CONNECTING THE DOTS

in Integrated Water Management

A CRITICAL ANALYSIS OF A TANGLED CONCEPT

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CONTENT

CHAPTER 1

General Introduction

1 The rise of integrated river management

River systems belong to the most intensely used ecosystems in the world. Ever since humans settled near rivers they have directed purposeful activities to exploit and manage for the multiple benefits and functions that river systems provide, including the supply of drinking water, provision of fish, transport and disposal of waste for example. While these human activities were local and small scale at first, they have grown increasingly intensive and large scale in many river systems over time (Vitousek et al. 1997).

In Europe modern river management has progressed through different periods since the start of large scale industrialization (Kuks 2004; Van Ast 1999). In the 19th century river management was mainly in an engineering stage with large scale flood protection and embanking for improving the navigability of rivers. This was followed by a provision-sanitation phase, from the 1900s to the 1950s, where attention shifted to public health and the construction of clean water supply and safe sewage disposal systems. Next came a pollution control phase between the 1950s and the 1990s, where the emphasis was on water quality improvement through the control of point source discharges of pollution. This period is strongly related to the environmentalist wave of the early 1970s that brought awareness that nature is intrinsically valuable and that humans have been incurring heavy ecological debts (Disco 2002). Worldwide pressures on water systems and their ecosystem services had severely increased (Baron et al. 2002) resulting in a range of environmental issues such as overexploitation of resources and ecological damage because of chemical waste disposal.

While early environmental issues were well-defined, local and directly experienced by humans, mainly concerning water quantity and quality, it was now more and more recognized that the complexity of water resource management challenges had increased due to factors such as population growth, increased welfare and the interplay of phenomena at different temporal and spatial scales in social, economic and ecological dimensions (Medema 2008). In the eighties river management entered a new phase in which traditional single function approaches with a strong development emphasis were questioned. Until then the predominant paradigm in river management had been an engineering-dominated perspective on river control and improvement. Using top-down and reach-scale reductionist approaches based on principles from fluid mechanics and hydraulics, these engineering approaches to river management reflected human desires for simple, efficient and predictable systems (Hillman & Brierley 2005). Calls for more inclusive and coordinated approaches appeared, induced by an increasing awareness that engineering-based river management was neither biophysically nor socially sustainable. Instead ecosystem-oriented approaches to water management were deemed necessary to meet sustainable development aspirations (Brundtland Commission 1987) that balanced environmental concerns with social and economic benefits.

Over the last decades perspectives on holism and sustainability have challenged science and policy into developing a range of new management concepts and strategies that are commonly labelled under the general banner of *integrated approach*. Multiple elaborations in many variations have appeared using similar labels like Integrated Water Management, Integrated Water Resource Management, Integrated Natural Resource Management and Integrated River Basin Management (Gottret & White 2001; Jønch-Clausen & Fugl 2001; Surridge & Harris 2007).

These approaches generally share the recognition that water systems are complex systems with ecological, social and economic dimensions and that their properties need to be understood and managed from scientific, political and social points of view instead of its separate components (Van Kerkhoff 2005). Especially water presents a particularly complex natural resource to manage because of the associated scalar dynamics. For example, depletion or pollution of water in one part of a river basin may affect users a great distance away.

A critical analysis of the meaning and scope of the integrated approach in river management and science forms the central topic in this thesis. Such an analysis seems timely given the fact that various scholars have signalled bottlenecks in the formalization and implementation of integrative scientific and management strategies, and raised fundamental questions about their effectiveness (Biswas 2008; Downs et al. 1991; Gilman et al. 2004; Jeffrey & Gearey 2006). However, before arriving at the rationale, aims and specific research questions regarding this analysis, I will first sketch some key driving developments that set the scene for this thesis and explain the basic conceptualizations underlying integrated approaches.

2 The challenges of integration

The rise of integrative strategies in river management is linked with mutually dependent developments in system and complexity thinking, governance approaches and the scientific practices which are used to facilitate the process of river management (Gregory et al. 2011). These developments will be subsequently addressed in the following paragraphs.

Understanding the system under management

System thinking in its broadest sense has a long history, especially in mathematics. A basic and formal definition of a *system* is a *set* of objects together with *relationships* between the objects and between their attributes. In research oriented definitions of systems these entities are commonly interpreted empirically rather than being interpreted as abstract mathematical objects. The mathematical elements are replaced by things, components or parts, and the term relationship by coupling, interaction, binding, connection or linkage (Becker 2012).

