FROM INTEGRATED APPROACHES TO SUSTAINABLE RIVER BASIN MANAGEMENT

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Abstract

This paper describes current issues in river management, such as river regulation, flooding, pollution, habitat destruction and fragmentation, water recourse allocation and water-related conflicts. The evolution from integrated approaches to sustainable river basin management is highlighted. Integrated approaches mainly refer to technical, organisational and institutional means of river basin management. Sustainable river basin management focuses on the management goal, *i.e.*, sustainable development. Experiences, innovative viewpoints and new ideas for sustainable management of river basins are summarised. The key to sustainable river basin management is promoting dialogue, encouraging networking and the exchange of data, information and knowledge between decision-makers, scientists, engineers and all stakeholders. Sustainable development requires a carefully considered strategy for the entire river catchment, which includes the following measures: (1) conservation orrestoration of the natural flow regime and the hydromorphological dynamics of rivers,(2) allowing space for rivers and (3) adapting user functions to natural river dynamics. Recommendations for further research focus on integrated modelling and scientific monitoring and the evaluation of river development and rehabilitation programmes, for the sake of improving both science and policy.

1. Introduction

River basins are an essential part of the earth's freshwater cycle and have great potential in terms of water related resources and functions, such as navigation, drinking water supply, agriculture, fisheries, biodiversity and outdoor recreation (Smits 2000b, Sparks 2000, Stortenbeker 2000). The history and consequences of river alterations are similar in most of the industrialised nations, where rivers have been increasingly regulated and isolated from their floodplains to increase navigation and commercial activity, but where as a result the flows of natural services from the river-floodplain system have declined (Sparks *et al.* 2000, Smits *et al.* 2000b). Nowadays, there is widespread public support in developed river basins to recover lost or diminished natural functions (Hunt 2000a, Smits *et al.* 2000b, Sparks *et al.* 2000).

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The rational answer to the drawbacks of single purpose measures has been integrated approaches, *e.g.*, integrated river basin management, where more than one sectoral interest is linked at both strategic and operational levels, and where the entire drainage basin is conceived of as a single ecosystem (Downs *et al.* 1991). Integrated approaches mainly refer to technical, organisational and institutional means, whereas sustainable river basin management has a well defined goal, *i.e.*, sustainable development. In order to prevent further decline of natural services and to recover diminished functions, it is important that international efforts are made to search for ways that lead to sustainable development of river basins (HRH 2000). Sustainable development has become a household word since the "Our common future" report by the World Commission on Environment and Development (Brundtland Commission 1997), and river basin management should also be checked against its "sustainability" standards. An almost classic starting point is to quote the definition this commission gave: "Sustainable development is to ensure that humanity meets the needs of the present, without compromising the ability of future generations to meet their own needs". To "sustain" is to hold, keep up, keep alive, literally "able to last". The concept of sustainable development implies limits imposed by the present state of technology and social organisation on environmental resources, and by the ability of the biosphere to absorb the effects of human activities.

In developing river basins, such as the Elbe, Mekong, Odra, Paraguay and Vistula, loss of natural services does not have be an inevitable consequence of commercial development, if citizens, government officials, planners and engineers learn from previous experience in developed basins (Da Silva 2000, Hunt 2000a, Nienhuis *et al.* 2000, Sparks *et al.* 2000). However, ecological values in developing river basins are often recognised in theory, but in practice 'strong' economic imperatives are still confronted with 'weak' ecological principles. Sound and internationally validated arguments to defend both the environmental quality and the biodiversity of these river basins are often lacking (Da Silva 2000, Nienhuis *et al.* 2000).

A motivating hypothesis for sustainable river basin management is that the total flow of social benefits (broadly defined to include both natural and commercial services) from regulated floodplain-river ecosystems can be increased by selective reconnection of rivers to their floodplains and re-creation of more natural flooding regimes (Sparks *et al.* 2000). A comparable hypothesis for developing basins is that the greatest total flow of benefits will occur from commercial development that retains critical natural processes (Hunt 2000b). However, it is of little use to talk about what could and should be done, if it is more or less clear beforehand that river authorities grant only little space for management alternatives (Hunt 2000a). Therefore, the objective of the book *New approaches to river management* is not to reject or confirm scientific hypotheses, such as those referred to above, but to elucidate expertise and to discuss with all parties concerned (*e.g.*, scientists, non-governmental organisations, policymakers, river managers and authorities) innovative viewpoints and new ideas for sustainable management of river basins (Smits *et al.* 2000a). The available expertise and new approaches may form the basis for future river research, development and rehabilitation programmes.

The goal of this paper is to describe the major results discussed in the present book. Experience, innovative viewpoints and new ideas for sustainable management of river basins will be summarised. The sequence of topics follows the outline given

in the general introduction (Smits *et al.* 2000a). Section 2 focuses on developments in river basin management such as current management problems, means and goals, and the lessons learnt. Section 3 deals with the participation of new stakeholders in river basin management. Section 4 presents new methodologies and instruments in sustainable river basin management. Finally, section 5 offers some general conclusions and recommendations for river policy, management and research.

