayan foothills: people's participation', *Ambio*, 19(1), 45–8.

Griffith, B. (2001) *The Gardens of their Dreams: Desertification and Culture in World History*, London: Zed Books.

Grundy, K. J. and Gleeson, B. J. (1996) 'Sustainable management and the market: the politics of planning reform in New Zealand', *Land Use Policy*, 13(3), 197–211.

Guerquin, F., Ahmed, T., Hua, M., Ikeda, T., Ozbilen, V. and Schuttelar, M. (2003) *World Water Actions: Making Water Flow for All*, London: Earthscan.

Guerrieri, F. and Vianello, G. (1990) 'Identification and reclamation of erosion-affected lands in the Emilia-Romagna region, Italy', in J. Boardman, I. D. L. Foster and J. A. Dearing (eds), *Soil Erosion on Agricultural Land*, Chichester: Wiley, 621–5.

Guillerme, A. E. (1988) *The Age of Water*, College Station: Texas A&M University Press.

Guijt, I. and Thompson, J. (1994) 'Landscapes and livelihoods: environmental and socioeconomic dimensions of small-scale irrigation', *Land Use Policy*, 11(4), 294–308.

Gupta, R. K. (2001a) 'River basin management: a case study of Narmada Valley development with special reference to the Sardar Sarovar Project in Gujarat, India', *Water Resources Development*, 17(1), 55–78.

Gupta, R. K. (2001b) 'Human rights dimension of regional water transfer: experience of the Sardar Sarovar Project', *Water Resources Development*, 17(1), 125–47.

Gurnell, A. (2007) 'Wood in world rivers', *Earth Surface Processes and Landforms*, 32(8), 1129–30.

Gustard, A., Cole, G., Marshall, D. and Bayliss, A. (eds) (1987) *A Study of Compensation Flows in the UK*, Report No. 99, Wallingford, Oxon: Institute of Hydrology.

Haagsma, B. (1995) 'Traditional water management and state intervention: the case of Santo Antao, Cape Verde', *Mountain Research and Development*, 15(1), 39–56.

Haddadin, M. J. (2002) 'Water in the Middle East peace process', *Geographical Journal*, 168(4), 324–40.

Hall, C. (1989) *Running Water*, London: Robertson McCarta.

Hall, J. W., Evans, E. P., Penning-Rowsell, E. C., Sayers, P. B., Thorne, C. R. and Saul, A. J. (2003) 'Quantified scenarios analysis of drivers and impacts of changing flood risk in England and Wales: 2030–2100', *Global Environmental Change*, B5(3–4), 51–65.

Hallsworth, E. G. (1987) *Anatomy, Physiology and Psychology of Erosion*, Chichester: Wiley.

Hamilton, L. S. (1988) 'Forestry and watershed management', in J. Ives and D. C. Pitt (eds), *Social Dynamics in Watersheds and Mountain Ecosystems*, London: Routledge, 99–131.

Hamley, W. (1990) 'Hydrotechnology, wilderness and culture in Quebec', in D. Cosgrove and G. E. Petts (eds), *Water, Engineering and Landscape*, London: Belhaven, 144–58.

Handley, C. D. (2001) *Water Stress: Some Symptoms and Causes – A Case Study of Ta'iz, Yemen*, Aldershot: Ashgate.

Handmer, J. W. (1987) 'Guidelines for floodplain acquisition', *Applied Geography*, 7, 203–21.

Hannah, D. M., Wood, P. J. and Sadler, J. P. (2004) 'Ecohydrology and hydroecology: a new paradigm?', *Hydrological Processes*, 18, 3439–45.

Harden, B. (1996) *A River Lost: The Life and Death of the Columbia*, New York: Norton.

Harper, D. E. (1988) 'Improving the accuracy of the universal soil loss equation in Thailand', in S. Runwanich (ed.), *Land Conservation for Future Generations*, Bangkok: Department of Land Development, 531–40.

Harper, D. M., Kemp, J. L., Vogel, B. and Newson, M. D. (2000) 'Towards the assessment of "ecological integrity" in running waters of the United Kingdom', *Hydrobiologia*, 422/423, 133–42.

Harremoës, P., Gee, D., MacGarvin, M., Stirling, A., Keys, J., Wynne, B. and Gudes Vaz, S. (eds) (2002) *The Precautionary Principle in the 20th Century: Late Lessons from Early Warnings*, London: Earthscan.

Harriman, R. (1978) 'Nutrient leaching from fertilised forest watersheds in Scotland', *Journal of Applied Ecology*, 15, 933–42.

Harriman, R., Watt, A. W., Christie, A. E. G., Moore, D. W., McCartney, A. G. and Taylor, E. M. (2003) 'Quantifying the effects of forestry practices on the recovery of upland streams and lochs from acidification', *Science of the Total Environment*, 310, 101–11.

Harris, G. and Heathwaite, A. L. (2005) 'Inadmissible evidence: knowledge and prediction in land and riverscapes', *Journal of Hydrology*, 304, 3–19.

Harris, T. and Boardman, J. (1990) 'A rule-based expert system approach to predicting waterborne soil erosion', in J. Boardman, I. D. L. Foster and J. A. Dearing (eds), *Soil Erosion on Agricultural Land*, Chichester: Wiley, 401–12.

Harvey, A. M. (2002) 'Effective timescales of coupling within fluvial systems', *Geomorphology*, 44, 175–201.

Hasfurther, V. R. (1985) 'The use of meander parameters in restoring hydrological balance to reclaimed stream beds', in J. A. Gore (ed.), *The Restoration of Rivers and Streams: Theories and Experience*, Stoneham, MA: Ann Arbor Science (Butterworth), 21–40.

Haslam, S. M. (1991) *The Historic River: Rivers and Culture down the Ages*, Cambridge: Cobden.

Hatt, B. E., Fletcher, T. D., Walsh, C. J. and Taylor, S. L. (2004) 'The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams', *Environmental Management*, 34(1), 112–24.

Hauck, G. F. W. and Novak, R. A. (1987) 'Interaction of flow and incrustation in the Roman aqueduct of Nimes', *Journal of Hydraulic Engineering*, 113(2), 141–57.

Haughton, G. (1998) 'Private profits – public drought: the creation of a crisis in water management for West Yorkshire', *Transactions of the Institute of British Geographers*, NS23, 419–33.

Hausler, S. (1995) 'Listening to the people: the use of indigenous knowledge to curb environmental degradation', in D. Stiles (ed.), *Social Aspects of Sustainable Dryland Management*, Chichester: Wiley, 179–88.

Hawkes, J. (1976) *The Atlas of Early Man*, London: Macmillan.

Haycock, N. E. and Muscutt, A. D. (1995) 'Landscape management strategies for the control of diffuse pollution', *Landscape and Urban Planning*, 31, 313–21.

Hayman, P. and Cox, P. (2003) 'Perceptions of drought risk: the farmer, the scientist and the policy economist', in L. C. Botterill and M. Fisher (eds), *Beyond Drought: People, Policy and Perspectives*, Collingwood, Victoria: CSIRO Press, 153–73.

Heathcote, R. L. (1969) 'Drought in Australia: a problem of perception', *Geographical Review*, 49(2), 175–94.

Heinz Center (2002) *Dam Removal: Science and Decision Making*, Washington, DC: H. John Heinz III Center for Science, Economics and the Environment.

Helley, E. J. and Smith, W. (1971) *Development and Calibration of a Pressure Difference*

Bedload Sampler, Open File Report 8037–01, Menlo Park, CA: US Geological Survey.

Hellier, C. (1990) ‘Running the rivers dry’, *Geographical Magazine*, July, 32–5.

Hens, L. and Nath, B. (2003) ‘The Johannesburg Conference’, *Environment, Development and Sustainability*, 5, 7–39.

Herweg, K. and Ludi, E. (1999) ‘The performance of selected soil and water conservation measures: case studies from Ethiopia and Eritrea’, *Catena*, 36, 99–114.

Hewlett, J. D. and Nutter, W. L. (1970) *The Varying Source Area of Streamflow from Upland Basins: Interdisciplinary Aspects of Watershed Management*, New York: American Society of Civil Engineers, 65–83.

Hey, R. D. (1994) ‘Environmentally sensitive river engineering’, in P. Calow and G. E. Petts (eds), *The Rivers Handbook*, Vol. II, Oxford: Blackwell, 337–62.

Hey, R. D. (1995) ‘River processes and management’, in T. O’Riordan (ed.), *Environmental Science for Environmental Management*, London: Longman, 131–50.

Hibbard, M. and Lurie, S. (2006) ‘Some community socio-economic benefits of Watershed Councils: a case study from Oregon’, *Journal of Environmental Planning and Management*, 49(6): 891–908.

Hicks, D. M. (1994) ‘Land-use effects on magnitude-frequency characteristics of storm sediment yields: some New Zealand examples’, in *Variability in Stream Erosion and Sediment Transport*, Proceedings of the Canberra Symposium, IAHS Publication 224, Wallingford, Oxon: International Association of Hydrological Sciences, 395–402.

Hicks, D. M. and Griffiths, G. A. (1992) ‘Sediment load’, in M. P. Mosley (ed.), *Waters of New Zealand*, Wellington: New Zealand Hydrological Society, 229–48.

Higgitt, D. L. and Lu, X. X. (2001) ‘Sediment delivery to the Three Gorges. 1. Catchment controls’, *Geomorphology*, 41, 143–56.

Hill, A. R. (1990) ‘Groundwater cation concentrations in the riparian zone of a forested headwater stream’, *Hydrological Processes*, 4, 121–30.

Hillel, D. (1992) *Out of the Earth: Civilization and the Life of the Soil*, London: Aurum Press.

Hillman, M. and Brierley, G. (2002) ‘Information needs for environmental-flow allocation: a case study from the Lachlan River, New South Wales, Australia’, *Annals of the Association of American Geographers*, 92(4), 617–30.

Hoare, R. A. and Rowe, L. K. (1992) ‘Water quality in New Zealand’, in M. P. Mosley (ed.), *Waters of New Zealand*, Wellington: New Zealand Hydrological Society, 207–28.

Hodgson, S. (2004) *Land and Water: The Rights Interface*, LSP Working Paper 10, Rome: Food and Agriculture Organization of the United Nations.

Hoekstra, A. Y. (2003) ‘Virtual water: an introduction’, in A. Y. Hoekstra (ed.), *Virtual Water Trade: Proceedings of the International Expert Meeting on Virtual Water Trade*, Value of Water Research Report Series 12, Delft: UNESCO-IHE.

Hoekstra, A. Y. and Chapagain, A. K. (2008) *Globalization of Water: Sharing the Planet’s Freshwater Resources*, Oxford: Blackwell.

Hofer, T. (1993) ‘Himalayan deforestation, changing river discharge and increasing floods: myth or reality’, *Mountain Research and Development*, 13(3), 213–33.

Holl, K. D. and Howarth, R. B. (2000) ‘Paying for restoration’, *Restoration Ecology*, 8(3), 260–7.

Holland, A.-C. S. (2005) *The Water Business: Corporations versus People*, London: Zed Books.

Holling, C. S. (ed.) (1978) *Adaptive Environmental Assessment and Management*, Chichester: Wiley.

Hollis, G. E. (1990) 'Environmental impacts of development on wetlands in arid and semi-arid lands', *Hydrological Sciences Journal*, 35(4), 411–28.

Hooke, J. (2003) 'River meander behaviour and instability: a framework for analysis', *Transactions of the Institute of British Geographers*, NS28, 238–53.

Hooke, J. M. and Kain, R. J. P. (1982) *Historical Change in the Physical Environment*, London: Butterworth.

Hooper, B. (2005) *Integrated River Basin Governance: Learning from International Experience*, London: IWA Publishing.

Horta, K. (1995) 'The mountain kingdom's white oil: the Lesotho Highlands Water Project', *Ecologist*, 25(6), 227–31.

Houghton, J. T., Callander, B. A. and Varney, S. K. (1992) *Climate Change 1992*, Cambridge: Cambridge University Press.

Howarth, W. (1988) *Water Pollution Law*, London: Shaw & Sons.

Howe, J. and White, I. (2002) 'The geography of the autumn 2000 floods in England and Wales', *Geography*, 87(2), 116–24.

Howell, P., Lock, M. and Cobb, S. (1988) *The Jonglei Canal: Impact and Opportunity*, Cambridge: Cambridge University Press.

Hughes, F. M. R. (1990) 'The influence of flooding regimes on forest distribution and composition in the Tana River floodplain, Kenya', *Journal of Applied Ecology*, 27, 475–91.

Hume, M. (1992) *The Run of the River: Portraits of Eleven British Columbia Rivers*, Vancouver, BC: New Star Books.

Hunt, R. L. (1993) *Trout Stream Therapy*, Madison: University of Wisconsin Press.

Hurni, H. (1983) 'Soil erosion and soil formation in agricultural ecosystems: Ethiopia and northern Thailand', *Mountain Research and Development*, 3(2), 131–42.

Hurni, H., Tato, K. and Zeleka, G. (2005) 'The implications of changes in population, land use and land management for surface runoff in the upper Nile basin area of Ethiopia', *Mountain Research and Development*, 25(2), 147–54.

Hvidt, M. (1998) *Water, Technology and Development: Upgrading Egypt's Irrigation System*, London: Tauris.

Imhof, A., Wong, S. and Bosshard, P. (2002) *Citizens' Guide to the World Commission on Dams*, Berkeley, CA: International Rivers Network.

Ingram, H. (1990) *Water Politics: Continuity and Change*, Albuquerque: University of New Mexico Press.

Ingram, J. and Morris, C. (2007) 'The knowledge challenge within the transition towards sustainable soil management: an analysis of agricultural advisors in England', *Land Use Policy*, 24, 100–17.

Institution of Civil Engineers (ICE) (2001) *Learning to Live with Rivers*, London: ICE.

Intergovernmental Panel on Climate Change (IPCC) (1990) *Science Assessment of Climate Change*, Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (1995) *Climate Change: Second Assessment*, Geneva: IPCC.

Intergovernmental Panel on Climate Change (1997) *The Regional Impacts of Climate*

Change: An Assessment of Vulnerability, Summary for Policymakers, Geneva: IPCC.

Intergovernmental Panel on Climate Change (2000) *Land Use, Land-Use Change and Forestry*, Summary for Policymakers, Special Report, Geneva: IPCC.

IPCC (2001) *Climate Change 2001*, Geneva: IPCC.

Intergovernmental Panel on Climate Change (2007a) *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the IPCC, Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (2007b) *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the IPCC (web copy).

International Rivers Network (IRN) (2006) *Spreading the Water Wealth: Making Water Infrastructure Work for the Poor*, Dams, Rivers and People Report, Berkeley, CA: IRN.

International Union for Conservation of Nature (IUCN) (1980) *World Conservation Strategy*, Gland, Switzerland: IUCN/UNEP/WWF.

International Union for Conservation of Nature (2000) *Vision for Water and Nature: A World Strategy for Conservation and Sustainable Management of Water Resources in the 21st Century*, Gland, Switzerland: IUCN.

Inyan, B. J. and Williams, M. W. (2001) ‘Protection of headwater catchments from future degradation: San Miguel River basin, Colorado’, *Mountain Research and Development*, 21(1), 54–60.

Irujo, A. E. (2007) ‘The right to water’, *Water Resources Development*, 23(2), 267–83.

Ison, R., Röling, N. and Watson, D. (2007) ‘Challenges to science and society in the sustainable management and use of water: investigating the role of social learning’, *Environmental Science and Policy*, 10, 499–511.

Ives, J. and Pitt, D. C. (eds) (1988) *Deforestation: Social Dynamics in Watersheds and Mountain Ecosystems*, London: Routledge.

Ives, J., Messerli, B. and Thompson, M. (1987) ‘Research strategy for the Himalayan region’, *Mountain Research and Development*, 7(3), 332–44.

Jägerskog, A., Granit, J., Risberg, A. and Yu, W. (2007) *Transboundary Water Management as a Regional Public Good: Financing Development – An Example from the Nile Basin*, Report 20, Stockholm: Stockholm International Water Institute.