The essence of a system lies in the relationships between components, i.e. that systems are composed of interrelated parts. Another basic principle of the system message is that system function is related to structural relationships. Both principles are captured in complexity, a central concept in system science. Complexity concerns how the *nature* and *properties* of a system may be characterized with reference to its constituent parts in a non-reductionist manner, i.e. how systems change and evolve over time due to interaction of the constituent parts. It expresses that the components of a system and their relationships are interactive, overlapping and interdependent. Relationships of various strengths between component parts define the internal structure of a complex system involving many different processes, subsystems and interconnections in which subsystems assume specific functions.

System and complexity research requires a *systems approach*. This involves methods of enquiry that in contrast to the traditional reductionist scientific method try to understand situations by looking at the properties of wholes rather than breaking them down into their constituent parts (Grant 1998). These properties in complex systems include non-linear behaviour, positive and negative feedback loops, the formation of hierarchies of scales, as well as a strong dependence on the context and history (Holling 2001; Stephens & Hess 1999). This form of complexity has been labeled ‘aggregate’ complexity and attempts to access the holism and synergy resulting from the interaction of individual system elements working in concert (Manson 2001). Aggregation in this sense refers to the tendency of such systems to generate emergent properties that produce unanticipated outcomes. It includes the perspective of holism, i.e. that ‘the whole is more than the sum of its parts’, thus properties emerge from an assembly of sub-systems which are not possessed by the constituent sub-systems independently (Stephens & Hess 1999). It is especially the idea of aggregate complexity that has been taken up by scholars studying environmental and sustainability issues. It is now widely accepted that these properties of complexity, including variation and change are inherent to natural as well as social processes and should somehow be reflected in new integrative resource management strategies (Medema et al. 2008).

In the context of applying a system approach the process of *integration* means interrelating elements that were not related before. The theorization and application of this integrating process is referred to as (taking) an *integrated approach*. Water management subsequently expresses a focus on the interrelationships within and between natural and human water system components, and incorporating (understanding of) these linkages and components in management. Research efforts directed to the investigation of these interrelationships can be distinguished in at least three communities; a ‘hard’ and ‘soft’ one, and one in between (Glaser 2006; Richardson & Cilliers 2001). Hard relations uncover the general bio-physical principles of complex systems, and emphasize factual knowledge whereas soft relates to the social world which is intrinsically different from the natural world, being constituted through language and meaning, emphasizing subjective perceptions (Pahl-Wostl 2007).

A specific form of the system approach has become particularly important in environmental and conservation management. The *ecosystem approach* defines an “ecosystem” as the unit of study (Slocombe 1993) and most generally is a methodology for studying a natural system entity, its environment, and the interactions between them. An ecosystem approach has also come to refer to the application of ecological concepts and analysis outside the traditional domain of ecology. In management the ecosystem approach has evolved from 'hard' to include 'soft' relations (Waltner-Toews & Kay 2005) and the recognition and inclusion of humans as an integral component of ecosystems. Taking the complexity of environmental problems fully into account means that the frame of analysis not only includes the basic biophysical system but incorporates economic, political, social and cultural systems as well. Various conceptual models of human-environmental systems and their relationships currently exist, based on different viewpoints (Glaser 2006). Examples include the recognition of the cultural dimension (Lenders & Knippenberg 2005) in river management, concepts from sustainability science (Kates et al. 2001), and *social-ecological systems* which recently receive much attention (Becker 2012; Liu et al. 2007). These scholars commonly agree that complexity thinking provides vital insights for a more realistic and richly contextual understanding of intricate social-ecological systems such as river systems with their multi-scalar structures, functions and processes of change over time (Tulloch 2010).

System theorists over the years have developed a wide array of tools to conceptualize and study systems. Especially *networks*, which are maps of interconnecting parts in a complex system, can be considered a natural tool for thinking about complexity. Networks can be conceptualized where there are transfers or connections between definable entities, i.e. nodes. These transfers may involve energy, materials, knowledge, or may concern connections like family or working ties between people or institutions for example (Schlüter et al. 2012). Network analysis has a long tradition in work on networks of human social agents such as individuals or organizations which have connections of some kind to some or all of the others. Recently there is more attention for networks in natural resource contexts where they are studied as the physical fabric on which social-ecological systems operate. A network perspective is considered especially useful for gaining insights in systems and complexity, because it focuses explicitly on the structure of the interactions between identifiable components of systems and the ways in which this structure affects the performance of systems (Gross & Sayama 2009; Janssen et al. 2006; Mali et al. 2012; McMahon et al. 2001).