2. Developments in river basin management: applications and lessons learnt

2.1 Major problems in river basin management

Large river basins of the world show various stages of development and alterations to their streams and floodplains. Western Europe has been modifying its river basins for thousands of years (*cf.* Havinga & Smits 2000), whereas most North American rivers have been seriously altered during the last three centuries (Galloway 2000, Sparks *et al.* 2000). Nowadays, only a few large rivers in the world are more or less pristine. Rare examples are some sections of the Odra and Vistula in Central Europe (Nienhuis *et al.* 2000), the Congo in Africa (Serageldin 1999), and the Amazon and Paraguay in South America (Serageldin 1999, Da Silva 2000). In spite of extensive hydraulic engineering and management efforts, most large river basins are still facing major problems, such as water and sediment pollution, drawbacks of river regulation, water shortage and flooding risks and conflicts related to the allocation of water recourses.

River regulation
River regulation is a general term describing the physical changes that people impose on watercourses, such as land drainage, flood protection, the building and maintenance of reservoirs, dams and weirs, channelisation and bend cut-offs to serve navigation and water-borne transport, water abstraction for industrial, agricultural and drinking water purposes, and waste-water discharge, leading to the destruction of the original ecosystems. Many of the large rivers in the world have now been regulated, particularly in Western and Southern Europe, where the percentage of rivers that are still in a natural state is very low, *viz.* 0 to 20 per cent. By contrast, many rivers in countries such as Poland, Estonia and Norway still have 70 to 100 per cent of their reaches in a natural state. River regulation often causes major changes in biological river processes, primarily in the flow regime and the transport of dissolved and particulate organic matter, and have led to a river system which has lost its hydrological resilience. The water regime of regulated rivers is subject to unnatural fluctuations during the growing season, which limit native plants and animals on the hydraulically connected floodplains. In the upper Mississippi river basin, unnatural fluctuations appear to be attributable to the operation of the navigation dams (Sparks *et al.* 2000). In addition, leveeing and draining of the floodplains has replaced fish, wildlife and timber production with production of dry land commodity crops (Smits *et al.* 2000b, Sparks *et al.* 2000). The effects of river regulation are seen not just locally, but may be extensive, especially in the downstream reaches of the river (Stanners & Bourdeau 1995). Up to now, river regulation has often been characterised by a dominant technological approach,

and certainly not by a sustainable use of environmental resources. Over the last decades, flood risks in many river basins have increased as a result of changes in land use and unintended side effects of river regulation. In spite of extensive civil engineering measures, extreme climatic circumstances still cause dramatic floods in many developed river basins, such as the Meuse, Mississippi and Rhine (Galloway 2000, Smits *et al.* 2000b, Van Leussen *et al.* 2000). In the Rhine river basin, potential damage caused by future flooding is expected to increase and can only be prevented at great efforts and costs (Havinga & Smits 2000).

Past development strategies have focused on the construction of large dams and related infrastructure to achieve the objectives of hydroelectricity generation, expansion of irrigated agriculture, flood control and inland navigation. The idea that dams are the most convenient way to manage rivers and to use water resources is strongly contested by Hunt (2000a). According to Goodland (2000) there still could be a future for dams, but only if they are made to be sustainable. His main message is that while hydropower is far from perfect, its impacts are mitigable, while the impacts of alternatives to hydropower, namely nuclear energy and coal, cannot be mitigated. However, the recent earth quake in Taiwan underlines the break-risks of large dams. Moreover, in October 1999 between 500 and 1,000 inhabitants of floodplains along the Niger were been drowned and more than 300,000 people became homeless after the opening of dams in Shiroro, Kainji and Jebba to prevent extremely high water levels in the upper parts of Niger river basin. In the United States of America nearly five hundred dams have been removed to recover native fish populations, alleviate dam safety concerns or revitalise local communities (Sparks *et al.* 2000).

River pollution

River pollution became particularly manifest following the industrial revolution: the river Thames was already extremely polluted in the first half of the 19th century, culminating around the 1950s, while the river Rhine reached its worst pollution level in the late 1960s and early 1970s, and rivers like the Odra, Vistula and Paraguay may not have reached their most polluted state yet (Da Silva 2000, Nienhuis *et al.* 1998, 2000). Water pollution control seems to have been rather successful in several developed river basins. In the past decades, the protection of water quality has mainly focused on the abatement of organic pollution and significant toxic elements, such as heavy metals and non-degradable organic constituents, in order to protect drinking water supplies, fish production and recreation facilities. The result is that the river water quality in Western Europe (*e.g.*, the rivers Thames and Rhine) and the United States of America (*e.g.*, the Mississippi river) has improved significantly over the last decades, mainly due to the drastic clean-up of point-source discharges. Policymakers are eager to illustrate this quality improvement with colourful graphs of decreasing concentrations of pollutants such as cadmium, PCBs, PAHs and phosphate. As a consequence, the priority in river restoration is slowly shifting from classical pollution issues to issues of habitat creation and rehabilitation. Although this shift in priorities is sensible, we should be aware of the fact pollution problems have only partly been solved (Nienhuis *et al.* 1998). The pollution problems that remain to be solved can be typified as persistent, relatively inconspicuous and difficult to master (mainly diffuse sources). The complexity of the remaining pollution problem has been governed by the law of the dimin-