Jakobsen, F., Zeaul Hoque, A. K. M., Paudyal, G. N. and Bhuiyan, M. S. (2005) ‘Evaluation of short-term processes forcing the monsoon river floods in Bangladesh’, *Water International*, 30(3), 389–99.

Jalludin, M. (2007) ‘Groundwater and the challenges for future water supply of the Republic of Djibouti in an arid climate (Horn of Africa)’, in C. Laurence and G. de Marsily (eds), *Aquifer Systems Management: Darcy’s Legacy in a World of Impending Water Shortage*, London: Taylor & Francis, 127–35.

Jeffers, J. N. R. (1998) ‘Characterization of river habitats and prediction of habitat features using ordination techniques’, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 8: 529–40.

Jewitt, G. (2001) ‘Can integrated water resources management sustain the provision of ecosystem goods and services?’, 2nd WARFSA/WaterNet Symposium: Integrated Water Resources Management: Theory, Practice, Cases, Cape Town, 30–31 October.

Johansson, D. and Azar, C. (2007) 'A scenario based analysis of land competition between food and bioenergy production in the US', *Climate Change*, 82, 267–91.

Johnson, A. K. L., Shrubsole, D. and Merrin, M. (1996) 'Integrated catchment management in northern Australia, from concept to implementation', *Land Use Policy*, 13(4), 303–16.

Johnson, C., Tunstall, S. and Penning-Rowsell, E. (2005) 'Floods as catalysts for policy change: historical lessons from England and Wales', *Journal of Water Resources Development*, 21(4), 561–75.

Johnson, C., Penning-Rowsell, E. and Tapsell, S. (2007) 'Aspiration and reality: flood policy, economic damages and the appraisal process', *Area*, 39(2), 214–23.

Johnson, P. (1988) 'River regulation: a regional perspective – Northumbrian Water Authority', *Regulated Rivers: Research and Management*, 2, 233–55.

Johnston, W. B. (1985) 'Sector and place: the place of environment in government administration', *Proceedings of the 13th New Zealand Geography Conference, Hamilton*, Auckland: New Zealand Geographical Society, 96–8.

Jonch-Clausen, T. and Fugl, J. (2001) 'Firming up the conceptual basis of integrated water resources management', *Water Resources Development*, 17(4), 501–10.

Jowett, I. (1992) 'River hydraulics and instream habitat modelling for river biota', in M. P. Mosley (ed.), *Waters of New Zealand*, Wellington: New Zealand Hydrological Society, 249–63.

Julia, R. and Duchin, F. (2007) 'World trade as the adjustment mechanism of agriculture to climate change', *Climate Change*, 82, 393–409.

Kaika, M. (2004) 'Water for Europe: the creation of the European Water Framework Directive', in J. Trottier and P. Slack (eds), *Managing Water Resources Past and Present*, Oxford: Oxford University Press, 89–116.

Kalpavriksh and the Hindu College Nature Club (1986) 'The Narmada Valley Project: development or destruction?', in E. Goldsmith and N. Hildyard (eds), *The Social and Environmental Effects of Large Dams*, Cambridge: Cambridge University Press, 224–44.

Kandel, R. (2003) *Water from Heaven: The Story of Water from the Big Bang to the Rise of Civilization and Beyond*, New York: Columbia University Press.

Karpiscak, M. M., Foster, K. E. and Rawles, R. L. (1984) 'Water harvesting and evaporation suppression', *Arid Lands Newsletter*, 21, 11–17.

Karr, J. R. (1991) 'Biological integrity: a long-neglected aspect of water resource management', *Ecological Applications*, 1, 66–84.

Karr, J. R. (1999) 'Defining and measuring river health', *Freshwater Biology*, 41, 221–34.

Karr, J. R., Fausch, K. D., Angermeier, P. L., Yant, P. R. and Schlosser, I. J. (1986) *Assessing Biological Integrity in Running Waters: A Method and Its Rationale*, Special Publication 5, Champaign, IL: Illinois Natural History Survey.

Kasai, M., Brierley, G. J., Page, M. J., Marutani, T. and Trustrum, N. A. (2005) 'Impacts of land use change on patterns of sediment flux in Weraamaia catchment, New Zealand', *Catena*, 64, 27–60.

Keay-Bright, J. and Boardman, J. (2006) 'Changes in the distribution of degraded land over time in the Central Karoo, South Africa', *Catena*, 67, 1–14.

Keen, M., Brown, V. A. and Dyball, R. (2005) 'Social learning: a new approach to environmental management', in M. Keen, V. A. Brown and R. Dyball (eds), *Social*

Learning in Environmental Management: Towards a Sustainable Future, London: Earthscan, 3–21.

Keketso, L. (2003) ‘The mixed blessings of the Lesotho Highlands Water Project: an assessment based on local perspectives’, *Mountain Research and Development*, 23(1), 7–10.

Keller, E. A. (1978) ‘Pools, riffles and channelization’, *Environmental Geology*, 2, 119–27.

Keller, J., Keller, A. and Davids, G. (1998) ‘River basin development phases and implications of closure’, *Journal of Applied Irrigation Science*, 33(2), 145–63.

Kentula, M. E. (2000) ‘Perspectives on setting success criteria for wetland restoration’, *Ecological Engineering*, 15, 199–209.

Kern, K. (1992) ‘Rehabilitation of streams in south-west Germany’, in P. J. Boon, P. Calow and G. E. Petts (eds), *River Conservation and Management*, Chichester: Wiley, 332–5.

Kessler, C. A. (2007) ‘Motivating farmers for soil and water conservation: a promising strategy from the Bolivian mountain valleys’, *Land Use Policy*, 24, 118–28.

Khalid, F. and O’Brien, J. (eds) (1992) *Islam and Ecology*, London: Cassell.

Kidd, S. and Shaw, D. (2007) ‘Integrated water resource management and institutional integration: realising the potential of spatial planning in England’, *Geographical Journal*, 173(4), 312–29.

Kiessling, K. L. (1998) ‘Conference on the Aral Sea: women, children, health and environment’, *Ambio*, 27(7), 560–4.

Kijne, J. W., Barker, R. and Molden, D. (eds) (2003) *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, Wallingford, Oxon: CABI Publishing.

King, J. and Louw, D. (1998) ‘Instream flow assessments for regulated rivers in South Africa using the building block methodology’, *Aquatic Ecosystem Health and Management*, 1, 109–24.

Kingsford, R. T., Boulton, A. J. and Puckridge, J. T. (1998) ‘Challenges in managing dryland rivers crossing political boundaries: lessons from Cooper Creek and the Paroo River, central Australia’, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 8, 361–78.

Kinnersley, D. (1988) *Troubled Water: Rivers, Politics and Pollution*, London: Hilary Shipman.

Kirby, C., Newson, M. D. and Gilman, K. (1992) *Plynlimon Research: The First Two Decades*, Report 109, Wallingford, Oxon: Institute of Hydrology.

Kittredge, J. ([1948] 1973) *Forest Influences*, New York: Dover.

Kliot, N. (1994) *Water Resources and Conflict in the Middle East*, London: Routledge.

Knighton, A. D. (1984) *Fluvial Forms and Processes*, Harlow: Edward Arnold.

Knox, J. C. (1989) *Long- and Short-Term Episodic Storage and Removal of Sediment in Watersheds of Southwestern Wisconsin and Northwestern Illinois*, IAHS Publication 184, Wallingford, Oxon: International Association of Hydrological Sciences, 157–64.

Kolba, M., Morton, P. and Quinn, N. P. (2002) ‘Public involvement in the Red River basin management decisions and preparedness for the next flood’, *Global Environmental Change*, B4(4), 87–104.

Kondolf, G. M. and Wilcock, P. R. (1996) ‘The flushing flow problem: defining and evaluating objectives’, *Water Resources Research*, 32, 2589–99.

Kondolf, G. M. and Piégay, H. (eds) (2003a) *Tools in Geomorphology*, Chichester: Wiley.

Kondolf, G. M. and Piégay, H. (2003b) 'Tools in fluvial geomorphology: problem statement and recent practice', in G. M. Kondolf and H. Piégay (eds), *Tools in Geomorphology*, Chichester: Wiley, 3–22.

Konrad, J. A., Baumann, J. S. and Ott, J. A. (1986) 'Non-point source planning and implementation in Wisconsin', in J. F. Solb (ed.), *Effects of Land Use on Fresh Waters*, Chichester: Ellis Horwood, 283–95.

Kowalik, R. A., Cooper, D. M., Evans, C. D. and Ormerod, S. J. (2007) 'Acidic episodes retard the biological recovery of upland British streams from chronic acidification', *Global Change Biology*, 13, 2439–52.

Kronvang, B., Svendsen, L. M., Brookes, A., Fisher, K., Moller, B., Ottosen, M., Newson, M. and Sear, D. (1998) 'Restoration of the rivers Brede, Cole and Skerne: a joint Danish and British EU-LIFE project. 3: Channel morphology, hydrodynamics and transport of sediments and nutrients', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 8, 209–22.

Kumar, D. M., Ghosh, S., Patel, A., Singh, O. P. and Ravindranath, R. (2006) 'Rainwater harvesting in India: some critical issues for basin planning and research', *Land Use and Water Resources Research*, 6, 1–17.

Kurian, M. and Dietz, T. (2005) *How Pro-Poor Are Participatory Watershed Management Projects? An Indian Case Study*, Research Report 92, Colombo: International Water Management Institute.

Ladson, A. R. and White, L. J. (2000) 'Measuring stream condition', in S. Brizga and B. Finlayson (eds), *River Management: The Australasian Experience*, Chichester: Wiley, 265–85.

Ladson, A. and Finlayson, B. (2002) 'Rhetoric and reality in the allocation of water to the environment: a case study of the Goulborn River, Victoria, Australia', *River Research and Applications*, 18, 555–68.

Laki, S. L. (1994) 'The impact of the Jonglei Canal on the economy of the local people', *International Journal of Sustainable Development and World Economy*, 1, 89–96.

Lal, R. (1993) 'Challenges in agriculture and forest hydrology in the humid tropics', in M. Bonnell, M. M. Hufschmidt and J. S. Gladwell (eds), *Hydrology and Water Management in the Humid Tropics*, Cambridge: Cambridge University Press, 273–300.

Lane, S. N., Brookes, C. J., Heathwaite, A. L. and Reaney, S. (2006) 'Surveillant science: challenges for the management of rural environments emerging from the new generation of diffuse pollution models', *Journal of Agricultural Economics*, 57(2), 239–57.

Langford, M. (2005) 'The United Nations concept of water as a human right: a new paradigm for old problems?', *Water Resources Development*, 21(2), 273–82.

Langford-Smith, T. and Rutherford, J. (1966) *Water and Land: Two Case Studies in Irrigation*, Canberra: Australian National University.

Lant, C. L. (1991) 'Potential of the Conservation Reserve Program to control agricultural surface pollution', *Environmental Management*, 15(4), 507–18.

Lant, C. L. (2003) 'Watershed governance in the United States: the challenges ahead', Universities Council on Water Resources, *Water Resources Update*, 126, 21–8.

Large, A. R. G. L., Mayes, W. M., Newson, M. D. and Parkin, G. (2007) 'Using long-term monitoring of fen hydrology and vegetation to underpin wetland restoration strategies', *Applied Vegetation Science*, 10, 417–28.

Larkin, P. (1964) *The Whitsun Weddings*, London: Faber.

Laurie, N. (2005) 'Establishing development orthodoxy: negotiating masculinities in the water sector', *Development and Change*, 36(3), 527–49.

Law, F. (1956) 'The effect of afforestation upon the yield of water catchment areas', *Journal of the British Waterworks Association*, 38, 484–94.

Lawrence, P., Meigh, J. and Sullivan, C. (2002) *The Water Poverty Index: An International Comparison*, KERP 2002/19, Keele Economics Research Series, Keele: Keele University.

Leach, W. D. and Pelkey, N. W. (2001) 'Making watershed partnerships work: a review of the empirical literature', *Journal of Water Resources Planning and Management*, 127(6), 378–85.

Lee, K. N. (1993) *Compass and Gyroscope: Integrating Science and Politics for the Environment*, Washington, DC: Island Press.

Leeks, G. J. L. (1992) 'Impact of plantation forestry on sediment transport processes', in P. Billi, R. D. Hey, C. R. Thorne and P. Tacconi (eds), *Dynamics of Gravel-Bed Rivers*, Chichester: Wiley.

Leeks, G. J. L. and Newson, M. D. (1989) 'Responses of the sediment system of a regulated river to a scour valve release: Llyn Clywedog, Mid-Wales, UK', *Regulated Rivers*, 3, 93–106.

Leopold, L. B. (1968) *Hydrology for Urban Land Planning*, Circular 554, Menlo Park, CA: US Geological Survey.

Leopold, L. B. (1991) 'Closing remarks', in GCES Committee, *Colorado River Ecology and Dam Management*, Washington, DC: National Academy Press, 254–7.

Leopold, L. B. and Maddock, T. (1954) *The Flood Control Controversy*, New York: Donald.

Leopold, L. B., Wolman, M. G. and Miller, J. P. (1964) *Fluvial Processes in Geomorphology*, San Francisco, CA: W. H. Freeman.

Le Quesne, T., Pegram, G. and Von Der Heyden, C. (2007) *Allocating Scarce Water: A WWF Primer on Water Allocation, Water Rights and Water Markets*, Godalming, Surrey: WWF-UK.

Lesch, W. and Scott, D. F. (1997) 'The response in water yield to the thinning of *Pinus radiata, Pinus patula* and *Eucalyptus grandis* plantations', *Forest Ecology and Management*, 99, 295–307.

Leuven, R. S. E. W., Ragas, A. M. J., Smits, A. J. M. and van der Velde, G. (eds) (2006) *Living Rivers: Trends and Challenges in Science and Management*, Dordrecht: Springer.

Levi, E. (1995) *The Science of Water: The Foundation of Modern Hydraulics*, New York: ASCE Press.

Lewin, J., Macklin, M. G. and Newson, M. D. (1988) 'Regime theory and environmental change: irreconcilable concepts?', in W. R. White (ed.), *International Conference on River Regime*, Chichester: Wiley, 431–45.

Lewis, G. and Williams, G. (1984) *Rivers and Wildlife Handbook: A Guide to Practices which Further the Conservation of Wildlife on Rivers*, Sandy, Beds.: Royal Society for the Protection of Birds/Royal Society for Nature Conservation.

Lindesay, J. A. (2003) 'Climate and drought in Australia', in L. C. Botterill and M.

Fisher (eds), *Beyond Drought: People, Policy and Perspectives*, Collingwood, Victoria: CSIRO Press, 21–47.

Local Government Management Board (LGMB) (1998) *Sustainable Water Management: Promoting Water Efficiency*, London: LGMB.

Logan, J., Walker, F. R., Jolly, B. A. and Foster, T. (2005) 'A GIS-based inventory of sediment pollution for watershed restoration planning', *Land Use and Water Resources Research*, 5, 2.1–2.5 (online at http://www.luwrr.com).

Lomborg, B. (2001) *The Skeptical Environmentalist: Measuring the Real State of the World*, Cambridge: Cambridge University Press.

Loomis, J. B., Quattlebaum, K., Brown, T. C. and Alexander, S. J. (2003) 'Expanding institutional arrangements for acquiring water for environmental purposes: transactions evidence from the United States', *Water Resources Development*, 19(1), 21–8.

Loucks, D. P. (1997) 'Quantifying trends in system sustainability', *Hydrological Sciences Journal*, 42(4), 513–30.

Loucks, D. P. (2003) 'Managing America's rivers: who's doing it?', *International Journal of River Basin Management*, 1(1), 21–31.

Loucks, D. P. and Gladwell, J. S. (1999) *Sustainability Criteria for Water Resource Systems*, Cambridge: Cambridge University Press.

Lowe, P. and Goyder, J. (1983) *Environmental Groups in Politics*, London: Allen & Unwin.

Lowry, T. S., Bright, J. C., Close, M. E., Robb, C. A., White, P. A. and Cameron, S. G. (2003) 'Management gaps analysis: a case study of groundwater resource management in New Zealand', *Water Resources Development*, 19(4), 579–92.