Finally, in order to be useful in the context of management the meaning of the term 'system' has to be defined; otherwise 'system' is just a metaphor for a compound of things. This definition includes the identification of its components, the relationships and the patterns between its parts. Central, and arguably the most critical problem that faces natural resource managers, in the development of management and understanding resource problems is recognizing and deciding which components of the real-world system should be included in the system of interest and how they should be conceptually related to one another, i.e. making sense of its complexity. This also comprises deciding on the appropriate physical or spatial boundaries (Stephens & Hess 1999). Importantly, as there are no pre-determined boundaries to a system it needs definition of the spatial or functional boundaries at different levels.

In water management the critical subsystems for decision making are the resource system, its dependent human communities with their underlying needs, and their systems of governance. For river systems specifically there has been attention for the social and biophysical connectivity at the level of river catchments (Hillman & Brierley 2008). In river systems a large number of biophysical and hydraulic processes interact at the catchment scale. Consequently, a reach in a catchment cannot be considered in isolation of wider catchment processes (Cohen & Davidson 2011; Gregory et al. 2011). Recent endeavours by river ecologists and geomorphologists have promoted a more holistic view of landscapes in catchment-scale thinking, seeking to integrate spatial and temporal dimensions of change including cultural dimensions as well (De Groot & Lenders 2006).

Understanding the points of view on management

Over the last decades the increasing awareness of the cross-scale nature of environmental problems and reconsideration of human-natural relations has encouraged the development of new management approaches and governance strategies. In resource management there has been a shift away from managing individual resources to the broader perspective of ecosystems (Imperial 1999). The tenet that rivers and watersheds should be managed solely to maximize consumptive uses slowly gave way to a belief that resources should also be managed for environmental values such as biodiversity and social and cultural values. So called ecosystem management emphasizes long-term resource sustainability instead of a sustained yield of products and outputs by maintaining ecological function and balance (Cortner & Moote 1994).

Furthermore new resource strategies acknowledge that systems to be managed are, in broad terms, complex, non-linear and characterized by unexpected responses to management interventions (Folke et al. 2005; Pahl-Wostl et al. 2011). Rather than trying to change the structure of complex systems to make them controllable by external intervention, innovative strategies aim to make use of the self-organizing properties of the systems to be managed through adaptation and learning processes (Pahl-Wostl 2007).

Another level of challenge for managing complex systems with human components is provided by the importance of values, language and meaning, which cannot be ignored in interactions between individual agents and in understanding their desire to achieve goals. New strategies thus recognize the need for collaborative decision making in order to address the previously mentioned ‘soft system relations’ that manifest themselves as value and interest disputes in multi-scale environment–society dilemmas (Armitage et al. 2008). In collaborative management the external definition and measurement of system goals is deemed insufficient for successful management projects. Traditional command-and-control approaches towards resource issues have been replaced by new views on management in which command is arguably replaced by ‘meaningful engagement’, and control by ‘influence’. Claims about the legitimacy of intervention and change no longer belong exclusively to authorities, and privileged knowledge claims are no longer exclusive to the realm of science (Gearey & Jeffrey 2006). In these strategies the legitimacy of management actions depends on shared visions of both problem setting and problem solving (Pahl-Wostl et al. 2011). Therefore a key to operationalizing integrated approaches of environmental management has been thought to involve stakeholder coordination, i.e. moving to integration through interaction by the public, authorities and other stakeholders, including scientists (Folke et al. 2005; Margerum 2008; Margerum & Born 2000).

Water management discourses have evolved from speaking of “government” to speaking of “governance”. Hereby the notion of government as the single decision-making authority, where state authorities exert sovereign control over the people and groups making up civil society, has been enriched by the notion of multi-level, polycentric governance approaches that recognize the contribution of a large number of stakeholders, functioning in different institutional settings. Views on political steering as promoted by these governance concepts embrace complexity and and uncertain change. In particular the concepts of reflexive and adaptive governance try to enhance the adaptive capacity of a social-ecological system by emphasizing science/management/society partnerships and the role of learning (Pahl-Wostl et al. 2007; Rogers 2006).