ishing returns: the curve of the costs of pollution control versus the results gained shows a downward trend. However, prolonged neglect of the remaining pollution problems may severely endanger the successful implementation of other river rehabilitation measures. An important example highlighted in the present book is the accumulation of pollutants in sediment (Eijsackers & Doelman 2000, Schouten *et al.* 2000). Persistent contaminants are bound to the deeper soil layers of riverbanks, where they are subject to little biodegradation and mobilisation. Within the Netherlands alone, strongly polluted sediments cover more than 100 km^2 of the floodplain (Schouten *et al.* 2000). While some of this area is urbanised and most of it is used for agriculture, these polluted sediments represent a direct risk to human health. For persistent compounds which easily bio-accumulate, risks may increase in the course of time. Stepwise massive release caused by accidents, excavations or substantial erosion during high tides results in sudden mobilisation and a flush of released contaminants. At low discharges with limited dilution, this causes acute harmful effects (Eijsackers & Doelman 2000). In addition, erosion of floodplains, riverbanks and riverbeds during major floods release older layers of polluted deposits to be redistributed elsewhere in the basin (Schouten *et al.* 2000). The costs of rehabilitation projects and construction works increase dramatically in areas where the riverbed and the floodplain sediment are highly polluted with heavy metals and organic contaminants. The execution of many projects and public works is stagnating as a result of the high remedial costs of polluted soil.

Habitat destruction and fragmentation

Habitat quality has rather recently been recognised as an important aspect of river basin management; it focuses strongly on the ecological integrity of the (mostly physically disturbed) land or water units, based on widely accepted conservation criteria such as naturalness, representativeness, (bio)diversity and rarity (Boon 1993). Habitat quality is exemplified as the environmental quality of a spatial unit, defined at the level of the landscape, ecosystem, ecotope or habitat. Habitat quality is also expressed at the level of the occurrence or absence of populations of specific plants or animals or vegetation units. All over the world, riverine habitats are being destroyed and fragmented due to the utilisation of floodplains for agriculture, housing, industry and transport. Area reduction of 'wild' river habitats, as found in the agriculture-dominated floodplains of most European lowland rivers, increases the risk of local and regional extinction of plant and animal species. Habitat destruction and fragmentation can only be reversed or partly mitigated through extensive ecological infrastructure and high reallocation costs of spatial user functions.

Water resources allocation

Rivers are among the most valuable but also the most abused resources on earth. In the course of human history, intensive use has been made of riverine resources, and consequently the quality of the river ecosystems has slowly degraded. During the 21st century, the pressure on freshwater resources will increase dramatically. The world's population has already reached 5.5 billion, and will pass 8 billion within two decades. It is expected that by 2025, two-thirds of the world's population will live under water-stress conditions (United Nations 1997). Demand for water can only increase, but growing pollution is likely to reduce the available quantity of

suitable water. Irrigated agriculture, hydroelectric power generation and maintaining the health of aquatic ecosystems compete with other uses for limited water recources. Due to industrial, domestic and agricultural water demands, water tables are falling fast in many river catchments and an increasing number of rivers have ceased to discharge into the ocean for much of the dry season as so much water is being is abstracted (Goodland 2000). Essentially, no freshwater is released to the sea during a large portion of the dry season by the rivers Ganges, Yellow river, Chao Phraya, Nile and Colorado. For instance, the Yellow river in China's most important agricultural region ran dry in its lower reaches for 226 days out of the year 1997 (Serageldin 1999). Consequently, sea water is penetrating further upstream, hampering yields.

World-wide, there are about 300 river basins which are shared among two or more nations; competition for water among such nations could become a potential source of conflict. Water resource experts around the world have witnessed several examples of conflicts in which control of water resources has played a major role (Bennett 1991, Homer Dixon 1991, Noorduyn & De Groot 1998, Smith 1995). Examples include disagreements between the USA and Mexico over flows and water quality in the Colorado river, disputes between India and Pakistan over the Indus river, disagreements between Iraq and Turkey over apportionment of Tigres and Euphrates flows, discussions in Africa over the water of the Nile and conflicts between India and Bangladesh involving the Farrakah Barrage on the Ganges, between Oezbekistan and Turkmenistan over the water diversion of Amoe river and between Israel, Syria and Jordan over the Jordan river.

2.2 Evolution towards sustainable river management

The evolution of river management started with no management at all in the prehistory and basic management in the times of ancient cultures. Since the industrial revolution, we have successively had several stages of sectoral river management (*i.e.,* from single-interest to multi-sectoral approaches), which from the end of the 1970s has subsequently evolved into more integrated approaches. The plethora of terms to define various types of river management makes it difficult to develop a standardised terminology, not least because of the regional nuances attached to each definition (Werritty 1997). This paper generally adopts definitions used by the various authors of the present book.

Sectoral river management is characterised by a static, single-interest, product-oriented engineering approach (Hunt 2000b). Integrated river management (synonymous with comprehensive management) is water system oriented, *i.e.*, focusing on the multifunctional use of the coherent whole of water, sediment, bed, bank, technical infrastructure and biological components (Van de Kamer *et al.* 1998, Smits *et al.* 2000b). It has gradually evolved in integrated river basin management (synonymous with integrated catchment management), which focuses on the entire river catchment. In the Netherlands it has become clear that integrated river basin management should not concentrate only on all the internal factors affecting the water systems, such as water quality, water quantity, sediments and banks, but should also take into account all the external relations which affect water systems. This so-called total river management makes it a part of society, which means that economy, ecol-