Lu, X. X. and Higgitt, D. L. (2001) 'Sediment delivery to the Three Gorges. 2. Local response', *Geomorphology*, 41, 157–69.

Lundqvist, J., Appasamy, P. and Nelliyat, P. (2003) 'Dimensions and approaches for Third World city water security', *Philosophical Transactions of the Royal Society of London B*, 358, 1985–96.

McClimans, J. (1980) 'Best management practices for forestry activities', *Watershed Management 1980*, New York: American Society of Civil Engineers, 694–705.

McClintock, D., Ison, R. and Armson, R. (2003) 'Metaphors for reflecting on research practice: researching with people', *Journal of Environmental Planning and Management*, 46(5), 715–31.

McColl, R. H. S. and Gibson, A. R. (1979) 'Downslope movement of nutrients in hill pasture, Taita, New Zealand. III Amounts involved and management implication', *Journal of Agricultural Research*, 22, 279–86.

McCully, P. (1996) *Silenced Rivers: The Ecology and Politics of Large Dams*, 1st edn, London: Zed Books.

McCully, P. (2001) *Silenced Rivers: The Ecology and Politics of Large Dams*, 2nd edn, London: Zed Books.

McCully, P. (2007) *Before the Deluge: Coping with Floods in a Changing Climate*, Berkeley, CA: International Rivers Network.

Macdonald, A. (2001) 'Water resources in the twenty-first century: a global challenge', *Journal CIWEM*, 15, 157–61.

McDonald, A., Lane, S., Kirkby, M., Holden, J., Ashley, D., Reid, S., Tayefi, V. and Brookes, C. (2003) *Information Requirements for the Integrated Management of Agricultural Areas in Sensitive River Basins*, R&D Technical Report E1–108/TR, York: Environment Agency.

McDonald, A., Lane, S. N., Haycock, N. E. and Chalk, E. A. (2004) 'Rivers of dreams: on the gulf between theoretical and practical aspects of an upland river restoration', *Transactions of the Institute of British Geographers*, NS29, 257–81.

McDonald, D. A. and Ruiters, G. (2005) 'Theorizing water privatization in Southern Africa', in D. A. McDonald and G. Ruiters (eds), *The Age of Commodity: Water Privatization in Southern Africa*, London: Earthscan, 13–42.

MacDonald, D. H. and Lamontagne, S. (2005) 'Moving from piecemeal accounting to a pragmatic economic approach to water pricing in Australia', *Land Use and Water Resources Research*, 5, 1–9.

McDonald, R. (2006) 'Sustainable development as freedom', *International Journal of Sustainable Development and World Ecology*, 13, 445–7.

Macklin, M. G. and Dowsett, R. B. (1989) 'The chemical and physical speciation of trace metals in fine grained overbank flood sediments in the Tyne basin, North East England', *Catena*, 16(2), 135–51.

Macklin, M. G. and Rumsby, B. T. (2007) 'Changing climate and extreme floods in the British uplands', *Transactions of the Institute of British Geographers*, NS32, 168–86.

McQueen, C., Noemdoe, S. and Jezile, N. (2001) 'The Working for Water Programme', *Land Use and Water Resources Research*, 1, 1–4.

Madej, M. A. (1984) *Recent Changes in Channel-Store Sediment, Redwood Creek, California*, Technical Report, California: Redwood National Park Authority.

Magalhaes, A. R. (1994) 'Sustainable development planning and semi-arid regions', *Global Environmental Change*, 4(4), 275–9.

Maheshwari, B. L., Walker, K. F. and McMahon, T. A. (1995) 'Effects of regulation on the flow regime of the River Murray, Australia', *Regulated Rivers: Research and Management*, 10, 15–38.

Majot, J. (1997) *Beyond Big Dams: A New Approach to Energy Sector and Watershed Planning*, Berkeley, CA: International Rivers Network.

Majumdar, C. and Gupta, G. (2007) 'The debate over municipal water pricing: evidence from Kolkata, India', *Water Resources Development*, 23(4), 571–82.

Majumdar, S. K., Miller, E. W. and Sage, L. E. (1988) *Ecology and Restoration of the Delaware River Basin*, Easton, PA: Pennsylvania Academy of Science.

Makhoalibe, S. (1999) 'Management of water resources in the Maloti/Drakensberg Mountains of Lesotho', *Ambio*, 28(5), 460–1.

Makin, J., Sanders, J. and Smithers, H. (2004) 'Sustainable water resource management at the catchment level: recent experiences in north west England', in *Hydrology: Science and Practice for the 21st Century*, Vol. II, Wallingford, Oxon: British Hydrological Society, 425–33.

Malanson, G. P. (1993) *Riparian Landscapes*, Cambridge: Cambridge University Press.

Maltby, E. (1986) *Waterlogged Wealth: Why Waste the World's Wet Places?*, London: Earthscan.

Mambo, J. and Archer, E. (2007) 'An assessment of land degradation in the Save catchment of Zimbabwe', *Area*, 39(3), 380–91.

Manchester City Council (1995) *First Steps: Local Agenda 21 in Practice*, London: HMSO.

Manouchehri, G. R. and Mahmoodian, S. A. (2002) 'Environmental impacts of dams constructed in Iran', *Water Resources Development*, 18(1), 179–82.

Mansell, M. and Rollet, F. (2006) ‘Water balance and the behaviour of different paving surfaces’, *Water and Environment Journal*, 20, 7–10.

Marchand, M. and Toornstra, F. H. (1986) *Ecological Guidelines for River Basin Development*, Leiden: Dept 28, Centrum voor Milienkunde, Rijksuniversiteit.

Margat, J. (2007) ‘Great aquifer systems of the world’, in C. Laurence and G. de Marsily (eds), *Aquifer Systems Management: Darcy’s Legacy in a World of Impending Water Shortage*, London: Taylor & Francis, 105–16.

Margerum, R. D. and Whitall, D. (2004) ‘The challenges and implications of collaborative management on a river basin scale’, *Journal of Environmental Planning and Management*, 47(3), 407–27.

Marsh, G. P. ([1864] 1965) *Man and Nature: Or Physical Geography as Modified by Human Action*, reprinted, Cambridge, MA: Belknap Press of Harvard University Press.

Mason, S. (2005) ‘Are we scorpions? The role of upstream–downstream dialogue in fostering cooperation in the Nile basin’, *Mountain Research and Development*, 25(2), 115–20.

Mas’ud, A. F. (1987) ‘Land use and physical hydrology of selected mesoscale catchments in Wales’, Unpublished Ph.D. thesis, University College of North Wales, Bangor.

Mather, A. S. (1982) ‘The changing perception of soil erosion in New Zealand’, *Geographical Journal*, 148(2), 207–18.

Mathur, K. and Jayal, N. G. (1993) *Drought, Policy and Politics: The Need for a Long-Term Perspective*, New Delhi: Sage.

Meade, R. H. (1982) ‘Sources, sinks and storage of river sediment in the Atlantic drainage of the United States’, *Journal of Geology*, 90(3), 235, 252.

Meadows, M. E. and Hoffman, M. T. (2002) ‘The nature, extent and causes of land degradation in South Africa: legacy of the past, lessons for the future?’, *Area*, 34(4), 428–37.

Meko, D. M., Woodhouse, C. A., Baisan, C. A., Knight, T., Lukas, J. J., Hughes, M. K. and Salzer, M. W. (2007) ‘Medieval drought in the upper Colorado River basin’, *Geophysical Research Letters*, 34, L10705.

Mensching, H. (1986) ‘Is the desert spreading? Desertification in the Sahel zone of Africa’, *Applied Geography and Development*, 27, 7–18.

Merrett, S. (2003a) ‘Virtual water and Occam’s razor’, *Water International*, 28(1), 103–5.

Merrett, S. (2003b) ‘Virtual water and the Kyoto consensus’, *Water International*, 28(4), 540–2.

Merrett, S. (2005) *The Price of Water*, Studies in Water Resource Economics and Management, London: IWA Publishing.

Mertz, B., Davidson, O., Swart, R. and Pan, J. (eds) (2001) *Climate Change 2001: Mitigation*, Cambridge: Cambridge University Press.

Metawie, A. F. (2004) ‘History of cooperation in the Nile basin’, *Water Resources Development*, 20(1), 47–63.

Meybeck, M. (2003) ‘Global analysis of river systems: from Earth system controls to Anthropocene syndromes’, *Philosophical Transactions of the Royal Society of London B*, 358, 1935–55.

Michener, J. A. (1975) *Centennial*, London: Corgi Books.

Millennium Ecosystem Assessment (MEA) (2005) *Ecosystems and Human Well-Being: General Synthesis*, Washington, DC: Island Press.

Milliman, J. D., Broadus, J. M. and Gable, F. (1987) 'Environmental and economic implication of rising sea level and subsiding deltas: the Nile and Bengal examples', *Ambio*, 18(6), 340–5.

Millington, C. E. and Sear, D. A. (2007) 'Impacts of river restoration on small-wood dynamics in a low-gradient headwater stream', *Earth Surface Processes and Landforms*, 32(8), 1204–18.

Ministry of Health (1948) *Gathering Grounds: Public Access to Gathering Grounds, Afforestation and Agriculture on Gathering Grounds*, London: HMSO.

Ministry of Natural Resources, Ontario (1986) *Conservation Areas Guide*, Toronto: Government Bookstore.

Mitchell, B. (ed.) (1990) *Integrated Water Management*, London: Belhaven.

Mitchell, B. (1997) *Resource and Environmental Management*, Harlow: Longman.

Mitchell, B. (2005) 'Integrated water resource management, institutional arrangements and land-use planning', *Environment and Planning A*, 37, 1335–52.

Mitchell, B. and Pigram, J. J. (1989) 'Integrated resource management and the Hunter Valley Conservation Trust, NSW, Australia', *Applied Geography*, 9, 196–211.

Mitchell, J. K. and Bubenzer, G. D. (1980) 'Soil loss estimation', in M. J. Kirkby and R. P. C. Morgan (eds), *Soil Erosion*, Chichester: Wiley, 17–62.

Moberg, F. and Galaz, V. (2005) *Going from Conventional to Adaptive Freshwater Management for Human and Ecosystem Compatibility*, Swedish Water House Policy Brief 3, Stockholm: Stockholm International Water Institute.

Mogaka, H., Gichere, S., Davis, R. and Hirji, R. (2006) *Climate Variability and Water Resources Degradation in Kenya: Improving Water Resources Development and Management*, Working Paper 69, Washington, DC: World Bank.

Molden, D. (2002) 'Balancing ecological and human livelihood security in a catchment: a hydronomic zones approach', in *Balancing Human Security and Ecological Security Interests in a Catchment: Towards Upstream/Downstream Hydrosolidarity*, Proceedings of the SIWI Seminar, Stockholm, Report 17, Stockholm: Stockholm International Water Institute, 9–23.

Molden, D. (ed.) (2007) *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*, London: International Water Management Institute/Earthscan.

Molle, F. (2003) *Development Trajectories of River Basins: A Conceptual Framework*, Research Report 72, Colombo: International Water Management Institute.

Molle, F. (2007) 'Scales and power in river basin management: the Chao Phraya River in Thailand', *Geographical Journal*, 173(4), 358–73.

Molle, F., Marmanpoush, A. and Miranzadeh, M. (2004) *Robbing Yadullah's Water to Irrigate Saeid's Garden: Hydrology and Water Rights in a Village of Central Iran*, Research Report 80, Colombo: International Water Management Institute.

Mollinga, P. P. (2001) 'Water and politics: levels, rational choice and South Indian canal irrigation', *Futures*, 33, 733–52.

Montgomery, D. R. (2007) *Dirt: The Erosion of Civilizations*, Berkeley: University of California Press.

Montgomery, D. R. and Buffington, J. M. (1997) 'Channel-reach morphology in mountain drainage basins', *Geological Society of America Bulletin*, 109(5), 596–611.

Montz, B. and Gruntfest, E. C. (1986) 'Changes in American urban floodplain occupancy since 1958: the experiences of nine cities', *Applied Geography*, 6, 325–38.

Moorehead, A. (1973) *The White Nile*, Harmondsworth: Penguin Books.

Moorehead, A. (1983) *The Blue Nile*, Harmondsworth: Penguin Books.

Moreyra, A. and Wegerich, K. (2006) 'Highlighting the "multiple" in MSPs: the case of Cerro Chapelco, Patagonia', *Water Resources Development*, 22(4), 629–41.

Morgan, R. P. C. (2005) *Soil Erosion and Conservation*, 3rd edn, Oxford: Blackwell.

Morid, S. and Massah, A. R. (2004) 'Modelling Zayandeh Rud basin under climate change', in *Hydrology: Science and Practice for the 21st Century*, Vol. I, Wallingford, Oxon: British Hydrological Society, 50–6.

Mormont, M. (1996) 'Towards concerted river management in Belgium', *Journal of Environmental Planning and Management*, 39(1), 131–41.

Mortimore, M. (1989) *Adapting to Drought: Farmers, Famines and Desertification in West Africa*, Cambridge: Cambridge University Press.

Mosley, M. P. (ed.) (1992) *Waters of New Zealand*, Wellington: New Zealand Hydrological Society.

Moss, B. (2002) 'Intricate, elegant, delicate: the inner workings of healthy rivers', *World Rivers Review*, 17(3), 2–3, 7.

Moss, T. (2004) 'The governance of land use in river basins: prospects for overcoming problems of institutional interplay with the EU Water Framework Directive', *Land Use Policy*, 21, 85–94.

Mostert, E., Pahl-Wostl, C., Rees, Y., Searle, B., Tabara, D. and Tippett, J. (2007) 'Social learning in European river basin management: barriers and fostering mechanisms from 10 river basins', *Ecology and Society*, 12(1), 1–12.

Motiee, H., McBean, E., Semsar, A., Gharabaghi, B. and Ghomashchi, V. (2006) 'Assessment of the contributions of traditional qanats in sustainable water resources management', *Water Resources Development*, 22(4), 575–88.

Mounsey, S. C. and Newson, M. D. (1995) 'Acid episodes in the Coalburn catchment', in *British Hydrological Society 5th National Hydrology Symposium, Edinburgh*, Wallingford, Oxon: British Hydrological Society, 5.17–5.27.

Mount, N. J., Sambrook Smith, G. H. and Stott, T. A. (2005) 'An assessment of the impact of upland afforestation on lowland river reaches: the Afon Trannon, mid-Wales', *Geomorphology*, 64, 255–69.

Muckleston, K. W. (1990) 'Integrated water management in the United States', in B. Mitchell (ed.), *Integrated Water Management*, London: Belhaven.

Mujwahuzi, M. R. (2002) *Drawers of Water II: 30 Years of Change in Domestic Water Use and Environmental Health in East Africa*, Tanzania Country Study, London: International Institute for Environment and Development.

Mwendera, E. J., Mohamed Saleem, M. A. and Dibabe, A. (1997) 'The effect of livestock grazing on surface runoff and soil erosion from sloping pasture lands in the Ethiopian Highlands', *Australian Journal of Experimental Agriculture*, 37, 421–30.

Mythen, G. (2004) *Ulrich Beck: A Critical Introduction to the Risk Society*, London: Pluto Press.

Nace, R. (1974) *General Evolution of the Concept of the Hydrological Cycle*, Paris: UNESCO/WMO/IAHS, 40–51.

Naiman, R. J., Magnuson, J. J., McKnight, D. M. and Stanford, J. A. (1995) *The Freshwater Imperative: A Research Agenda*, Washington, DC: Island Press.

Napier, T. L. (1990) 'The evolution of US soil conservation policy: from voluntary adoption to coercion', in J. Boardman, I. D. L. Foster and J. A. Dearing (eds), *Soil Erosion on Agricultural Land*, Chichester: Wiley, 627–44.

National Audit Office (2001) *Inland Flood Defence*, London: HMSO.

National Research Council (1992) *Restoration of Aquatic Ecosystems: Science, Technology and Public Policy*, Washington, DC: National Academy Press.

National Research Council (1995) *Wetlands: Characteristics and Boundaries*, Washington, DC: National Academy Press.