Understanding different disciplines in support of management

Next to a revaluation of how resource systems should be managed the challenges encountered in understanding and managing complex systems have also triggered a change in thinking about the role of science. In society the scientific enterprise is the main and generally most authoritative contributor to the design, development, implementation and evaluation of resource management policies and practices. However new understandings of systems and awareness of the combined social-biophysical complexity of environmental management issues have changed the views on scientific practice and led to recognition of the limitations of reductionist disciplinary approaches (e.g. Ewel 2001; Kates et al. 2001).

The understanding of heterogeneous system components from ecological, economic and social system dimensions invites the cross-disciplinary bridging of expertise, methodologies, philosophical and epistemological perspectives from different disciplines (Klein 2004). There is widespread recognition that cross-disciplinary efforts in environmental science in general and water management specifically are likely to yield substantial benefits (e.g. Benda et al. 2002; McCulloch 2007; Naiman 1999; Palmer & Bernhardt 2006; Wear 1999). In particular the engagement of both biophysical and social processes in management has triggered calls to bring social science into natural science debates (Ludwig 2001). The bridging of disciplinary perspectives has figured prominently on the scientific agenda evidenced by newly promoted fields such as civic science and eco-hydromorphology (Plummer 2006; Vaughan et al. 2009).

Different scholars have addressed the communication of knowledge and interaction of academics with other stakeholders at the science-policy interface and have proposed new practical and epistemic perspectives, as well as new organizational forms for science (Cortner 2000; Lubchenco 1998; Roux et al. 2006). They bring forward that for understanding the complexity of environmental management issues scientific efforts underlying integrative management need to be both socially and scientifically relevant. This means coherently taking into account the existing societal values, as well as being scientifically relevant in terms of improving both the understanding of complex systems and the ability to enact effective policy and practice. Science is no longer understood as merely advancing the certainty of knowledge of, and control over natural systems but as coping with the many uncertainties in policy issues and the environment (Gallopin et al. 2001). Thereby scientific research is expected to contribute to the wellbeing of society which in turn enables and supports its existence (Blackstock & Carter 2007). Newly proposed modes of science like Mode 2 –science (Gibbons 1999) and Post-Normal Science (Funtowicz & Ravetz 1993) recognize that research should not solely be decided within the academic domain alone, but in learning and negotiation with other actors of various intellectual and social backgrounds (Van Kerkhoff 2005). Such a process of collaborative knowledge production is based on the idea that diverse world views generate varying interpretations of a common physical reality and how it should be managed. It holds the perspective that the same base of factual knowledge may be used by different actors to derive entirely different but equally plausible meanings and thus conclusions for interacting with the world surrounding them (Pahl-Wostl et al. 2011).

3 Rationale for this study

The above sketched developments collectively underlie the rise of integrated approaches in water management and their supporting scholarly research the last decades. In short, integrated efforts in water management (i.e. Integrated Water Management, here IWM[1]) have been pursued in the following dimensions: i) an increased understanding of complex and uncertain systems phenomena (in particular the relationships between parts and wholes); ii) a move towards catchment-scale planning (as opposed to reach-scale applications); ii) collaborative decision-making (including a weakening of the previously privileged role of ‘science’ in knowledge production); iv) the need to incorporate different scientific disciplines (Gregory et al. 2011).

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[1] In this thesis Integrated Water Management (IWM) will be used as a generic term for indicating integrative efforts in water management without referring to a specific socio-political setting. When necessary the contextual setting in which IWM is considered will be specified, e.g. when referring to the Netherlands or river systems specifically.

Despite widespread recognition of the integrated approach its interpretation and elaboration in management strategies and practice has been qualified as troublesome by scholars for various reasons (Biswas 2008; Gilman et al. 2004; Jeffrey & Gearey 2006; Medema et al. 2008; Saravanan et al. 2009; Van der Zaag 2005). Firstly, it is not always clear what is meant when calls are made for more integrated forms of management. Various authors have observed that consensus on the scope of integrated water management is lacking, arguing that uncritical use of the concept has led to poor articulation and elaboration in different competing definitions (Downs et al. 1991; Scrase & Sheate 2002). Furthermore it has been claimed that the integrated approach and its inherent process of 'integration' has become a vague and malleable notion, one supposedly able to function as a general approach to systems analysis that can be used by different scientific disciplines and research fields. Also the nature of IWM as a value-laden concept involving political goals as well as scientific understandings has been suggested to underlie difficulties and ambiguities in elaboration of the concept (Jeffrey & Gearey 2006). Water management has been considered to be quite slow to take up innovations that should follow as a logical consequence of adopting an integrated approach; substantive changes have been restricted to problem reframing rather than leading to significant transformation of water management principles and practice (Pahl-Wostl 2007; Pahl-Wostl et al. 2011). Finally Hillman (2009) noted a reluctance to apply the full range of scientific and experiential knowledge to river management in a variety of case studies.