ogy and sociology become directive (Van Rooy & De Jong 1995, Van de Kamer *et al.* 1998). The economy is directive through its awareness of the scarcity of water related resources, ecology through the awareness of the vulnerability and resilience of natural resources, and sociology through its human standards and values. Based on past experiences with extreme floods, present day river management strives to be more in line with the river's natural behaviour. Therefore, river managers are looking for engineering solutions that can both maintain the original objectives and increase the hydrological resilience of river basins (Havinga & Smits 2000). These solutions will have to be more flexible than traditional river management measures. Such aims seem achievable with the help of modern technology and an increasing knowledge of the system. This new form of river management aims to maximise the use of natural dynamics and is therefore referred to as dynamic river management. Both total and dynamic management are regarded as a further elaboration of integrated river basin management. The means whereby integrated river basin management is undertaken typically involve the development and implementation of a catchment management plan whose fundamental aim is to conserve, enhance, and, where appropriate, restore the total river environment through effective land and water resource planning, across the entire catchment area (Gardiner & Cole 1992).

At the end of the 20th century, adaptive management approaches have been evolved in the United States of America. Adaptive river management mainly refers to the planning process. Under a process of adaptive management, river managers are continually adjusting their actions in response to monitoring data which alerts them to changing environmental and economic conditions and social preferences (Galloway 2000, Hunt 2000b, Sparks *et al.* 2000). Adaptive river management is characterised by a more dynamic, multiple-objective management approach. Water resource agencies no longer dominate the decision-making process, but have begun to provide a technical support function to a more democratic process of negotiation among various interests affected by water resource management. Monitoring data and simulation models are used to inform stakeholders and to support decisions (Sparks *et al.* 2000). Water projects are less frequently designed for single purposes, such as flood control or environmental restoration, and more frequently encompass a number of objectives including flood damage reduction, navigation enhancement, water supply, water quality, and development and conservation of natural resources (including biodiversity).

Integrative and adaptive approaches mainly refer to technical, organisational and institutional means and planning processes in river management. Sustainable management of river basins must not be regarded as the means, but refers to the management goal, *i.e.*, sustainable development. This requires a process of change in which the exploitation of resources, the allocation of investments, the orientation of technological developments and institutional arrangements must be in harmony and increase the present, as well as the future, opportunities to accommodate human needs (Brundtland Commission 1987, Leuven *et al.* 1997). This process has socio-economic as well as ecological dimensions, which in practice are closely related (Van Wetten 2000). The strategies needed to solve current problems may differ greatly depending on the economic development and geographical location of individual countries, *e.g.*, developed versus developing river basins or lack of water versus unbalanced use of river systems. Furthermore, strategies for sustainable water management may differ with respect to the perception of risks (*e.g.*, avoid-

ance of ecological versus socio-economic risks) and target images for nature (*e.g.*, conservation versus compensation of ecological values). However, indispensable elements of sustainable management of river basins are (Wójcik *et al.* 1997, Bouma & Saeijs 2000, Goodland 2000, HRH 2000, Hunt 2000a, Matthews & Horner 2000, Quang 2000, Smits *et al.* 2000b, Sparks *et al.* 2000):

- acceptance of the right to safe water resources as one of the basic human rights;
- attention to the long-term impacts of economic development on the river system and future generations;
- mutual dependence of environmental quality (*e.g.*, healthy river and riverine ecosystems) and socio-economic development (*e.g.*, improvement of the livelihoods of the basin's inhabitants);
- inter-basin water diversion and utilisation with special attention to the improvement of in-stream uses of water, including fish production, protection of endangered species and recreational opportunities;
- use of water resources without degrading their quality or reducing their quantity or exceeding the carrying capacity of the river system and inclusion of inevitable environmental damage costs in cost-benefit analysis;
- strategic planning with clear visions, goals and strategies for entire river basins (*i.e.*, integrated or comprehensive catchment management planning);
- transparency and public participation via open planning processes and free access to credible and reliable data, information and knowledge about the quality status and impacts of management alternatives for river systems;
- mutual understanding and respect between riparian nations and international cooperation, in particular to solve transboundary problems concerning water quality and quantity, and to guarantee security or solve conflicts over water resources diversion;
- development and application of sophisticated technical capabilities, *e.g.*, integrated monitoring, modelling, decision support systems, users-friendly knowledge and information systems supporting stakeholder participation and ecologically sound hydraulic infrastructure, navigation and land use concepts.

At present, more and more riparian countries of transboundary rivers are signing agreements for sustainable development of river basins and establishing international river commissions for the joint development and integrated management of the entire catchment area (Nienhuis *et al.* 2000, Quang 2000). In February 1997, the European Commission adopted a proposal for a Water Framework Directive. Its purpose is to establish a framework in order to achieve the following four main objectives of a sustainable water policy: (1) sufficient provision of drinking water; (2) sufficient provision of water for other economic requirements; (3) protection of the environmental quality; (4) alleviation of the adverse impact of floods and droughts. The environmental objective of the directive is to achieve "good status" for all groundwaters and surface waters by 2010 at the latest. To this aim, it will introduce river basin management based on an assessment of the characteristics of each basin; monitoring of the status of its surface and groundwaters; definition of quality objectives; establishment of programmes of measures to achieve the defined objective. However, the administrative structure to achieve this river basin management is left to the discretion of member states of the European Union.