National Research Council (1999) *New Strategies for America's Watersheds*, Washington, DC: National Academy Press.

National Rivers Authority (NRA) (1992) *Policy and Practice for the Protection of Groundwater*, Bristol: NRA.

National Rivers Authority (1994) *The Implications of Climate Change for the National Rivers Authority*, Research and Development Report 12, London: HMSO.

National Rivers Authority (1995) *Thames 21: A Planning Perspective and a Sustainable Strategy for the Thames Region*, Reading: NRA, Thames Region.

National Rivers Authority (1996) *River Habitats in England and Wales: A National Overview*, Bristol: NRA.

National Water Council (1976) *We Didn't Wait for the Rain*, London: National Water Council.

National Water Demand Management Centre (NWDMC) (1998) *Saving Water: On the Right Track*, Bristol: NWDMC/Environment Agency.

National Water Demand Management Centre (1999) *Saving Water: On the Right Track*, Bristol: NWDMC/Environment Agency.

Negi, G. C. S. and Joshi, V. (1997) 'Land use in a Himalayan catchment under stress: system responses', *Ambio*, 26(2), 126–8.

Nel, E. and Illgner, P. (2001) 'Tapping Lesotho's "white gold": interbasin water transfer in Southern Africa', *Geography*, 86, 163–7.

Nelson, A. and Chomitz, K. M. (2004) *The Forest–Hydrology–Poverty Nexus in Central America: An Heuristic Analysis*, Policy Research Working Paper 3430, Washington, DC: World Bank.

Newbold, C., Honnor, J. and Buckley, K. (1989) *Nature Conservation and the Management of Drainage Channels*, Peterborough: Nature Conservancy Council.

Newson, M. D. (1980) 'The geomorphological effectiveness of floods: a contribution stimulated by two recent events in mid-Wales', *Earth Surface Processes*, 5, 1–16.

Newson, M. D. (1986) 'River basin engineering: fluvial geomorphology', *Journal of the Institution of Water Engineers and Scientists*, 40(4), 307–24.

Newson, M. D. (1988) 'Upland land use and land management: policy and research aspects of the effects on water', in J. M. Hooke (ed.), *Geomorphology in Environmental Planning*, Chichester: Wiley, 19–32.

Newson, M. D. (1989) 'Flood effectiveness in river basins: progress in Britain in a decade of drought', in K. Beven and P. Carling (eds), *Floods: Hydrological, Sedimentological and Geomorphological Implications*, Chichester: Wiley.

Newson, M. D. (1990) 'Forestry and water, "good practice" and UK catchment policy', *Land Use Policy*, 7(1), 53–8.

Newson, M. D. (1991) 'Catchment control and planning: emerging patterns of definition, policy and legislation in UK water management', *Land Use Policy*, 9(1), 9–15.

Newson, M. D. (1992a) *Land, Water and Development: River Basin Systems and their Sustainable Management*, 1st edn, London: Routledge.

Newson, M. D. (1992b) 'Land and water: convergence, divergence and progress in the UK policy', *Land Use Policy*, 9(2), 111–21.

Newson, M. D. (1992c) 'Geomorphic thresholds in gravel-bed rivers: refinements for an era of environmental change', in P. Billi, R. D. Hey, C. R. Thorne and P. Tacconi (eds), *Dynamics of Gravel-Bed Rivers*, Chichester: Wiley, 3–20.

Newson, M. D. (1994a) 'Sustainable integrated development and the basin sediment system: guidance from fluvial geomorphology', in C. Kirby and W. R. White (eds), *Integrated River Basin Development*, Chichester: Wiley, 1–10.

Newson, M. D. (1994b) 'The roles and potential of development planning and catchment management planning in bringing about sustainable use of freshwater capacity', in N. Ward and G. Garrod (eds), *Water Quality: Understanding the Benefits and Meeting the Demands*, Newcastle upon Tyne: Centre for Rural Economy, Department of Agricultural Economics and Food Marketing, University of Newcastle upon Tyne, 85–104.

Newson, M. D. (1995) 'Catchment-scale solute modelling in a management context', in S. T. Trudgill (ed.), *Solute Modelling in Catchment Ecosystems*, Chichester: Wiley, 445–60.

Newson, M. D. (1997) *Land, Water and Development: Sustainable Management of River Basin Systems*, 2nd edn, London: Routledge.

Newson, M. D. (2002) 'Geomorphological concepts and tools for sustainable river ecosystem management', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 12, 365–79.

Newson, M. D. (2004a) 'Integrating the biophysical and social science frameworks for IWRM/IRBM: rationality and reality', in *Hydrology: Science and Practice for the 21st Century*, Vol. II, Wallingford, Oxon: British Hydrological Society, 439–43.

Newson, M. D. (2004b) *Options for Convergence (under the WFD) of Water Planning in England and Wales*, Wallingford, Oxon: W. S. Atkins.

Newson, M. D. (2007) 'Contrasting UK experiences with participatory approaches to integrated river basin management', in J. Warner (ed.), *Multi-Stakeholder Platforms for Integrated Water Management*, Aldershot: Ashgate, 69–94.

Newson, M. D. (in press) ' "Catchment consciousness" – will mantra, metric or mania best protect, restore and manage habitats?', in P. Kemp (ed.), *Atlantic Salmon Trust 40th Anniversary Conference*, Oxford: Blackwell.

Newson, M. D. and Robinson, M. (1983) 'Effects of agricultural drainage on upland streamflow: case studies in mid-Wales', *Journal of Environmental Management*, 17, 333–48.

Newson, M. D. and Leeks, G. J. (1987) 'Transport processes at the catchment scale', in C. R. Thorne, J. C. Bathurst and R. D. Hey (eds), *Sediment Transport in Gravel-Bed Rivers*, Chichester: Wiley, 187–223.

Newson, M. D. and Calder, I. R. (1989) 'Forests and water resources: problems of prediction on a regional scale', *Philosophical Transactions of the Royal Society of London B*, 324, 283–98.

Newson, M. D. and Lewin, J. (1991) 'Climatic change, river flow extremes and fluvial erosion: scenarios for England and Wales', *Progress in Physical Geography*, 15(1), 1–17.

Newson, M. D. and Sear, D. A. (1992) 'River conservation, river dynamics, river maintenance: contradictions?', in C. Stevens, J. E. Gordon, C. P. Green and

M. G. Macklin (eds), *Conserving Our Landscape*, Proceedings of the Conference 'Conserving Our Landscape: Evolving Landforms and Ice-Age Heritage', Crewe, Peterborough: English Nature, 125–30.

Newson, M. D. and Sear, D. A. (1994) 'Sediment and gravel transportation in rivers including the use of gravel traps', Research and Development Note C5/384/2, National Rivers Authority, Bristol.

Newson, M. D. and Ghazi, I. (1995) *River Basin Management and Planning in the Zayandeh Rud Basin, Iran*, Isfahan: University of Isfahan.

Newson, M. D. and Newson, C. L. (2000) 'Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges', *Progress in Physical Geography*, 24, 195–217.

Newson, M. D. and Sear, D. A. (2001) 'Geomorphological procedures and river restoration: science, survey and sustainability', in H. J. Nijland and M. J. R. Cals (eds), *River Restoration in Europe: Practical Approaches*, Lelystad: Institute for Inland Water Management and Wastewater Treatment/RIZA, 251–3.

Newson, M. D. and Chalk, L. (2004) 'Environmental capital: an information core to public participation in strategic and operational decisions – the example of river basin "best practice" projects', *Journal of Environmental Planning and Management*, 47, 899–920.

Newson, M. D. and Large, A. R. G. (2006) ' "Natural" rivers, "hydromorphological quality" and river restoration: a challenging new agenda for applied fluvial geomorphology', *Earth Surface Processes and Landforms*, 31, 1606–24.

Newson, M. D. and Clark, M. J. (2008) 'Uncertainty and the sustainable management of restored rivers', in S. Darby and D. Sear (eds), *River Restoration: Managing the Uncertainty in Restoring Physical Habitat*, Chichester: Wiley, 287–301.

Newson, M. D., Clark, M. J., Sear, D. A. and Brookes, A. (1998) 'The geomorphological basis for classifying rivers', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 8: 415–30.

Newson, M. D., Pitlick, J. and Sear, D. A. (2002) 'Running water: fluvial geomorphology and river restoration', in M. R. Perrow and A. J. Davy (eds), *Handbook of Ecological Restoration*, Vol. 1, Cambridge: Cambridge University Press, 133–52.

Newton, C. (1998) 'An introduction to the Environment Agency's contribution to sustainable development', in *Sustainable Development: What Does It Really Mean for Rivers and Coasts?*, Annual Meeting, Rivers and Coastal Group and Environment Group, Leamington Spa: Chartered Institution of Water and Environmental Management.

Ngigi, S. N., Savenije, H. H. G. and Gichuki, F. N. (2007) 'Land use changes and hydrological impacts related to up-scaling of rainwater harvesting and management in Upper Ewaso Ng'iro basin, Kenya', *Land Use Policy*, 24, 129–40.

Nicholas, A. P. and Walling, D. E. (1998) 'Numerical modelling of floodplain hydraulics and suspended sediment transport and deposition', *Hydrological Processes*, 12, 1339–55.

Nicholson, M. (1987) *The New Environmental Age*, Cambridge: Cambridge University Press.

Nienhuis, P. H., Leuven, R. S. E. W. and Ragas, A. M. J. (1998) 'Discussion and state of the art: new concepts emerging', in P. H. Nienhuis, R. S. E. W. Leuven and A. M. J. Ragas (eds), *New Concepts for Sustainable Management of River Basins*, Leiden: Backhuys, 353–67.

Ninan, K. N. and Lakshmikanthamma, S. (2001) ‘Social cost–benefit analysis of a watershed development project in Karnataka, India’, *Ambio*, 30(3), 157–61.

Nisbet, T. R. (2001) ‘The role of forest management in controlling diffuse pollution in UK forestry’, *Forest Ecology and Management*, 143, 215–26.

Nishat, A. (1996) ‘Impact of Ganges water dispute on Bangladesh’, in A. K. Biswas and T. Hashimoto (eds), *Asian International Waters from Ganges–Brahmaputra to Mekong*, Bombay: Oxford University Press.

Obeng, L. E. (1978) ‘Environmental impacts of four African impoundments’, in C. G. Gunnerson and J. M. Kalbermatten (eds), *Environmental Impacts of International Civil Engineering Projects and Practices*, New York: American Society of Civil Engineers, 29–43.

Odemerho, F. O. and Sada, P. O. (1984) ‘The role of urban surface characteristics on the extent of gullying in Auchi, Bendel State, Nigeria’, *Applied Geography*, 4, 333–44.

Olsson, P. and Folke, C. (2001) ‘Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Ratten, Sweden’, *Ecosystems*, 4, 85–104.

Organisation for Economic Co-operation and Development (OECD) (1989) *Water Resource Management: Integrated Policies*, Paris: OECD.

Office of the Deputy Prime Minister (ODPM) (2006) *Proposals for Introducing a Code for Sustainable Homes*, London: ODPM.

Ohlsson, L. (ed.) (1995) *Hydropolitics: Conflict over Water as a Development Constraint*, London: Zed Books.

Okoba, B. O. and Sterk, G. (2006) ‘Farmers’ identification of erosion indicators and related erosion damage in the Central Highlands of Kenya’, *Catena*, 65, 292–301.

O’Riordan, T. (1976) ‘Policy making and environmental management: some thoughts on purposes and research issues’, *Natural Resources Journal*, 16, 55–72.

O’Riordan, T. (1977) ‘Environmental ideologies’, *Environment and Planning A*, 9, 3–14.

O’Riordan, T. (2004) ‘Environmental science, sustainability and politics’, *Transactions of the Institute of British Geographers*, NS29, 234–47.

O’Riordan, T. and Rayner, S. (1991) ‘Risk management for global environmental change’, *Global Environmental Change*, 1, 91–108.

Orr, H. G. *et al.* (2008, in press).

Ortolando, L. and Cushing, K. K. (2002) ‘Grand Coulee dam 70 years later: what can we learn?’, *Water Resources Development*, 18(3), 373–90.

Osborn, T. J. and Hulme, M. (2002) ‘Evidence for trends in heavy rainfall events over the UK’, *Philosophical Transactions of the Royal Society of London A*, 360, 1313–25.

Owuor, B., Eriksen, S. and Mauta, W. (2005) ‘Adapting to climate change in a dryland mountain environment in Kenya’, *Mountain Research and Development*, 25(4), 310–15.

Ozdemiroglu, E. and Mourato, S. (2000) ‘Valuing marginal changes in river flow: do people care?’, in P. McMahon and D. Moran (eds), *Economic Valuation of Water Resources*, London: Chartered Institution of Water and Environmental Management, 149–68.

Page, B. (2005) ‘Paying for water and the geography of commodities’, *Transactions of the Institute of British Geographers*, NS30, 293–306.

Pahl-Wostl, C. (2006) 'The importance of social learning in restoring the multifunctionality of rivers and floodplains', *Ecology and Society*, 11(1), 10.

Palmer, T. (1986) *Endangered Rivers and the Conservation Movement*, Berkeley: University of California Press.

Palmer, T. (1997) *The Columbia: Sustaining a Modern Resource*, Seattle, WA: The Mountaineers.

Palutikov, J. P. (1987) *Some Possible Impacts of Greenhouse Gas Induced Climatic Change on Water Resources of England and Wales*, Publication 168, Wallingford, Oxon: International Association of Scientific Hydrology, 585–96.

Park, C. C. (1977) 'World-wide variations in hydraulic geometry exponents of stream channels: an analysis and some observations', *Journal of Hydrology*, 35, 133–46.

Parker, R. (1976) *The Common Stream*, London: Paladin.

Parliamentary Office of Science and Technology (POST) (2001) *Managing Flooding*, Postnote 169, London: POST.

Parliamentary Office of Science and Technology (2006a) *Balancing Water Supply and the Environment*, Postnote 259, London: POST.

Parliamentary Office of Science and Technology (2006b) *Adapting to Climate Change in the UK*, Postnote 267, London: POST.

Parliamentary Office of Science and Technology (2006c) *Adapting to Climate Change in Developing Countries*, Postnote 269, London: POST.

Parsons, A. J., Wainwright, J., Braizier, R. E. and Powell, D. M. (2006) 'Is sediment delivery a fallacy?', *Earth Surface Processes and Landforms*, 31, 1325–8.

Passmore, D. G., Macklin, M. G., Brewer, P. A., Lewin, J., Rumsby, B. T. and Newson, M. D. (1995) 'Variability of late Holocene braiding in Britain', in J. L. Best and C. S. Bristow (eds), *Braided Rivers*, Special Publication 75, London: Geological Society, 205–29.

Patrick, R. (1992) *Surface Water Quality: Have the Laws Been Successful?*, Princeton, NJ: Princeton University Press.

Patterson, A. (1987) *Water and the State*, Geographical Paper 98, Reading: Department of Geography, University of Reading.

Paulo, A. A. and Pereira, L. S. (2006) 'Drought concepts and characterisation: comparing drought indices applied at local and regional scales', *Water International*, 31(1), 37–49.

Pavan, A. (2005) *The Ganges: Along Sacred Waters*, London: Thames and Hudson.

Pearce, D (ed.) (1993) *Blueprint 3: Measuring Sustainable Development*, London: Earthscan.

Pearce, D. (2000) 'Controversies in economic valuation', in P. McMahon and D. Moran (eds), *Economic Valuation of Water Resources*, London: Chartered Institution of Water and Environmental Management, 49–63.

Pearce, F. (1994) 'High and dry in Aswan', *New Scientist*, 142, 7 May, 28–32.

Penning-Rowsell, E. and Wilson, T. (2006) 'Gauging the impact of natural hazards: the pattern and cost of emergency response during flood events', *Transactions of the Institute of British Geographers*, NS31, 99–115.

Perret, S. (2006) 'New paradigms, policies and governance in the water sector', in S. Perret, S. Farolfi and R. Hassan (eds), *Water Governance for Sustainable Development*, London: Earthscan, xxi–xxiv.