Bernauer (2002) concludes that these solutions for river management problems remain incomplete without substantive input from the social sciences. In the case of Dutch water management Mostert (2006) observed that many technical experts focus on their area of expertise and pay little attention to communication and cooperation with other actors in the process.

Scientific integration and cross-disciplinary collaborations are notably difficult in practice due to differences with regard to the visions, aims and problem definitions that guide disciplinary research, as well as the scientific logic, language, methodological approaches and techniques that are needed to perform specific research (Benda et al. 2002; Boulton et al. 2008; Cullen 1990; Petts et al. 2006). Difficulties in translating diversified perspectives on integrated management into action as well as lack of organizational and practical change on the ground have also been suggested to underlie problems with implementing the integrative agenda.

Institutional next to personal barriers have been claimed to limit the development of collaborative partnerships involving the co-production and bidirectional exchange of knowledge (Surridge & Harris 2007).

Given the large water management challenges that society is currently facing and the on-going need for effective water management strategies it seems timely and urgent to raise the question: what is the present meaning and status of the integrative discourse in water management and its supporting science, and what is its significance for future water management strategies?

4 Aim and Scope

The central issue of this thesis is to present an analysis of the integrative discourse regarding current water management with specific attention to its scientific framing. Here the ‘integrative discourse’ is understood as the mutual outcome of strategic policy- and formal scientific activities that aim at understanding and acknowledging the interconnections in water systems in its broadest sense. More particular I aim to address how underlying theoretical developments concerning systems thinking and societal policy- and value settings have shaped IWM conceptualizations, and how the challenge of cross-disciplinarity has shaped the relationships and interactions within research. I thereby focus on the science and management of river systems. The final aim of this thesis is to present an evaluation of the meaning and scope of the integrated approach and its wider meaning for (future) water management strategies.

Water management presents a broad endeavor with a focus on different water systems within a large variety of geographic, political and societal settings. This thesis however zooms in on *river system* management and research. The inherent complex nature of river systems –as compared to other water systems - in a bio-physical- as well as socio-political sense makes river systems especially relevant and suitable to study complexity and integrative processes. The national case of Dutch water management is taken to study the role of socio-political settings in the integrative discourse. The arena of integrated management in the Netherlands provides a suitable context because of the strong socio-economic association of the Netherlands with water and the fact that integrated water management has been adopted as *the* approach in Dutch water policy for the last two decades (Van

Heezik 2007). Furthermore the Netherlands has a leading international reputation in water management reflected in an established knowledge structure supporting water management (NRLO AWT & RMNO 2000). The focus on river science and river basin management is relevant considering the geographical position of the Netherlands, which is located in the delta of the Rhine, Meuse and Scheldt rivers.

The analysis and evaluation of the integrative IWM discourse as performed in the subsequent chapters is directed by a set of research questions that collectively address the different aspects of the systemic, societal and scientific contexts of integration in a coherent way.

5 Research questions

As outlined above IWM of rivers requires understanding of the combined social-ecological functioning of a river system and its human and natural relationships characterized by complex dynamics, uncertainty and political contentiousness (Surridge & Harris 2007). A range of system concepts and approaches have been suggested in environmental management for understanding and evaluating these relationships based on different ways of integrative framing models (Callicott et al. 1999). These are guiding concepts and heuristics of systemic integration that help to seek knowledge, guide description and evaluation of the joined social and ecological dimensions of environmental management. Examples include concepts such as sustainability, ecosystem services, ecological integrity and ecosystem health. This latter concept, ecosystem health, has gained significant popularity in the nineties (Costanza et al. 1992; Rapport 1999) and provides an illustrative case of scientific developments in systemic integration acknowledging human-nature relations. In this research the models of systemic framing will be explored that connect scientific understanding of system components and relations with the normative assessment of river system condition. Focussing on the case of ecosystem health the following question is posed:

a) *In what way do systemic framing concepts, here elaborated for ecosystem health, allow combining scientific facts with societal values for supporting and assessing IWM strategies?*