In spite of many positive developments towards sustainable river basin management, integrated management plans for entire river catchments and adaptive management processes are still in their infancy for most of the developed and developing river basins (*cf.* Da Silva 2000, Galloway 2000, Nienhuis *et al.* 2000, Quang 2000, Van Leussen 2000). Hunt (2000b) concludes that, despite the past efforts, the myriad of plans for water resource development in the Mekong river basin have not been assessed from a systematic perspective. Such a perspective would require consideration of the full range of hydrologic, social and economic impacts that implementing all or a subset of these plans would have on the region as a whole. In fact, basic economic, sociological and environmental data regarding the potential impacts of individual water resource development plans is lacking in many cases.

3. Participation of new stakeholders in river basin management

Sustainable management of river basins makes high demands on the transparency of the decision process and participation of stakeholders. The key to fair and equitable water resource allocation is the promoting dialogue, encouraging networking and the exchange of data, information and knowledge between decision-makers, scientists, engineers and stakeholders in different countries about river basin management and related issues (Matthews & Horner 2000).

Greater involvement of the public, including local stakeholders who are most directly affected by river development, appears to be a growing, world-wide phenomenon. According to Havinga & Smits (2000) Dutch river authorities have learnt that management measures without public support are almost equivalent to mismanagement. For this reason, public participation is a prerequisite in the decision and implementation stages of river rehabilitation projects. Goodland (2000) describes the historic evolution of transparency and participation in the USA over the period 1945 – 2000, broadening, for instance, the constituency of a dam design team from engineers to economists, environmentalists, sociologists, affected people and NGOs. The treatment of stakeholders has evolved from warning, through information, consultation and participation, to partnerships.

Goodland (2000) states that stakeholder participation is essential for democracy, and greatly improves project selection and design. External scrutiny and participation in the whole process is essential to reduce any possible conflict of interest. Most importantly, participation and transparency foster early agreement and builds consensus, thus reducing controversy and opposition later on. This expedites project implementation. Transparency and participation mean that civil society exercises a role in the selection of criteria to be subsequently used for decision-making and in identifying stakeholders. These normally include affected people (ultimately all tax payers) or their advocates, government, academia, syndicates, consumer and safety organisations, as well as project proponents. Civil society assists in the selection and design of studies needed before decisions can be made, in the interpretation of the findings of such studies, in the burden sharing or relative weights given to criteria for multi-criteria analyses (MCA) or integrated evaluation methods. Proponents receive many useful proposals from non-traditional stakeholders. With the objective of developing a consensus approach to solving water problems, those

responsible have learned that more available information produces better results than less (Galloway 2000).

Partnerships with other stakeholders and actors play a dominant role in initiatives aimed at river rehabilitation, whereas scaling up of results and approaches (*e.g.*, transcending to other political levels, sectors or regions) can be regarded as an even higher goal than the immediate project results. Van Wetten (2000) describes a new approach to wetland management interventions by partnerships. Instead of focusing solely on 'problems', more attention is given to 'opportunity identification' as a basis for modifying programmes and projects for wetland management. Assessing the basic causes of opportunities as well as constraints creates new options for innovative partnerships and coalitions. The concepts of scaling up and strategic communication are used to improve the outreach, outputs and sustainability of the interventions.

The World Hydrological Cycle Observing System (WHYCOS) is one of the networks providing communication services between stakeholders (Matthews & Horner 2000). It provides a scientific basis for monitoring and assessing water resources for sustainable river basin management. In addition, WHYCOS aspires to contribute to an improved understanding of the interaction of hydrological processes with the climate, the environment, natural resource capital, investment and national, regional and global markets through managed open discussion. Through WHYCOS and appropriate decision aiding tools and skills, it would be possible to bring together all the social, technological, ecological and scientific aspects of river basin development. By observing the interaction between the hydrological cycle and all social, economic and environmental activities, WHYCOS can provide data and information to generate knowledge. In turn, this knowledge can be managed by the communities within the river basin for decision-making with the objective of discovering the "truth" about the sustainable development potential of the river basin.

At present, many river rehabilitation projects and hydro dam projects are being undertaken by a variety of partnerships among private landowners, non-governmental conservationists and environmental organisations, and governmental agencies (Sparks *et al.* 2000, Goodland 2000 Van Wetten 2000). In the USA, a rising tide of public interest in protecting and restoring rivers and floodplains has stimulated the expansion of governmental conservation programmes to encourage farmers to convert erodible and flood-prone land near streams from crop production into permanent vegetation (Sparks *et al.* 2000). The new generations of these programmes concentrate on riparian zones and on specific problem watersheds that deliver excessive amounts of sediment and water. Corporaal (2000) proposes a new tax bonus for rural entrepreneurs (so-called "fisquality") to improve water retention by watersheds. These entrepreneurs can play an important role in the establishment of a hydro-ecological network in river catchments, aiming at flood as well as drought prevention.

Economic arguments play an important role in societal discussions on justifying interventions in river systems. Bouma & Saeijs (2000) discuss the need for an ecocentric cost-benefit analysis and illustrate their plea with a case study of hydraulic engineering projects in lake Grevelingen, situated in the delta of the rivers Rhine and Meuse.

4. New methodologies and instruments in sustainable river basin management

4.1 Natural resilience and flow regime as driving forces

There is increasing awareness that the structure and function of natural and restored rivers vary across space and time. This variation (disturbance regime) is required to maintain many riverine ecosystems (Poff *et al.*1997). Planning and engineering to incorporate this variability requires changes on the part of the development agencies, whose historic missions have generally involved reducing variability in water flow, shoreline configurations, channel positions of rivers, etc. (Havinga & Smits 2000, Hunt 2000b, Smits *et al.* 2000b, Sparks *et al.* 2000).