Perry, C. J. (2001) *Charging for Irrigation Water: The Issues and Options, with a Case*

Study from Iran, Research Report 52, Colombo: International Water Management Institute.

Peters, E. (1992) ‘Protecting the land under modern land claims agreements: the effectiveness of the environmental regime negotiated by the James Bay Cree in the James Bay and Northern Quebec Agreement’, *Applied Geography*, 12, 133–45.

Petersen, R. C., Petersen, B.-M. and Lacoursire, J. (1992) ‘A building-block model for stream restoration’, in P. Boon, G. Petts and P. Calow (eds), *River Conservation and Management*, Chichester: Wiley, 293–309.

Petroski, H. (1982) *To Engineer Is Human: The Role of Failure in Successful Design*, New York: St Martin’s Press.

Petroski, H. (2006) *Success through Failure: The Paradox of Design*, Princeton, NJ: Princeton University Press.

Petts, G. E. (1979) ‘Complex response of river channel morphology subsequent to reservoir construction’, *Progress in Physical Geography*, 3(3), 329–62.

Petts, G. E. (1984) *Impounded Rivers: Perspectives for Ecological Management*, Chichester: Wiley.

Petts, G. E. (1987) ‘Timescales for ecological change in regulated rivers’, in J. Craig and J. B. Kemper (eds), *Regulated Streams: Advances in Ecology*, New York: Plenum, 257–66.

Petts, G. E. (2003) ‘Editorial’, *River Research and Applications*, 19, 375–6.

Petts, G. E. and Thoms, M. C. (1987) ‘Morphology and sedimentology of a tributary confluence bar in a regulated river’, *Earth Surface Processes*, 12(4), 433–40.

Petts, G. E. and Amoros, C. (eds) (1996) *Fluvial Hydrosystems*, London: Chapman Hall.

Petts, G. E. and Maddock, I. (1996) ‘Flow allocation for in-river needs’, in G. E. Petts and P. Calow (eds), *River Restoration*, Oxford: Blackwell, 60–79.

Petts, G. E., Foulger, T. R., Gilvear, D. J., Pratts, J. D. and Thoms, M. C. (1985) ‘Wave-movement and water quality variations during a controlled release from Kielder reservoir, North Tyne River, UK’, *Journal of Hydrology*, 80, 371–89.

Petts, G. E., Maddock, I., Bickerton, M. and Ferguson, A. J. D. (1995) ‘Linking hydrology and ecology: the scientific basis for river management’, in D. M. Harper and A. J. D. Ferguson (eds), *The Ecological Basis for River Management*, Chichester: Wiley, 1–16.

Petts, G. E., Nestler, J. and Kennedy, R. (2006) ‘Advancing science for water resources management’, *Hydrobiologia*, 565, 277–88.

Petts, J. (2007) ‘Learning about learning: lessons from public engagement and deliberation on urban river restoration’, *Geographical Journal*, 173, 300–11.

Pezzey, J. (1989) *Definitions of Sustainability*, CEED Discussion Paper 9, London: Centre for Economic and Environmental Development.

Piégay, H. and Landon, N. (1997) ‘Promoting ecological management of riparian forests on the Drôme River, France’, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 7, 287–304.

Pielke, R. A. (2006) ‘When scientists politicize science’, *Regulation*, Spring, 28–34.

Pilkey, O. H. and Pilkey-Jarvis, L. (2007) *Useless Arithmetic: Why Environmental Scientists Can’t Predict the Future*, New York: Columbia University Press.

Pinay, A. and Decamps, H. (1988) ‘The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: a conceptual model’, *Regulated Rivers: Research and Management*, 2, 507–16.

Pinay, G., Decamps, H., Chauvet, E. and Fustec, E. (1990) ‘Functions of ecotones in fluvial systems’, in R. J. Naiman and H. Decamps (eds), *The Ecology and Management of Aquatic–Terrestrial Ecotones*, Carnforth, Lancs.: Parthenon Publishing, 141–69.

Pires, M. (2004) ‘Watershed protection for a world city: the case of New York’, *Land Use Policy*, 21, 161–75.

Pitlick, J. (1997) ‘A regional perspective of the hydrology of the 1993 Mississippi River basin floods’, *Annals of the Association of American Geographers*, 87(1), 135–51.

Pitlick, J. and van Steeter, M. M. (1998) ‘Geomorphology and endangered fish habitats of the Upper Colorado River: 2. Linking sediment transport to habitat maintenance’, *Water Resources Research*, 34, 303–16.

Playfair, J. (1802) *Illustrations of the Huttonian Theory of the Earth*, Edinburgh: William Creech.

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegaard, K. L., Richter, B. D., Sparks, R. E. and Stromberg, J. C. (1997) ‘The natural flow regime: a paradigm for river conservation and restoration’, *BioScience*, 47(11), 769–84.

Polhemus, Van Dyke (1988) ‘Delaware River Basin Commission’s river management role: the interface between water users and managing entities’, in S. K. Majumdar, E. W. Miller and L. E. Sage (eds), *Ecology and Restoration of the Delaware River Basin*, Easton, PA: Pennsylvania Academy of Science.

Polls, I. and Lanyon, R. (1980) ‘Pollutant concentrations from homogenous land uses’, *Journal of Environmental Engineering Division*, Proceedings of the American Society of Civil Engineers, 106, 69–80.

Poole, A. L. (1983) ‘Catchment control in New Zealand’, Water and Soil Miscellaneous Publication 48, Wellington: Ministry of Works and Development.

Poole, G. C. (2002) ‘Fluvial landscape ecology: addressing uniqueness within the river discontinuum’, *Freshwater Biology*, 47, 641–60.

Poolman, M. and van de Giesen, N. (2006) ‘Participation: rhetoric and reality: the importance of understanding stakeholders based on a case study in Upper East Ghana’, *Water Resources Development*, 22(4), 561–73.

Pope, W. (1980) ‘Impact of man in catchments. II. Roads and urbanisation’, in A. M. Gower (ed.), *Water Quality in Catchment Ecosystems*, Chichester: Wiley, 73–112.

Popham, A. E. (1946) *The Drawings of Leonardo da Vinci*, London: Jonathan Cape.

Postel, S. and Richter, B. (2003) *Rivers for Life: Managing Water for People and Nature*, Washington, DC: Island Press.

Pottinger, L. (1999) *River Keepers Handbook: A Guide to Protecting Rivers and Catchments in Southern Africa*, Berkeley, CA: International Rivers Network.

Poyner, A. M. (1998) ‘Watering Las Vegas’, *Geography*, 83(1), 37–45.

Price, D. K. (1965) *The Scientific Estate*, New York: Oxford University Press.

Prime, R. (1992) *Hinduism and Ecology*, London: Cassell.

Prince, H. (1995) ‘Floods in the upper Mississippi River basin, 1993: newspapers, official views and forgotten farmlands’, *Area*, 27(2), 118–26.

Pringle, C. (2003a) ‘What is hydrological connectivity and why is it ecologically important?’, *Hydrological Processes*, 17, 2685–9.

Pringle, C. (2003b) ‘Interacting effects of altered hydrology and contaminant transport: emerging ecological patterns of global concern’, in M. Holland, E. Blood and L Shaffer (eds), *Achieving Sustainable Freshwater Systems: A Web of Connections*, Washington, DC: Island Press, 85–107.

Prudhomme, C., Jakob, D. and Svensson, C. (2003) 'Uncertainty and climate change impact on the flood regime of small UK catchments', *Journal of Hydrology*, 277, 1–23.

Pughe, D. L. (2001) 'The lost notebook of the aqueous perspective', in D. Rothenburg and M. Ulvaeus (eds), London: MIT Press, 229–35.

Purseglove, J. (1988) *Taming the Flood*, Oxford: Oxford University Press.

Quevauviller, P., Balabanis, P., Fragakis, C., Weydert, M., Oliver, M., Kaschl, A., Arnold, G., Kroll, A., Galbiati, L., Zaldivar, J. M. and Bidoglio, G. (2005) 'Science–policy integration needs in support of the implementation of the EU Water Framework Directive', *Environmental Science and Policy*, 8, 203–11.

Raddum, G. G. and Fjellheim, A. (2003) 'Liming of River Audna, Southern Norway: a large-scale experiment of benthic invertebrate recovery', *Ambio*, 32(3), 230–4.

Rast, W. and Holland, M. M. (2003) 'Sustainable freshwater resources: achieving secure water supplies', in M. M. Holland, E. R. Blood and L. R. Shaffer (eds), *Achieving Sustainable Freshwater Systems: A Web of Connections*, Washington, DC: Island Press, 283–321.

Ravnborg, H. M. (2006) 'Water management and the poor: issues and scales of action', *Water International*, 31(3), 387–97.

Rawat, D. S., Sharma, J. S., Rikhari, H. C. and Palni, L. M. S. (1997) 'Sustainable development and management of rural ecosystems in the Central Himalaya: a case study from Haigad watershed', *International Journal of Sustainable Development and World Ecology*, 4, 214–25.

Rees, J. A. (1969) *Industrial Demand for Water: A Study of South East England*, London: London School of Economics/Weidenfeld & Nicolson.

Reid, I. and Parkinson, R. J. (1984) 'The nature of the tile-drain outfall hydrograph in heavy clay soils', *Journal of Hydrology*, 72, 289–305.

Reid, I. and Frostick, L. E. (1986) 'Dynamics of bedload transport in Turkey Brook', *Earth Surface Processes and Landforms*, 11, 143–55.

Reisner, M. (1990) *Cadillac Desert: The American West and its Disappearing Water*, London: Secker & Warburg.

Renard, K. G., Foster, G. R., Weesies, G. A. and Porter, J. P. (1991) 'RUSLE: revised universal soil loss equation', *Journal of Soil and Water Conservation*, 46, 30–3.

Renard, K. G., Laflen, J. M., Foster, G. R. and McCool, D. K. (1994) 'The revised universal soil loss equation', in R. Lal (ed.), *Soil Erosion Research Methods*, Ankeny, IA: Soil and Water Conservation Society, 105–24.

Renaud, F., Bechstedt, H. D. and Nakorn, U. N. (1998) 'Farming systems and soil-conservation practices in a study area of northern Thailand', *Mountain Research and Development*, 18(4), 345–56.

Rennison, R. W. (1979) *Water to Tyneside*, Newcastle upon Tyne: Newcastle and Gateshead Water Co.

Reuss, M. (2004) 'The development of American water resources: planners, politicians and constitutional interpretation', in J. Trottier and P. Slack (eds), *Managing Water Resources Past and Present*, Oxford: Oxford University Press, 51–71.

Revenga, C., Murray, S., Abramovitz, J. and Hammond, A. (1998) *Watersheds of the World: Ecological Value and Vulnerability*, Washington, DC: WRI/Worldwatch Institute.

Reynolds, E. R. C. and Leyton, L. (1967) 'Research data for forest policy: the purpose, methods and progress of forest hydrology', *Proceedings of the 9th British Commonwealth Forestry Conference*, Oxford: University of Oxford.

Reynolds, J. F., Stafford Smith, D. M. and Lambin, E. (2003) 'ARIDnet: seeking novel approaches to desertification and land degradation', *IGBP Global Change Newsletter*, 54, 5–9.

Rhoades, R. E. (1998) *Participatory Watershed Research and Management: Where the Shadow Falls*, Gatekeeper Series 81, London: IIED.

Richter, B. D., Baumgartner, J. V., Wigington, R. and Braun, D. P. (1997) 'How much water does a river need?', *Freshwater Biology*, 37, 231–49.

Ripl, W. (2003) 'Water: the bloodstream of the biosphere', *Philosophical Transactions of the Royal Society of London*, Biological Series, 358(1440), 1921–34.

River Restoration Centre (1999, 2002) *River Restoration: Manual of Techniques*, Silsoe, Beds.: River Restoration Centre.

RIZA (1991) *Sustainable Use of Groundwater: Problems and Threats in the European Communities*, Lelystad: Institute for Inland Water Management and Waste Water Treatment.

Roberts, C. R. (1989) 'Flood frequency and urban-induced channel change: some British examples', in K. Beven and P. Carling (eds), *Floods: Hydrological, Sedimentological and Geomorphological Implications*, Chichester: Wiley, 57–82.

Roberts, G. and Marsh, T. (1987) *The Effects of Agricultural Practices on the Nitrate Concentrations in the Surface Water Domestic Supply Sources of Western Europe*, Publication 164, Wallingford, Oxon: International Association of Hydrological Sciences.

Roberts, J. (1983) 'Forest transpiration: a conservative hydrological process?', *Journal of Hydrology*, 66, 133–41.

Robertson, W. A. (1993) 'New Zealand's new legislation for sustainable resource management: the Resource Management Act, 1991', *Land Use Policy*, October, 303–11.

Robertson, W. A. (1996) 'Sustainable management and the market in New Zealand', *Land Use Policy*, 13(3), 213–15.

Robinson, M. and Beven, K. J. (1983) 'The effect of mole drainage on the hydrological response of a swelling clay soil', *Journal of Hydrology*, 64, 205–23.

Robinson, M., Ryder, E. L. and Ward, R. C. (1985) 'Influence on streamflow of field drainage in a small agricultural catchment', *Agricultural Water Management*, 10, 145–58.

Robinson, M. *et al.* (2003) 'Studies of the impact of forests on peak flows and baseflows: a European perspective', *Forest Ecology and Management*, 186, 85–97.

Robinson, N. A. (1987) 'Marshalling environmental law to resolve the Himalaya–Ganges problem', *Mountain Research and Development*, 7(3), 305–15.

Robson, A. J. (2002) 'Evidence for trends in UK flooding', *Philosophical Transactions of the Royal Society of London A*, 360, 1327–43.

Rockström, J. (2003) 'Water for food and nature in drought-prone tropics: vapour shift in rain-fed agriculture', *Philosophical Transactions of the Royal Society of London B*, 358, 1997–2009.

Rockström, J. and Gordon, L. (2001) 'Assessment of green water flows to sustain major biomes of the world: implications for future ecohydrological landscape management', *Physics and Chemistry of the Earth*, B26(11–12), 843–51.

Rodda, J. C. and Young, G. J. (eds) (1992) *International Conference on Water and the Environment: Development Issues for the 21st Century – Keynote Papers*, Geneva:

International Conference on Water and the Environment (World Meteorological Organization).

Rodrigue, P. B. and Wright, K. M. (2003) ‘Wetland restoration: applications on the land in the lower Mississippi alluvial valley’, in M. M. Holland, E. R. Blood and L. R. Shaffer (eds), *Achieving Sustainable Freshwater Systems: A Web of Connections*, Washington, DC: Island Press, 173–91.

Rodriguez, P. (2004) ‘The debate on privatization of water utilities: a commentary’, *Water Resources Development*, 20(1), 107–12.

Roesner, L. A. (ed.) (1997) *Effects of Watershed Development and Management on Aquatic Ecosystems*, New York: American Society of Civil Engineers.

Rogers, K. and Biggs, H. (1999) ‘Integrating indicators, endpoints and value systems in strategic management of rivers of the Kruger National Park’, *Freshwater Biology*, 41, 439–51.

Rogers, K., Roux, D. and Biggs, H. (2000) ‘Challenges for catchment management agencies: lessons from bureaucracies, business and resource management’, *Water SA*, 26(4), 505–11.

Rolt, L. T. C. (1985) *Navigable Waters*, Harmondsworth: Penguin Books.

Roni, P. (ed.) (2005) *Monitoring Stream and Watershed Restoration*, Bethesda, MD: American Fisheries Society.

Rose, A. (ed.) (1992) *Judaism and Ecology*, London: Cassell.

Rosenberg, D. M., McCully, P. and Pringle, C. M. (2000) ‘Global-scale environmental effects of hydrological alterations: introduction’, *BioScience*, 50(9), 746–51.

Rosgen, D. L. (1994) ‘A classification of natural rivers’, *Catena*, 22, 169–99.

Rosgen, D. (1996) *Applied River Morphology*, Pagosa Springs, CO: Wildland Hydrology.

Rothenberg, D. and Ulvaeus, M. (eds) (2001) *Writing on Water*, London: MIT Press.