IWM acts at the science-policy interface by being scientifically informed and politically value laden. Differences in the processes of science and policy have been argued to underlie the difficulties and ambiguities in the elaboration and implementation of IWM strategies (Cullen 1990; Jeffrey & Gearey 2006). This incites the question how and if these differences express themselves when comparing scientific to political elaborations of IWM strategies. Here this question is phrased to address:

b) *What kind of scientific elaborations of IWM concepts have been made and how do these compare to IWM strategy development in water management policies?*

Part of the integrative discourse on IWM relates to societal integration and includes an emphasis on contextual relevance as well as the need for responsive and reflexive practices in which diverse societal values are taken into account. For river management to move beyond its traditional technical perspective it has been concluded that a clear understanding of societal value frames is required to guide scientific efforts for IWM support (Endter-Wada et al. 1998; Ludwig 2001; Pahl-Wostl 2002). This claim invites an analysis into of nature and constellations of societal values in IWM:

c) *What societal value orientations underpin IWM and what is their meaning for understanding river systems and developing IWM?*

As outlined in section 2 scientific integration in IWM poses challenges for science in the way it is organized and practiced. Although the necessity for cross-disciplinary scientific collaboration and its difficulties have been widely discussed (Benda et al. 2002; Cullen 1990; Petts et al. 2006), an evaluation of the extent to which current river science presents a cross-disciplinary endeavour is still lacking. This raises the question:

d) *What does the scientific landscape of current international river science look like and to what degree does the knowledge base of river science present evidence of cross-disciplinary efforts?*

This question results in an evaluation of what constitutes river science and where its disciplinary boundaries lie. However, (lack of) organizational structure and (differences in) scientific knowledge bases have been mentioned as important social and cognitive factors in limiting cross-disciplinary co-production and affecting the exchange of knowledge (Boulton et al. 2008; De Wilt et al. 2000; Van Hemert & Van der Meulen 2011). The importance of these factors for cross-disciplinary interactions is examined in the case of the Netherlands, led by the question:

e) *Do collaboration patterns and institutional organization facilitate or hinder knowledge exchange within the Dutch river scientific network?*

These research questions will be separately addressed in the studies presented in the upcoming chapters (2-6). The answers to these questions should contribute to providing insights in the various dimensions of meaning and scope of the integrated approach in IWM, and specifically to explaining how the herewith associated challenge of integrated learning has manifested itself in shaping scientific research activities in support of IWM.

The performed studies together provide a comprehensive analysis of integration in a structured way according the framework presented in Figure 1. This basic framework presents the main dimensions of integration that are being addressed in the subsequent chapters. The scope of these dimensions is based on work by Van Kerkhoff (2005) who reviewed currently existing thematic categories of integration in environmental science and policy. These encompass both integration within the scientific research sphere, as well as integration beyond the scientific research sphere including non-scientific partners. In addition foci of integration encompass the activities of doing research, as well as the organizational and institutional structures that surround them. Activity-oriented integration includes research methods, decision-making, and application- or dissemination activities of scientific work for example. In other words, the integration of what people actually do. In contrast, structural integration includes organizations, sectors and administration. It involves the creation of (or at least, removal of barriers to) connections among the formal organizational or institutional structures and rules so that integrated research can take place. Based on other reviews of the scope of integration (Downs et al. 1991; Scrase & Sheate 2002) another fundamental focus is added by distinguishing between externally-directed forms of integration, i.e. regarding behaviour and physical actions, or internally-directed forms of integration directed at beliefs and values.

As shown in Figure 1 the separate studies presented in the subsequent chapters together cover these different dimensions for analysing the integrative discourse of IWM.