The starting point of sustainable river basin management must be to accommodate user functions (*e.g.*, navigation, agriculture and urbanisation) to the dynamics of the natural river system and not the other way round (Hunt 2000b, Smits *et al.* 2000a,b). Rehabilitation of the natural resilience of rivers, by allowing them more space, is the best strategy to prepare for uncertain future developments such as climate change, rising surface levels of the floodplains by sedimentation and lowering surface levels on the landside of the dikes in the downstream parts of the river basin, due to subsidence of the soils (Smits et al. 2000b, Van Leussen 2000). However, there are clear indications that this is not sufficient in the long term. Therefore, more efforts will also have to be made to reallocate non-river based activities and to adapt present day riverine user functions to natural water systems. Moreover, the potential to naturalise rivers and their floodplains systemically cannot be fully realised just by restoration actions in the mainstem river and its floodplain. Rivers are products of their watersheds, so actions are also needed in tributaries and uplands, *i.e.*, the entire catchment (Smits *et al.* 2000a,b, Sparks *et al.* 2000, Van Leussen 2000). From this point of view, the tasks and responsibilities of future river managers are no longer confined to water quantity and water quality, but a more pro-active role in the spatial planning process of the entire river catchment is required (Smits *et al.* 2000b).

The water regime of regulated rivers is subject to unnatural fluctuations during the growing season, which limit native plants and animals on the hydraulically connected floodplains. It is encouraging that unnatural fluctuations appear to be attributable to the operation of the navigation dams. At several locations in the USA, the operating rules for dams, reservoirs, and other river facilities now take into account the natural life cycles of fish and wildlife affected by the contained rivers (Galloway 2000). Early results of experiments with a more natural flow regime indicate that the condition and production of wetland vegetation can be improved without adversely affecting commercial navigation (Sparks *et al.* 2000).

In addition, dike and revetment designs for the Mississippi river have been modified to increase the usefulness of dikes and revetments in developing habitat, while at the same time preserving their channel stabilisation functions. A specially submerged bendway weir has been designed to mitigate environmental impact (Galloway 2000).

4.2 Flood control

The focus of new flood control projects in the USA has recently shifted from the construction of hydraulic structures (*e.g.*, dams, levees and floodwalls) to more sustainable approaches, such as (Galloway 2000):

- avoidance of development in the floodplains, unless no alternative locations exist;
- reducing potential damages when development is to take place (structures in the floodplain should be flood-proof and where possible those most at risk should be relocated from the floodplain);
- retention of rainwater in the location in which it falls through the use of land treatment and natural and artificial reservoirs.

At present much attention is being given to supporting this flood control approach by federal programmes. Over 25,000 homes in the Mississippi river basin have been relocated from the floodplains since the extreme floods of 1993 and thousands of hectares of marginally productive bottomland habitat have been transferred from agriculture to natural uses (Galloway 2000).

Western European flood control strategies mainly focus on the rehabilitation of the natural resilience of rivers by allowing them more space (Havinga & Smits 2000, Schouten *et al.* 2000, Smits *et al.* 2000b, Van Leussen 2000). The water storage capacity of urbanised and rural areas will have to be increased to prevent the rapid run-off of rainwater. Man-made obstacles should be removed wherever possible and dikes repositioned, while floodplains which have silted up should be excavated and non-river based activities such as housing strictly prevented. Apart from plans to construct retention polders and measures aimed at reducing the hydraulic roughness of the floodplain, this has also led to the general conception that rehabilitation of riparian vegetation must be more in line with flood prevention interests. In order to synergise both interests, Smits *et al.* (2000b) propose a new approach to floodplain management, named "Cyclic rejuvenation of floodplains". The flood defence measures in the Meuse river basin illustrate that reduction of flood risks can well be combined with concepts of sustainable and balanced integration of navigation, agriculture, sand and gravel extraction and provision of drinking water, which fits the international policy of enlarging the carrying capacity of rivers and of ecological rehabilitation (Schouten *et al.* 2000, Van Leussen 2000).

Within the framework of the Joint Operational Programme IRMA (Interreg Rhine Meuse Activities), the Netherlands Centre for River Studies (NCR) has recently been commissioned to execute a large European research project (so-called SPONGE umbrella project), a cluster of innovative, transnational and complementary projects on flood risk, vulnerability assessment and flood risk defence. The deliverables of this project are:

- new and improved hydrologic and hydraulic models for various river sections, catchments and subcatchments of the Rhine and Meuse river basins that contribute to the assessment of impacts of flood risks;
- concepts and methodologies for the evaluation of scenarios and measures (climate change, creation of retention areas, floodplain lowering and wetland rehabilitation) and the assessment of risk and vulnerability with respect to hydraulic, ecological and socio-economic river functions;

- an extended and upgraded early warning system for floods and risk maps of various regions in the Rhine and Meuse basin;
- decision support systems implementing the concepts and methodologies for scenario evaluation, risk assessment and risk mapping;
- demonstration of decision support in river basin management and spatial planning.