Roux, D., de Moor, F., Cambray, J. and Barber-James, H. (2002) ‘Use of landscape-level river signatures in conservation planning: a South African case study’, *Conservation Ecology*, 6(2), 6.

Rowley, G. (1990) ‘The West Bank: native water-resource systems and competition’, *Political Geography Quarterly*, 9(1), 39–52.

Rowntree, K. (1990) ‘Political and administrative constraints on integrated river basin development: an evaluation of the Tana and Athi Rivers Development Authority, Kenya’, *Applied Geography*, 10, 21–41.

Rowntree, K. M. and Wadeson, R. A. (1998) ‘A geomorphological framework for the assessment of instream flow requirements’, *Aquatic Ecosystem Health and Management*, 1, 125–41.

Royal Geographical Society (RGS) (2001) *The Floods: What Have They Taught Us?*, Summary Statement 9, London: RGS.

Ruhl, J. B. and Gregg, R. J. (2001) ‘Integrating ecosystem services into environmental law: a case study of wetlands mitigation banking’, *Stanford Environmental Law Journal*, 20(2), 365–92.

Russell, J. M. and Johnson, T. C. (2007) ‘Little Ice Age drought in equatorial Africa: intertropical convergence zone migrations and El Niño southern oscillation variability’, *Geology*, 35(1), 21–4.

Sabatier, P. A., Focht, W., Lubell, M., Trachtenberg, Z., Vedlitz, A. and Matlock, M. (eds) (2005) *Swimming Upstream: Collaborative Approaches to Watershed Management*, Cambridge, MA: MIT Press.

Sadoff, C. W. and Grey, D. (2005) 'Cooperation on international rivers: a continuum for securing and sharing benefits', *Water International*, 30(4), 420–7.

Saha, S. K. and Barrow, C. J. (eds) (1981) *River Basin Planning, Theory and Practice*, Chichester: Wiley.

Saleth, R. M. (2006) 'Understanding water institutions: structure, environment and change process', in S. Perret, S. Farolfi and R. Hassan (eds), *Water Governance for Sustainable Development*, London: Earthscan, 3–20.

Salzman, J., Thompson, B. H. and Daily, G. C. (2001) 'Protecting ecosystem services: science, economics and the law', *Stanford Environmental Law Journal*, 20(2), 309–32.

Samir, A. (1990) 'Principles and precedents in international law governing the sharing of Nile waters', in P. P. Howell and J. A. Allan (eds), *The Nile*, London: School of Oriental and African Studies/Royal Geographical Society, 225–38.

Satterlund, D. R. and Adams, P. W. (1992) *Wildland Watershed Management*, New York: Wiley.

Schick, A. P. (1995) 'Fluvial processes on an urbanizing alluvial fan: Eilat, Israel', in J. E. Costa, A. J. Miller, K. W. Potter and P. R. Wilcock (eds), *Natural and Anthropogenic Influences in Fluvial Geomorphology*, Geophysical Monograph 89, Washington, DC: American Geophysical Union, 209–18.

Schmidt, J. C., Webb, R. H., Valdez, R. A., Marzolf, G. R. and Stevens, L. E. (1998) 'Science and values in river restoration in the Grand Canyon', *BioScience*, 48(9), 735–47.

Schofield, N. J. (2004) 'Consequences of past hydrological disturbance and emergent issues for water resources in Australia', *Hydrology: Science and Practice for the 21st Century*, Vol. II, Wallingford, Oxon: British Hydrological Society, 153–9.

Scholz, M. (2006a) 'Best management practice: a sustainable urban drainage system management case study', *Water International*, 31(3), 310–19.

Scholz, M. (2006b) *Wetland Systems to Control Urban Runoff*, Amsterdam: Elsevier.

Scholz, M., Morgan, R. and Picher, A. (2005) 'Stormwater resources development and management in Glasgow: two case studies', *International Journal of Environmental Studies*, 62(3), 263–82.

Schramm, G. (1980) 'Integrated river basin planning in a holistic universe', *Natural Resources Journal*, 20(4), 787–806.

Schreiner, B. (2006) 'Foreword', in S. Perret, S. Farolfi and R. Hassan (eds), *Water Governance for Sustainable Development*, London: Earthscan, ix–x.

Schulze, R. E. (1997) *South African Atlas of Agrohydrology and Climatology*, ACRU Report 46, Pretoria: Water Research Commission.

Schulze, R. E. (2000) 'Modelling hydrological responses to land use and climatic change: a Southern African perspective', *Ambio*, 29(1), 12–22.

Schulze, R., Horan, M., Seetal, A. and Schmidt, E. (2004) 'Roles and perspectives of the policy-maker, affected water sector and scientist in integrated water resources management: a case study from South Africa', *Water Resources Development*, 20(3), 325–44.

Schumm, S. A. (1963) *A Tentative Classification of Alluvial River Channels*, Circular 477, Menlo Park, CA: US Geological Survey.

Schumm, S. A. (1969) 'River metamorphosis', *Journal of Hydraulics Division*, American Society of Civil Engineers, 95, 255–73.

Schumm, S. A. (1977) *The Fluvial System*, New York: Wiley.

Schumm, S. A. (1985) ‘Patterns of alluvial rivers’, *Annual Review of Earth and Planetary Sciences*, 13, 5–27.

Schumm, S. A., Harvey, M. D. and Watson, C. C. (1984) *Incised Channels: Morphology, Dynamics and Control*, Littleton, CO: Water Resources Publications.

Scott, D. (1993) ‘New Zealand’s Resource Management Act and fresh water’, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 3, 53–65.

Scott, D. F. and Lesch, W. (1997) ‘Streamflow responses to afforestation with *Eucalyptus grandis* and *Pinus patula* and to felling in the Mokobulaan experimental catchments, South Africa’, *Journal of Hydrology*, 199, 360–77.

Scottish Executive (2005) *Diffuse Water Pollution from Rural Land Use*, Environment Group Paper 2005/35, Edinburgh: Scottish Executive.

Scudder, T. (2005) *The Future of Large Dams: Dealing with Social, Environmental, Institutional and Political Costs*, London: Earthscan.

Sear, D. A. (1992) ‘Impact of hydroelectric power releases on sediment transport processes in pool-riffle sequences’, in P. Billi, R. D. Hey, C. R. Thorne and P. Tacconi (eds), *Dynamics of Gravel-Bed Rivers*, Chichester: Wiley, 630–50.

Sear, D. A. (1994) ‘River restoration and geomorphology’, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 4, 169–77.

Sear, D. A., Newson, M. D. and Brookes, A. (1995) ‘Sediment-related river maintenance: the role of fluvial geomorphology’, *Earth Surface Processes and Landforms*, 20, 629–47.

Sear, D. A., Briggs, A. and Brookes, A. (1998) ‘A preliminary analysis of the morphological adjustment within and downstream of a lowland river subject to river restoration’, *Aquatic Conservation: Marine and Freshwater Ecosystems*, 8, 167–83.

Sear, D. A., Armitage, P. D. and Dawson, F. H. (1999) ‘Groundwater dominated rivers’, *Hydrological Processes*, 13, 255–76.

Sear, D. A., Wilcock, D., Robinson, M. and Fisher, K. (2000) ‘River channel modification in the UK’, in M. Acreman (ed.), *The Hydrology of the UK: A Study of Change*, London: Routledge, 55–81.

Sear, D. A., Newson, M. D. and Thorne, C. R. (2003) *Guidebook of Applied Fluvial Geomorphology*, R&D Technical Report FD1914, London: Department for Environment, Food and Rural Affairs.

Sear, D. A., Newson, M. D. and Thorne, C. R. (in press) *Guidebook of Applied Fluvial Geomorphology*, London: Thomas Telford.

Serageldin, E. (2001) ‘Assuring water for food: the challenge of the coming generation’, *Water Resources Development*, 17(4), 521–5.

Service, R. F. (2004) ‘As the West goes dry’, *Science*, 303, 1124–7.

Sewell, W. R. D., Handmer, J. W. and Smith, D. I. (eds) (1985) *Water Planning in Australia: From Myths to Reality*, Canberra: CRES, Australian National University.

Seymour, J. and Girardet, H. (1986) *Far from Paradise*, London: BBC Books.

Shady, A. M. (2005) ‘Feeding the world or damning the dams: the hard choices ahead’, *Water International*, 30(4), 545–6.

Shah, T., Makin, I. and Sakthivadivel, R. (2004) *Limits to Leapfrogging: Issues in Transposing Successful River Basin Institutions in the Developing World*, Colombo: International Water Management Institute.

Sharp, L. (2006) ‘Water demand management in England and Wales: constructions of the domestic water user', *Journal of Environmental Planning and Management*, 49(6), 869–89.

Sheail, J. (1988) 'River regulation in the United Kingdom: an historical perspective', *Regulated Rivers: Research and Management*, 2, 221–32.

Shindler, B. and Cheek, K. A. (1999) 'Integrating in adaptive management: a propositional analysis', *Conservation Ecology*, 3(1), article 9 (online at www.consecol.org/vol3/iss1).

Shrestha, H. M. and Singh, L. M. (1996) 'The Ganges–Brahmaputra system: a Nepalese perspective in the context of regional cooperation', in A. K. Biswas and T. Hashimoto (eds), *Asian International Waters from Ganges–Brahmaputra to Mekong*, Bombay: Oxford University Press, 81–94.

Shrubsole, D. A. (1990) 'Integrated water management strategies in Canada', in B. Mitchell (ed.), *Integrated Water Management*, London: Belhaven, 88–118.

Shuman, J. R. (1995) 'Environmental considerations for assessing dam removal alternatives for river restoration', *Regulated Rivers: Research and Management*, 11, 249–61.

Simpson, R. W. (1991) 'The international scene: the involvement of British hydrogeologists', in R. A. Downing and W. B. Wilkinson (eds), *Applied Groundwater Hydrology: A British Perspective*, Oxford: Clarendon Press, 314–31.

Simpungwe, E., Waalewijn, P. and Raven, B. (2007) 'Multi-stakeholder dissonance in the South African water arena', in J. Warner (ed.), *Multi-Stakeholder Platforms for Integrated Water Management*, Aldershot: Ashgate, 191–204.

Singh, D. K. and Singh, A. K. (2002) 'Groundwater situation in India: problems and perspective', *Water Resources Development*, 18(4), 563–80.

Sivanappan, R. K. (1995) 'Soil and water management in the dry lands of India', *Land Use Policy*, 12(2), 165–75.

SIWI and IWRA (1999) *Towards Upstream/Downstream Hydrosolidarity*, Proceedings of the SIWI Seminar, Stockholm: Stockholm International Water Institute.

SIWI and UNDP (2002) *Balancing Human Security and Ecological Security Interests in a Catchment: Towards Upstream/Downstream Hydrosolidarity*, Proceedings of the SIWI Seminar, Stockholm, Report 17, Stockholm: Stockholm International Water Institute.

SIWI and IWMI (2004) *Water: More Nutrition per Drop*, Stockholm: Stockholm International Water Institute.

SIWI, RSAS and UNIFEM (2000) *Water Security: Opportunity for Development and Cooperation in the Aral Sea Area*, Report 9, Stockholm: Stockholm International Water Institute.

SIWI, IFPRI, IUCN and IWMI (2005) *Let It Reign: The New Water Paradigm for Global Food Security*, Final Report to CSD-13, Stockholm: Stockholm International Water Institute.

Skinner, K. S. and Bruce-Burgess, L. (2005) 'Strategic and project level river restoration protocols: key components for meeting the requirements of the Water Framework Directive (WFD)', *Water and Environment Journal*, 19(2), 135–40.

Slater, S., Newson, M. D. and Marvin, S. J. (1995) 'Land use planning and the water sector: a review of development plans and catchment management plans', *Town Planning Review*, 65(4), 375–97.

Smith, A. and Ali, M. (2006) 'Understanding the impact of cultural and religious water use', *Water and Environment Journal*, 20, 203–9.

Smith, C. T. (1969) 'The drainage basin as an historical basis for human activity', in R. J. Chorley (ed.), *Water, Earth and Man*, London: Methuen, 101–10.

Smith, D. I. (1981) 'Actual and potential flood damage: a case study for urban Lismore, New South Wales', *Applied Geography*, 1, 31–9.

Smith, D. I. (1990) 'The worthwhileness of dam failure mitigation: an Australian example', *Applied Geography*, 10, 5–19.

Smith, D. I. and Finlayson, B. (1988) 'Water in Australia: its role in environmental degradation', in R. L. Heathcote and J. A. Mabbutt (eds), *Land, Water and People: Geographical Essays in Australian Resource Management*, Sydney: Allen & Unwin.

Smith, D. I. and Handmer, J. (eds) (1989) *Flood Insurance and Relief in Australia*, Canberra: CRES, Australian National University.

Smith, N. (1972) *A History of Dams*, Secaucus, NJ: Citadel Press.

Smith, W. (1993) *River God*, London: Macmillan.

Smits, A. J. M., Nienhuis, P. H. and Leuven, R. S. E. W. (1998) *New Approaches to River Management*, Leiden: Backhuys.

Snaddon, C. D., Wishart, M. J. and Davies, B. R. (1998) 'Some implications of inter-basin water transfers for river ecosystem functioning and for water resources management in Southern Africa', *Aquatic Ecosystem Health and Management*, 1, 159–82.

Soons, J. M. (1986) 'Erosion rates in a superhumid environment', in V. Gardiner (ed.), *International Geomorphology*, Vol. I, Chichester: Wiley, 885–96.

South Asia Network on Dams, Rivers and People (1999) Submission to the World Commission on Dams, available at www.sandrp.in.

Sowman, M. and Brown, A. L. (2006) 'Mainstreaming environmental sustainability into South Africa's integrated development planning process', *Journal of Environmental Planning and Management*, 49(5), 695–712.

Speas, D. W. (2000) 'Zooplankton density and community composition following an experimental flood in the Colorado River, Grand Canyon, Arizona', *Regulated Rivers: Research and Management*, 16, 73–81.

Stahl, D. W., Fye, F. K., Cook, E. R. and Griffin, R. D. (2007) 'Tree-ring reconstructed megadroughts over North America since AD 1300', *Climatic Change*, 83, 133–49.

Stahl, K. (2005) 'Influence of hydroclimatology and socioeconomic conditions on water-related international relations', *Water International*, 30(3), 270–82.

Stauffer, J. (1998) *The Water Crisis: Constructing Solutions to Freshwater Pollution*, London: Earthscan.

Steffen, W., Crutzen, P. J. and McNeil, J. R. (2007) 'The Anthropocene: are humans now overwhelming the great forces of nature?', *Ambio*, 36(8), 614–21.

Steinberg, T. (1991) *Nature Incorporated: Industrialization and the Waters of New England*, Cambridge: Cambridge University Press.

Stern, N. (2007) *The Economics of Climate Change*, Cambridge: Cambridge University Press.

Stern, P. (1979) *Small-Scale Irrigation*, London: Intermediate Technology Publications.

Stiles, D. (1995) *Social Aspects of Sustainable Dryland Management*, Chichester: Wiley.

Stoffberg, F. A., van Zyl, F. C. and Middleton, B. J. (1994) 'The role of integrated catchment studies in the management of water resources in South Africa', in W. R. White and C. Kirby (eds), *Integrated River Basin Development*, Chichester: Wiley, 455–62.

Stokes, E. (1992) 'The Treaty of Waitangi and the Waitangi Tribunal: Maori claims in New Zealand', *Applied Geography*, 12, 176–91.

Strang, V. (2002) *Life Down Under: Water and Identity in an Aboriginal Cultural Landscape*, Goldsmiths Anthropology Research Papers 7, London: Goldsmiths College, University of London.

Strang, V. (2004) *The Meaning of Water*, Oxford: Berg.

Strang, V. (2006) 'Substantial connections: water and identity in an English cultural landscape', *Worldview*, 10(2), 155–77.

Stringer, L. C., Twyman, C. and Thomas, D. S. G. (2007) 'Combating land degradation through participatory means: the case of Swaziland', *Ambio*, 36(5), 387–93.

Sullivan, C. A. and Meigh, J. (2007) 'Integration of the biophysical and social sciences using an indicator approach: addressing water problems at different scales', *Water Resource Management*, 21, 111–28.

Supalla, R. J. (2003) 'Institutional arrangements to improve water quality in irrigated agriculture', *Water Resources Development*, 19(1), 89–99.

Sutcliffe, J. V. (1974) 'A hydrological study of the southern Sudd region of the Upper Nile', *Hydrological Sciences Bulletin*, 19, 237–55.

Sutcliffe, J. V. and Parks, Y. P. (1987) 'Hydrological modelling of the Sudd and Jonglei Canal', *Hydrological Sciences Journal*, 32(2), 143–59.

Sutcliffe, J. V. and Parks, Y. P. (1999) *The Hydrology of the Nile*, IAHS Special Publication 5, Wallingford, Oxon: International Association of Hydrological Sciences.

Sutton, A. (2004) 'The Three Gorges Project on the Yangtze River in China', *Geography*, 89(2), 111–26.

Syme, G. J. and Nancarrow, B. E. (2006) 'Achieving sustainability and fairness in water reform: a Western Australian case study', *Water International*, 31(1), 23–30.

Syvitski, J. P. M., Vorosmarty, C. J., Kettner, A. J. and Green, P. (2005) 'Impacts of humans on the flux of terrestrial sediment to the global coastal ocean', *Science*, 308, 376–80.

Tabara, J. D. and Pahl-Wostl, C. (2007) 'Sustainability learning in natural resource use and management', *Ecology and Society*, 12(2), 3 (online at http://www.ecologyandsociety.org/vol12/iss2/art3/).

Takeuchi, K. (1997) *On the Scale Diseconomy of Large Reservoirs in Land Occupation*, Publication 240, Wallingford, Oxon: International Association of Hydrological Sciences, 519–27.

Tamene, L., Park, S. J., Dikau, R. and Vlek, P. L. G. (2006) 'Reservoir siltation in the semi-arid highlands of northern Ethiopia: sediment yield–catchment area relationship and a semi-quantitative approach for predicting sediment yield', *Earth Surface Processes and Landforms*, 31, 1364–83.

Tan, P.-L. (2006) 'Legislating for adequate public participation in allocating water in Australia', *Water International*, 31(1), 12–22.

Tané, H. (1996) 'The case for integrated river catchment management', in M. Cresser and K. Pugh (eds), *Multiple Land Use and Catchment Management*, Aberdeen: Aberdeen Research Consortium, Macaulay Land Use Research Institute, 5–10.

Tapsell, S. M., Penning-Rowsell, E. C., Tunstall, S. M. and Wilson, T. L. (2002)

'Vulnerability to flooding: health and social dimensions', *Philosophical Transactions of the Royal Society A*, 360, 1511–25.

Taylor, A. and Patrick, M. (1987) 'Looking at water through different eyes: the Maori perspective', *Soil and Water*, 23(4), 22–4.

Taylor, V., Schulze, R. and Jewitt, G. (2003) 'Application of the indicators of hydrological alteration method to the Mkomazi River, KwaZulu-Natal, South Africa', *African Journal of Aquatic Science*, 28(1), 1–11.

Tewari, A. K. (1988) 'Revival of water harvesting methods in the Indian desert', *Arid Lands Newsletter*, 26, 3–8.

Tewari, D. D. (2005) 'A brief historical analysis of water rights in South Africa', *Water International*, 30(4), 438–45.

Thakkar, H. (2007) 'A dam-made disaster: how large dams and embankments have worsened India's floods', in P. McCully (ed.), *Before the Deluge: Coping with Floods in a Changing Climate*, Berkeley, CA: International Rivers Network, 14–17.

Tharme, R. E. (2003) 'A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers', *River Research and Applications*, 19, 397–441.

Thatte, C. D. (2001) 'Aftermath, overview and appraisal of past events leading to some imbalances in the report of the World Commission on Dams', *Water Resources Development*, 17(3), 343–51.

Thomas, D. H. L. and Adams, W. M. (1997) 'Space, time and sustainability in the Hadejia-Jama'are wetlands and the Komodugu Yobe basin, Nigeria', *Transactions of the Institute of British Geographers*, NS22, 430–49.

Thomas, D. S. G. and Middleton, N. J. (1995) *Desertification: Exploding the Myth*, Chichester: Wiley.

Thompson, A. and Clayton, J. (2002) 'The role of geomorphology in flood risk assessment', *Civil Engineering*, 150, 25–9.

Thompson, P. M. and Sultana, P. (1996) 'Distributional and social impact of food control in Bangladesh', *Geographical Journal*, 162(1), 1–13.

Thoms, M. C. (2003) 'Floodplain–river ecosystems: lateral connections and the implications of human interference', *Geomorphology*, 56: 335–49.

Thorne, C. R. (1997) 'Channel types and morphological classification', in C. R. Thorne, R. D. Hey and M. D. Newson (eds), *Applied Fluvial Geomorphology for River Engineering and Management*, Chichester: Wiley.

Thorne, C. R. and Lewin, J. (1982) 'Bank process, bed material movement and planform development in a meandering river', in D. D. Rhodes and G. P. Williams (eds), *Adjustments of the Fluvial System*, London: Allen & Unwin, 117–37.

Thorne, C. R., Russell, A. P. G. and Alam, M. K. (1993) 'Planform pattern and channel evolution of the Brahmaputra River, Bangladesh', in J. L. Best and C. S. Bristow (eds), *Braided Rivers: Geological Society Special Publication*, 75, 257–6.

Thorp, J. H., Stanford, J. A., Thoms, M. C. and Petts, G. E. (2007) 'Editorial: global partnerships and the new International Society for River Science (ISRS)', *River Research and Applications*, 23, 1–5.

Tiffen, M., Mortimore, M. and Gichuki, F. (1994) *More People, Less Erosion: Environmental Recovery in Kenya*, Chichester: Wiley.

Tilman, D. *et al.* (2001) 'Forecasting agriculturally driven global environmental change', *Science*, 292, 281–4.

Tipping, D. C., Adom, D. and Tibaijuka, A. K. (2005) 'Achieving healthy urban futures in the twenty-first century: new approaches to financing water and basic sanitation', in F. Chru and C. Bradford (eds), *The Millennium Development Goals: Raising the Resources to Tackle World Poverty*, London: Zed Books, 181–210.

Tockner, K. and Stanford, J. A. (2002) 'Riverine flood plains: present state and future trends', *Environmental Conservation*, 29(3), 308–30.

Toro, S. M. (1998) 'Strategies towards sustainable development in Nigeria's semi-arid regions', *Water and Environment Journal*, 12, 212–15.

Tortajada, C. (2005) 'Editorial', *Water Resources Development*, 21(2), 225–7.

Toynbee, A. (1976) *Mankind and Mother Earth*, Oxford: Oxford University Press.

Trojanow, I. (2005) *Along the Ganges*, London: Haus Publishing.

Turner, R. K. (1993) *Sustainable Environmental Economics and Management*, London: Belhaven.

Turton, A. (2002) 'Hydropolitics: the concept and its limitations', in A. Turton and R. Henwood (eds), *Hydropolitics in the Developing World: A Southern Africa Perspective*, Pretoria: Centre for International Political Studies, University of Pretoria, 13–19.

Turton, A., Nicol, A. and Allan, T. (2003) *Policy Options in Water-Stressed States: Emerging Lessons from the Middle East and Southern Africa*, Pretoria: Centre for International Political Studies, University of Pretoria/London: Overseas Development Institute.

Turton, A., Schultz, C., Buckle, H., Kgomongoe, M., Malungani, T. and Drackner, M. (2006) 'Gold, scorched earth and water: the hydropolitics of Johannesburg', *Water Resources and Development*, 22(2), 313–35.

Tyagi, N. K. (2003) 'Managing saline and alkaline water for higher productivity', in J. W. Kijne, R. Barker and D. Molden (eds), *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, Wallingford, Oxon: CABI Publishing, 69–87.

Tyler, S. (1987) 'River birds and acid water', *RSPB Conservation Review*, 1, 68–70.

Uitto, J. I. and Duda, A. M. (2002) 'Management of transboundary water resources: lessons from international cooperation for conflict prevention', *Geographical Journal*, 168(4), 365–78.

Uitto, J. I. and Wolf, A. T. (2002) 'Water wars? Geographical perspectives: introduction', *Geographical Journal*, 168(4), 289–92.

UK Round Table on Sustainable Development (UKRTSD) (1997) *Freshwater*, London: UKRTSD.

UN-FPA (2007) *State of World Population: Unleashing the Potential of Urban Growth*, New York: United Nations Population Fund.

Ungate, C. D. (1996) 'Tennessee Valley Authority's Clean Water Initiative: building partnerships for watershed improvement', *Journal of Environmental Planning and Management*, 39(10), 113–22.

United Kingdom Climate Impacts Programme (UKCIP) (2002) *Climate Change Scenarios for the United Kingdom*, UKCIP02 Briefing Report, Norwich: Tyndall Centre for Climate Change Research, University of East Anglia.

United Nations Conference on Desertification (UNCOD) (1977) *Desertification: Its Causes and Consequences*, Nairobi: Pergamon.

United Nations Development Programme (UNDP) (2006) *Human Development Report 2006*, New York: Palgrave Macmillan.

United Nations Human Settlements Programme (UN-Habitat) (2003) *Water and Sanitation in the World's Cities: Local Action for Global Goals*, London: Earthscan.

United States Environmental Protection Agency (USEPA) (1986) *Water Quality Program Highlights: Arkansas Ecoregion Program*, Washington, DC: USEPA.

United States Environmental Protection Agency (1990) *Ground Water: Contamination and Methodology*, Lancaster, PA: Technomic.

UN-Water (2006) *Water: A Shared Responsibility*, United Nations World Water Development Report 2, Paris: UNESCO/New York: Berghahn Books.

US National Water Commission (1973) *Water Policies for the Future*, Port Washington, NY: Water Information Center.

van der Walt, I. J., Struwig, A. and van Rensburg, J. R. J. (2004) 'Forestry as a streamflow reduction activity in South Africa: discussion and evaluation of the proposed procedure for the assessment of afforestation permit applications in terms of water sustainability', *GeoJournal*, 61, 173–81.

Van Dyke, J. A. (1995) *Taking the Waters: Soil and Water Conservation among Settling Beja Nomads in Eastern Sudan*, London: Avebury/African Studies Centre.

van Koppen, B., Moriarty, P. and Boelee, E. (2006) *Multiple-Use Water Services to Advance the Millennium Development Goals*, Research Report 98, Colombo: International Water Management Institute.

van Niekerk, A. W. and Heritage, G. L. (1994) 'The use of GIS techniques to evaluate sedimentation patterns in a bedrock controlled channel in a semi-arid region', in W. R. White and C. Kirby (eds), *Integrated River Basin Development*, Chichester: Wiley, 257–69.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R. and Cushing, C. E. (1980) 'The river continuum concept', *Canadian Journal of Fisheries and Aquatic Sciences*, 37, 130–7.

van Steeter, M. M. and Pitlick, J. (1998) 'Geomorphology and endangered fish habitats of the Upper Colorado River: 1. Historic changes in streamflow, sediment load and channel morphology', *Water Resources Research*, 34, 287–302.

van Wilgen, B. W., Richardson, D. M., Le Maitre, D. C., Marais, C. and Magadlela, D. (2001) 'The economic consequences of alien plant invasions: examples of impacts and approaches to sustainable management in South Africa', *Environment, Development and Sustainability*, 3, 145–68.

van Wilgen, B. W., Breen, C. M., Jaganyi, J. J., Rogers, K. H., Roux, D. J., Sherwill, T., van Wyk, E. and Venter, F. (2003) *Principles and Processes for Supporting Stakeholder Participation in Integrated River Management: Lessons from the Sabie–Sand Catchment*, Water Research Commission Project K5/1062, Gezina, South Africa: Water Research Commission.

Varis, O. (2006) 'Megacities, development and water', *Water Resources Development*, 22(2), 199–225.

Varis, O. (2007) 'Water demands for bioenergy production', *International Journal of Water Resources Development*, 23(3), 519–35.

Vaughan, I. P., Diamond, M., Gurnell, A. M., Hall, K. A., Jenkins, A., Milner, N. J., Naylor, L. A., Sear, D. A., Woodward, G. and Ormerod, S. J. (2007) 'Integrating ecology with hydromorphology: a priority for river science and management', *Aquatic Conservation: Marine and Freshwater Ecosystems*.

Vayrynen, R. (2005) 'Global inequality, poverty and injustice: empirical and policy issues', in F. Chru and C. Bradford (eds), *The Millennium Development Goals: Raising the Resources to Tackle World Poverty*, London: Zed Books, 181–210.

Verghese, B. G. (1996) 'Towards an eastern Himalayan rivers concord', in A. K.

Biswas and T. Hashimoto (eds), *Asian International Waters from Ganges–Brahmaputra to Mekong*, Bombay: Oxford University Press, 25–59.

Verghese, B. G. (2001) 'Sardar Sarovar Project validated by Supreme Court', *Water Resources Development*, 17(1), 79–88.

Vicuna, S. and Dracup, J. A. (2007) 'The evolution of climate change impact studies on hydrology and water resources in California', *Climatic Change*, 82, 327–50.

Videira, N., Kallis, G., Antunes, P. and Santos, R. (2007) *Integrated Evaluation for Sustainable River Basin Governance*, London: IWA Publishing.

Vischer, D. (1989) 'Impact of 18th and 19th century river training works: three case studies from Switzerland', in G. E. Petts (ed.), *Historical Change of Large Alluvial Rivers: Western Europe*, Chichester: Wiley, 19–40.

Visser, F., Roth, C. H., Wasson, R. and Govers, G. (2007) 'A sediment budget for a cultivated floodplain in tropical North Queensland, Australia', *Earth Surface Processes and Landforms*, 32, 1475–90.

Vorosmarty, C. J., Sharma, K. P., Fekete, B. M., Copeland, A. H., Holden, J., Marble, J. and Lough, J. A. (1997) 'The storage and ageing of continental runoff in large reservoir systems of the world', *Ambio*, 26, 210–19.

Vorosmarty, C. J., Douglas, E. M., Green, P. A. and Revenga, C. (2005) 'Geospatial indicators of emerging water stress: an application to Africa', *Ambio*, 34(3), 230–6.

Vyas, J. N. (2001) 'Large dams and sustainable development: a case-study of the Sardar Sarovar Project, India', *Water Resources Development*, 17(4), 601–9.

Waalewijn, P., Wester, P. and van Straaten, K. (2005) 'Transforming river basin management in South Africa: lessons from the Lower Komati River', *Water International*, 30(2), 184–96.

Wackernagel, M. and Rees, W. (1996) *Our Ecological Footprint: Reducing Human Impact on the Earth*, Gabriola Island, BC: New Society Publishers.

Walker, J. and Reuter, D. J. (1996) *Indicators of Catchment Health: A Technical Perspective*, Collingwood, Victoria: CSIRO.

Walker, J., Diamond, M. and Naura, M. (2002) 'The development of physical quality objectives for rivers in England and Wales', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 12, 381–90.

Walker, S. and Langan, S. (2004) 'Delivering environmental improvements through integrated catchment management in sub-catchments of the River Dee, NE Scotland', in *Hydrology: Science and Practice for the 21st Century*, Wallingford, Oxon: British Hydrological Society, 520–5.

Wallace, J. S., Acreman, M. C. and Sullivan, C. A. (2003) 'The sharing of water between society and ecosystems: from conflict to catchment-based co-management', *Philosophical Transactions of the Royal Society of London B*, 385, 2011–26.

Walling, D. E. (1977) 'Assessing the accuracy of suspended sediment rating curves for a small basin', *Water Resources Research*, 13(3), 531–8.

Walling, D. E. (1979) 'The hydrological impact of building activity: a study near Exeter', in G. E. Hollis (ed.), *Man's Impact on the Hydrological Cycle in the UK*, Norwich: Geo Books, 135–51.

Walling, D. E. (1983) 'The sediment delivery problem', *Journal of Hydrology*, 65, 209–37.