4.3 Economic development of river basins

Hunt (2000a) states that the application of new technologies and approaches to river management offers opportunities to attain the same or even better results against lower economic costs, and with far fewer negative environmental and social side-effects. In the case of the upper Mississippi river system, Sparks *et al.* (2000) presume that it would probably have been cheaper to preserve natural services than it is to recover them after development.

Goodland (2000) specifies ways to make hydropower and irrigation dams environmentally and socially sustainable. However, Hunt (2000a) proposes that a diverse development strategy for river basins in third world countries, relying on more modern technologies than dam-dependent strategies, could result in a more robust and sustainable regional economy with improved protection of natural resources. According to Hunt (2000a), the most important strategy for developing river basins, such as the Mekong river basin, would be energy systems based on small, decentralised energy sources and demand-side management, and food production based largely on mixed agriculture systems, particularly in uplands. Such mixed agriculture systems, to the extent that they imitate the natural ecological structure of the forests, would contribute to a reduction of flood damages and of the need for dredging to maintain navigability downstream.

4.4 Dynamic soil management

Eijsackers & Doelman (2000) and Schouten *et al.* (2000) add the issue of sediment contamination and natural attenuation to the agenda of sustainable river basin management. Eijsackers & Doelman (2000) conclude that if these contaminants are released in a flush, as may happen at high tides or shortly after excavations, the high discharges connected with such high tides result in sufficient dilution. Potential release situations at low discharge levels have to be monitored as contaminants may then pose a risk, because the release kinetics exceed the degradation kinetics. Because the estuarine section of the river functions as a sink for any released contaminants, persistent contaminants might be bioaccumulated and bioconcentrated by general but sometimes also by very specific food-chain transfer routes. A preventive approach including some form of routine monitoring, in combination with specific ecological interpretation and additional monitoring after a positive signal, might be advisable. More fundamentally, it is important to determine the relevant time and space windows for ecological risk assessment.

Since the floodplains of the large rivers are contaminated as a result of diffuse pollution, it is impossible to remove all polluted sediments from the floodplains. There are not enough locations for disposal, due to public opposition against new

disposal sites and the high costs involved. In the Netherlands, a new policy of dynamic soil management has been developed in order to control the high costs of river rehabilitation projects resulting from polluted sediments, while maintaining the original management goals and reducing the risk to human health and ecosystems (Schouten *et al.* 2000). As long as polluted soils do not increase the overall risk, they may be reused as much as possible within the floodplain area. This approach opens up opportunities for re-using polluted sediments in local civil engineering works where pollution already exists, reducing costs and risks at the same time. Removal or isolation of strongly contaminated sediments should reduce the total emission of contaminants resulting from erosion and solution or dispersion after the work has been carried out. Accurate soil quality probability maps are being generated for the purpose of developing and applying dynamic soil management (Section 4.5).

4.5 New scientific tools

This book present several new tools for the scientific underpinning of sustainable river basin management, such as environmental least-cost ranking, stakeholder and policy analysis, new monitoring techniques and decision support systems.

According to Goodland (2000), the main means to approach sustainability is to integrate environmental and social criteria into traditional economic least-cost sequencing, which makes it environmental least-cost ranking (ELCR). When the best mode and the best site for a project (*e.g.*, a hydro dam) have been selected, the normal project-level environmental assessment (EA) should be used to mitigate residual impacts, such as by lowering the dam or moving it upstream. While project-level EA is essential and needs to be strengthened, ELCR to select the best projects is far more powerful.

Policy analysis provides a framework for sustainability assessment of large infrastructural projects by generating possible and feasible alternatives and comparing their socio-economic, ecological and institutional impacts. Leentvaar & Glas (2000) present results of a policy analysis for the Gabcikovo-Nagymaros hydropower project in the Danube, which aims to clarify and rationalise the various options for management actions and provides information on the 'pros' and 'cons' of the range of choices that can be made.

Stakeholder analysis has become a useful tool in promoting participation (Goodland 2000). Strategic environmental analysis (SEAN) is a new planning framework for opportunity identification and the designing of sustainable development policies (Van Wetten 2000). This methodological framework includes practical tools and guidelines for analysing the environmental potentials for, and constraints on, human development. It is designed for use at the earliest possible stage of policymaking, to allow the relevant environmental issues to be fully integrated into policy design. The methodology is based on experiences with environmental impact assessment (EIA), environmental profiles, and environmental planning, monitoring and evaluation.

Geographic information systems (GIS) and remote sensing (RS) are important tools for analysis and visualisation of geographical entities of river systems and for decision support for management measures (Leuven *et al.* 2000). Schouten *et al.* (2000) describe the development and application of new GIS-based soil quality

probability maps for dynamic soil management. These maps are prepared using the various statistical relations in combination with geomorphologic and soil information. These soil quality probability maps allow an estimate to be made of the amount of polluted sediments to be removed as well as a cost calculation. Smits *et al.* (2000b) discuss a new promising RS method involving laser-altimetry for monitoring of the vegetation dynamics in floodplains. Recently, some experiments have been carried out with the objective to convert data on the vegetation structure directly into hydraulic roughness data for a floodplain.

4.6 Further research and monitoring

According to Sparks *et al.* (2000) a key question for the public and for policymakers in developed river basins of the world is whether the total flow from natural and commercial benefits from a regulated river-floodplain system can be increased by selective re-connection of the rivers with their floodplains and re-establishment of more natural flooding regimes. The communities along the rivers are particularly concerned about the quality of the naturalised environment that is achieved and the impact it will have on the local economy and quality of life. Attractive natural environments could attract outdoor recreationists and offer an alternative to the agriculture-dependent economy that may be increasingly subject to boom-or-bust cycles governed by world market prices.

A comparative historical approach is especially useful in identifying impacts of alterations to river systems (Havinga & Smits 2000, Sparks *et al.* 2000). However, such insights need to be incorporated into models to predict effects of alternative development or recovery plans. Therefore, Sparks *et al.* (2000) make a plea for scientific monitoring and evaluation of both river recovery and river development programmes, for the sake of improving both science and policy. Management cannot be adaptive without information about the current status and trends in the key physical driving variables (*e.g.*, the sediment and water regimes), biological interactions and indicators of interest (*e.g.*, population status of key species). A management experiment is worthless without data to show whether the hypotheses can be rejected or accepted. Failure is instructive, as long as sufficient information is gathered to understand why the failure occurred. Similarly, little is gained by success if the reasons for success are not known; it may be impossible to extend the results to another site, or even to repeat them at the same site. According to Havinga & Smits (2000), sustainable river basin management means the application of measures that are able to cope with dynamic river reactions and that are flexible in view of future demands. These measures do not provoke large-scale effects, thus maintaining hydromorphological resilience. Instead of large rigid constructions, small sized measures to correct river responses will be used. To restore riverine habitats, more vegetation will be allowed in the floodplains. In practice, the river will show more dynamic changes, in water levels as well as in bed geometry, complicating river management. Readiness for action requires information regarding these changes. For this purpose an extensive monitoring and impact assessment programme (including forecasting) has to be available.

To support stakeholder participation in river rehabilitation projects, inter-related hydrological, ecological, and economic models must be developed to predict what

will happen to total social benefits (from both commercial and natural sources) if selected portions of the floodplain and of the annual flood cycle are restored, or to evaluate effects of development alternatives in river basins (Sparks *et al.* 2000). Assessing the sustainability of large dams and other hydraulic infrastructure necessitates the development of systemic models that have the ability to simulate the complex hydrodynamic processes that characterise water and sediment movement through an entire catchment (Hunt 2000b).

A comprehensive set of indicators for the sustainable development of river basins is often lacking (Nienhuis *et al.* 1998, 2000). There is a need to develop such indicators of interest. Examples of the areas in which indicators need to be developed include the above-mentioned key physically driven processes, efficiency of water resource use, the health of river and riverine ecosystems, and stakeholder participation.

5. General conclusions and recommendations

- Sustainable river basin management requires full understanding of rivers as dynamic and open systems, which should be considered as ecological continua from the source to the sea. Integrated river basin management, catchment management planning and adaptive management approaches are the means to achieve sustainability.
- Historical developments in river basin management along various large rivers in the USA and Europe have shown that prevention is better than cure. Neglecting water pollution control means roll-off problems to future generations in countries or areas located downstream in a river basin. Generally, it results in high risks and sanitation costs, due to deposits of polluted sediment. Rash habitat destruction always means high rehabilitation costs in future. An unbalanced inter-basin diversion of water recourses is a potential source of conflicts between nations or communities. Ill-considered and single-purpose river regulations always have drawbacks, which must be compensated for by other interventions. This action-reaction spiral decreases the resilience of river systems and ultimately results in higher risks of flooding, higher management costs and severe deterioration of riverine ecosystems. Therefore, sustainable river basin management requires the well-considered application of the precautionary principle.
- Restoration of resilience is the only solution to break the action-reaction spiral in unsustainably developed river basins. It requires a carefully considered strategy for the entire river catchment, which includes allowing more space to rivers and restoring of the natural flow regime and hydromorphological dynamics of rivers. These measures also fit in with the prerequisites for ecological rehabilitation of river basins.
- Sustainable management of developing river basins means that user functions of the catchment (*e.g.*, navigation, agriculture and urbanisation) must be accommodated to the dynamics of the natural river system and not the other way round; the damage experienced by several industrialised basins can be avoided.
- Stakeholder participation is a prerequisite for sustainable river basin management. River managers have learnt that management measures without public

support are almost equivalent to mismanagement, because much time and money is spent on the implementation and maintenance of undesirable measures. Stakeholder participation is not only essential for democracy, but may also greatly improve project selection and design. Most importantly, participation and transparency foster early agreement and build consensus, thus reducing controversy and opposition later on and expediting project implementation.

- Important issues for further research are integrated modelling, retrospective studies and scientific monitoring and evaluation of both river recovery and river development programmes, for the sake of improving both science and policy. First of all, this requires the development of a comprehensive set of indicators for the various dimensions of sustainable river basin management. Modelling of river basins must facilitate catchment management planning and adaptive management, and should be focussed on the development of inter-related hydrological, ecological, and economic models. The models must have the ability to simulate the complex hydrodynamic processes that characterise water and sediment movement through an entire catchment and to predict what will happen to total social benefits (from both commercial and natural sources) for various development alternatives in river basins (*e.g.*, changes in climate, water and land use and navigation). Retrospective research should not be focussed only on impacts of river alterations and rehabilitation, but must also include cost-benefit analysis, stakeholder participation and institutional arrangements.
- In spite of river-specific expertise and great differences in the development of river basins, the new approaches to sustainable river basin management are basically applicable to other river systems and are particularly important for those river basins which have not yet been developed.

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