Walling, D. E. (1990) 'Linking the field to the river: sediment delivery from agricultural land', in J. Boardman, I. D. L. Foster and J. A. Dearing (eds), *Soil Erosion on Agricultural Land*, Chichester: Wiley, 129–52.

Walling, D. E. (1999) ‘Linking land use, erosion and sediment yields in river basins’, *Hydrobiologia*, 410, 223–40.

Walling, D. E. and Webb, B. (1986) ‘Solutes in river systems’, in S. T. Trudgill (ed.), *Solute Processes*, Chichester: Wiley, 281–327.

Walling, D. E., Owens, P. N. and Leeks, G. J. L. (1999) ‘Rates of contemporary overbank sedimentation and sediment storage on the floodplains of the main channel systems of the Yorkshire Ouse and River Tweed, UK’, *Hydrological Processes*, 13, 993–1009.

Walling, D. E., Russell, M. A., Hodgkinson, R. A. and Zhang, Y. (2002) ‘Establishing sediment budgets for two small lowland catchments in the UK’, *Catena*, 47, 323–53.

Walling, D. E., Collins, A. L. and McMellin, G. K. (2003) ‘A reconnaissance survey of the source of interstitial fine sediment recovered from salmonid spawning gravels in England and Wales’, *Hydrobiologia*, 497, 91–108.

Ward, C. (1997) *Reflected in Water: A Crisis of Social Responsibility*, London: Cassell.

Ward, D., Holmes, N. and Jose, P. (eds) (1994) *The New Rivers and Wildlife Handbook*, Sandy, Beds.: Royal Society for the Protection of Birds.

Ward, J. V. and Stanford, J. A. (1983) ‘The serial discontinuity concept of lotic ecosystems’, in T. D. Fountain and S. M. Bartell (eds), *Dynamics of Lotic Ecosystems*, Stoneham, MA: Ann Arbor Science (Butterworth), 29–42.

Ward, R. C. (1967) *Principles of Hydrology*, New York: McGraw-Hill.

Ward, R. C. (1971) *Small Watershed Experiments: An Appraisal of Concepts and Research Developments*, Occasional Papers in Geography 18, Hull: University of Hull.

Ward, R. C. (1982) *The Fountains of the Deep and the Windows of Heaven*, Hull: University of Hull.

Warner, J. (2007) ‘The beauty of the beast: multi-stakeholder participation for integrated catchment management’, in J. Warner (ed.), *Multi-Stakeholder Platforms for Integrated Water Management*, Aldershot: Ashgate, 1–19.

Warner, R. F. (2000) ‘The role of stormwater management in Sydney’s urban rivers’, in S. Brizga and B. Finlayson (eds), *River Management: The Australasian Experience*, Chichester: Wiley, 173–96.

Wasson, R. J., Juyal, N., Jaiswal, M., McCulloch, M., Sarin, M. M., Jain, V., Srivastava, P. and Singhvi, A. K. (in press) ‘The mountain–lowland debate: deforestation and sediment transport in the upper Ganga catchment’, *Journal of Environmental Management*.

Water UK (2005) *The Value of Water*, London: Water UK.

Watson, C. (1980) ‘Watershed management: the California experience’, in *Watershed Management 1980*, New York: American Society of Civil Engineers, 1048–59.

Watson, N. (2004) ‘Integrated river basin management: a case for collaboration’, *International Journal of River Basin Management*, 2(3), 1–15.

Watson, N. (2007) ‘Collaborative capital: a key to the successful practice of integrated water resources management’, in J. Warner (ed.), *Multi-Stakeholder Platforms for Integrated Water Management*, Aldershot: Ashgate, 31–48.

Watson, N. and Howe, J. (2006) ‘Implementing the EU Water Framework Directive: experiences of participatory planning in the Ribble basin, north west England’, *Water International*, 31(4), 472–87.

Watson, N., Walker, G. and Medd, W. (2007) ‘Critical perspectives on integrated water management: editorial’, *Geographical Journal*, 173(4), 297–9.

Weisner, C. T. (1970) *Climate, Irrigation and Agriculture*, London: Angus and Robertson.

Werritty, A. (2006) 'Sustainable flood management: oxymoron or new paradigm?', *Area*, 38(1), 16–23.

Werritty, A. and Leys, K. F. (2001) 'The sensitivity of Scottish rivers and upland valley floors to recent environmental change', *Catena*, 42, 251–73.

Westcountry Rivers Trust (2007) 'Reducing the cause of climate change', *Confluence: The Journal of the WRT*, 7, 4–5.

Wester, P. and Warner, J. (2002) 'River basin management reconsidered', in A. Turton and R. Henwood (eds), *Hydropolitics in the Developing World: A Southern Africa Perspective*, Pretoria: Centre for International Political Studies, University of Pretoria, 61–71.

Weston, J. (2004) 'EIA in a risk society', *Journal of Environmental Planning and Management*, 47(2), 313–25.

Wheeler, B. D., Shaw, S. C., Foyt, W. J. and Robertson, R. A. (1995) *Restoration of Temperate Wetlands*, Chichester: Wiley.

Whipple, W., Jr and Van Abs, D. J. (1990) 'Principles of a ground-water strategy', *Journal of Water Resources Planning and Management*, American Society of Civil Engineers, 116(4), 503–16.

White, G. F., Bradley, D. J. and White, A. U. (1972) *Drawers of Water: Water Use in East Africa*, Chicago, IL: University of Chicago Press.

White, I. and Howe, J. (2003) 'Planning and the European Water Framework Directive', *Journal of Environmental Planning and Management*, 46(4), 621–31.

White, W. R. (1982) *Sedimentation Problems in River Basins: Studies and Reports in Hydrology*, Paris: UNESCO.

Whitelock, B. and Loughran, R. J. (1994) 'Sediment production and storage in an urbanizing basin, Lake Macquarie, New South Wales, Australia', in *Variability in Stream Erosion and Sediment Transport*, Proceedings of the Canberra Symposium, IAHS Publication 224, Wallingford, Oxon: International Association of Hydrological Sciences, 103–10.

Whitlow, J. R. and Gregory, K. J. (1989) 'Changes in urban stream channels in Zimbabwe', *Regulated Rivers: Research and Management*, 4, 27–42.

Wichelns, D. (2002) 'An economic perspective on subsurface drainage programmes in developing countries, with an example from Egypt', *Water Resources Development*, 18(3), 473–85.

Wichelns, D. (2005) 'The virtual water metaphor enhances policy discussions regarding scarce resources', *Water International*, 30(4), 428–37.

Wilby, R. L., Orr, H. G., Hedger, M., Forrow, D. and Blackmore, M. (2006) 'Risks posed by climate change to the delivery of Water Framework Directive objectives in the UK', *Environment International*, 32, 1043–55.

Wilcock, R. J., Monaghan, R. M., Thorrold, B. S., Meredith, A. S., Betteridge, K. and Duncan, M. J. (2007) 'Land–water interactions in five contrasting dairying catchments: issues and solutions', *Land Use and Water Resources Research*, 7, 2.1–2.10.

Wilhite, D. A. (ed.) (1993a) *Drought Assessment, Management and Planning: Theory and Case Studies*, Boston, MA: Kluwer Academic Publishers.

Wilhite, D. A. (1993b) 'Planning for drought: a methodology', in D. A. Wilhite (ed.), *Drought Assessment, Management and Planning: Theory and Case Studies*, Boston, MA: Kluwer Academic Publishers, 87–108.

Wilhite, D. A. (2003) ‘Drought policy and preparedness: the Australian experience in an international context’, in L. C. Botterill and M. Fisher (eds), *Beyond Drought: People, Policy and Perspectives*, Collingwood, Victoria: CSIRO Press, 175–95.

Wilhite, D. A. (ed.) (2005) *Drought and Water Crises: Science, Technology and Management Issues*, Boca Raton, FL: Taylor & Francis.

Wilhite, D. A. and Buchanan-Smith, M. (2005) ‘Drought as hazard: understanding the natural and social context’, in D. A. Wilhite (ed.), *Drought and Water Crises: Science, Technology and Management Issues*, Boca Raton, FL: Taylor & Francis, 3–29.

Wilhite, D. A., Botterill, L. and Monnik, K. (2005) ‘National drought policy: lessons learned from Australia, South Africa and the United States’, in D. A. Wilhite (ed.), *Drought and Water Crises: Science, Technology and Management Issues*, Boca Raton, FL: Taylor & Francis, 137–72.

Williams, C. (2003) ‘Long time no sea’, *New Scientist*, 4 January, 34–7.

Williams, M. (2000) ‘Desertification: general debates explored through local studies’, *Progress in Environmental Science*, 2(3), 229–51.

Williams, R. N. (ed.) (2006) *Return to the River: Restoring Salmon to the Columbia River*, Amsterdam: Elsevier.

Winid, B. (1981) ‘Comments on the development of the Awash valley, Ethiopia’, in S. K. Saha and C. J. Barrow (eds), *River Basin Planning: Theory and Practice*, Chichester: Wiley, 147–65.

Winpenny, J. T. (1994) *Managing Water as an Economic Resource*, London: Routledge.

Wischmeier, W. H. and Smith, D. D. (1965) *Predicting Rainfall Erosion from Cropland East of the Rocky Mountains*, Agriculture Handbook 282, Washington, DC: United States Department of Agriculture.

Wisdom, A. S. (1979) *The Law of Rivers and Watercourses*, London: Shaw & Sons.

Withers, B. and Vipond, S. (1978) *Irrigation Design and Practice*, London: Batsford.

Wittenberg, L. and Newson, M. D. (2005) ‘Particle clusters in gravel-bed rivers: an experimental morphological approach to bed material transport and stability concepts’, *Earth Surface Processes and Landforms*, 30, 1351–68.

Wittfogel, K. A. (1957) *Oriental Despotism*, New Haven, CT: Yale University Press.

Wohl, E. (2004) *Disconnected Rivers*, New Haven, CT: Yale University Press.

Wohl, E. (2005) ‘Compromised rivers: understanding historical human impacts on rivers in the context of restoration’, *Ecology and Society*, 10(2), 2.

Wolman, M. G. (1967) ‘A cycle of sedimentation and erosion in urban river channels’, *Geografiska Annale*, 49A, 385–95.

Wood, P. J. and Armitage, P. D. (1997) ‘Biological effects of fine sediment in the lotic environment’, *Environmental Management*, 21(2), 203–17.

Wood, R., Handley, J. and Kidd, S. (1999) ‘Sustainable development and institutional design: the example of the Mersey Basin Campaign’, *Journal of Environmental Planning and Management*, 42(3), 341–54.

Woodward, J. and Foster, I. (1997) ‘Erosion and suspended sediment transfer in river catchments’, *Geography*, 82(4), 353–76.

World Bank/IUCN/Nature Conservancy (2005) *How Much Is an Ecosystem Worth? Assessing the Value of Conservation*, Washington, DC: International Bank for Reconstruction and Development/World Bank.

World Business Community for Sustainable Development (WBCSD) (2007) *Water and Sustainable Development*, Geneva: WBCSD.

World Commission on Dams (WCD) (2000) *Dams and Development: A New Framework for Decision-Making*, London: Earthscan.

World Commission on Environment and Development (WCED) (1987) *Our Common Future*, Oxford: Oxford University Press.

World Wide Fund for Nature (WWF) and European Environmental Bureau (EEB) (2005) *EU Water Policy: Making the Water Framework Directive Work*, Brussels: WWF/EEB.

Worrall, F. and Burt, T. P. (2007) 'Trends in DOC concentration in Great Britain', *Journal of Hydrology*, 346, 81–92.

Worster, D. (1992) *Rivers of Empire: Water, Aridity and the Growth of the American West*, Oxford: Oxford University Press.

Wouters, P. K. (1997) *International Water Law: Selected Writings of Professor Charles R. Bourne*, London: Kluwer.

Wray, I. (ed.) (2007) *Mersey: The River that Changed the World*, Liverpool: Bluecoat Press.

Young, G. J., Dooge, J. C. I. and Rodda, J. C. (1994) *Global Water Resource Issues*, Cambridge: Cambridge University Press.

Young, W. J. (ed.) (2001) *Rivers as Ecological Systems*, Canberra: Murray–Darling Basin Commission.

Youngman, R. E. and Lack, J. (1981) 'New problems with upland waters', *Water Services*, 85, 13–14.

Younus, M. A., Bedford, R. D. and Morad, M. (2005) 'Not so high and dry: patterns of autonomous adjustment to major flooding events in Bangladesh', *Geography*, 90(2), 112–20.

Zeitoun, M. and Warner, J. (2005) 'Hydro-hegemony: a framework for analysis of transboundary water conflicts', *Water Policy*, 8(5), 435–60.

Zon, R. (1912) *Forests and Water in the Light of Scientific Investigation*, Document 469, Washington, DC: US Senate.

Web bibliography

Prologue

www.flow-exhibition.co.uk
www.watermagazine.com/poems.htm

Chapter 1

www.cgiar.org
www.fao.org/geonetwork/
www.fao.org/nr/aquastat
www.freshwaterlife.org
www.globwinet.org
www.gwpforum.org
www.internationalrivers.org
www.iwrm-net.org
www.millenniumassessment.org/en/

www.siwi.org
www.tearfund.org/campaigning/watergame/
www.thewaterpage.com
www.un.org/issues/docs/
www.undp.org
www.unwater.org
www.waterscarcity.org
www.watervision.org
www.worldwaterforum.org
www.wri.org/water/

Chapter 2

www.floodplains.org
www.georhs.org

Chapter 3

www.cuahsi.org
www.groundwateruk.org
www.psychic-project.org.uk
http://webworld.unesco.org/water/ihp

Chapter 4

http://www2.rivernetwork.org
www.americanrivers.org
www.awwa.org/waterwiser/
www.catchment.com
www.cciw.ca/nwri
www.cwp.org
www.epa.gov/owow/watershed
www.epa.gov/surf/
www.landcareweb.com
www.mdbc.gov.au
www.niwra.gov.au
www.qwc.qld.gov.au
www.rivers.gov.au
www.tva.gov/river/
www.usda.gov/stream_restoration
www.usgs.gov/osw
www.waterportal-americas.org
www.watershed.org

Chapter 5

www.ag.arizona.edu/OALS/watershed/
www.cluwrr.ncl.ac.uk
www.dfid.gov.uk
www.dwaf.pwv.gov.za
www.earthsummit2002.org
www.fao.org
www.indigenouswater.org
www.johannesburgsummit.org
www.nilebasin.org
www.sandrp.in
www.splash.bradford.ac.uk
www.suez.com
www.terra.geo.orst.edu
www.transboundarywaters.orst.edu/publications/atlas/
www.wateraid.org
www.who.int/water_sanitation_health/index.html
www.worldbank.org
www.wsp.org
www.wsscc.org
www.wsstp.org

Chapter 6

http://unfccc.int
www.cgiar.org/iwmi
www.climateprediction.net
www.dams.org
www.hewsweb.org/drought/
www.hrwallingford.co.uk
www.ipcc.ch
www.iucn.org
www.jncc.gov.uk
www.minvenw.nl
www.panda.org/livingwaters/
www.realclimate.org
www.therrc.co.uk
www.tyndall.uea.ac.uk
www.unep.org/dams
www.waterandnature.org
www.wcainfonet.org
www.wetlandaction.org
www.wwf.org

Chapter 7

http://ec.europa.eu/environment/water.water-framework
www.abi.org.uk/flooding/
www.ciria.org.uk/suds/
www.defra.gov.uk
www.environment-agency.gov.uk
www.friendsoftheriver.org
www.gwptoolbox.org
www.nwl.ac.uk/ih/nrfa/water_watch/
www.smurf-project.info
www.swel.org.uk
www.teamrevival.org
www.ukcip.org.uk
www.ukrivers.net
www.water.org.uk
www.watersave.uk.net
www.wfduk.org

Chapter 8

www.ecjw.org
www.inbo-news.org
www.ontrent.org.uk
www.whittledene.org

Chapter 9

www.adb.org/documents/guidelines/eco_analysis
www.harmoni-ca.info
www.purenorthsea.com
www.stakeholderforum.org

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