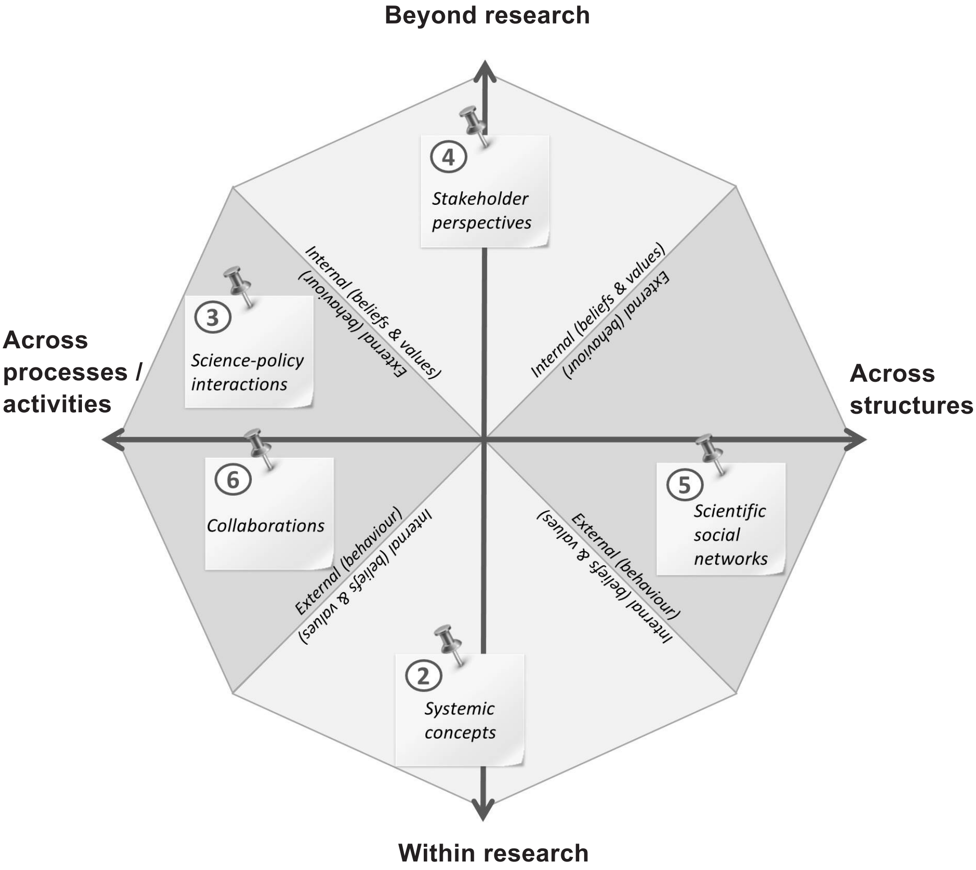

Figure 1. Thesis research structure

The framework distinguishes between the main dimensions for analyzing integration. The research questions (a-e) described in the text coherently cover these dimensions in subsequent chapters 2 to 6. Adapted from Van Kerkhoff (2005).

6 Outline

This thesis consists of five research chapters and closes with a synthesis chapter. Chapter 2 focuses on the conceptualization and elaboration of the River Ecosystem Health (REH) concept as an example of a normative concept that can guide integrated management. Based on a review of earlier elaborations a renewed definition is proposed as well as an assessment framework for REH. This framework encompasses indicators that may assess REH performance (i.e. top-down) as well as indicators for identifying the causative stress influencing system performance (i.e. bottom-up).

Next in Chapter 3 the elaborations of IWM in both the policy and science domain are compared and the different approaches are subjected to a thorough evaluation. Emphasis is given to describing how science has elaborated IWM in a conceptual way.

In Chapter 4 the nature and scope of societal values as expressed by stakeholders in water management are clarified using so called Q-sort methodology. This empirical approach is used to examine the way value orientations differentiate themselves amongst Dutch stakeholders. The wider meaning of these orientations for scientific elaborations and the policy context of IWM is assessed.

Chapter 5 then maps the scientific landscape of river science and assesses the extent to which river science represents a cross-disciplinary endeavor. Different bibliometric approaches and indicators are used to help understand the knowledge base of current river science and assess cross-disciplinarity.

In Chapter 6 the knowledge base of river science is further assessed from the perspective of social interactions determining whether and which institutional arrangements foster or hinder collaboration and the exchange of knowledge. Specifically, the study applies exploratory and statistical techniques from social network analysis to bibliographic data for mapping and evaluating cross-disciplinary collaboration in river science in The Netherlands.

Finally Chapter 7 synthesizes the overall findings following the separate studies and links them within an overarching conceptual framework. The discussion finally returns to the main question of what the integrative discourse beholds for current and future river management strategies.

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CHAPTER 2

Redefinition and elaboration of river ecosystem health: perspective for river management

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1 Introduction

Rivers serve many societal functions and belong to the most intensively human influenced ecosystems worldwide. Especially the last decades, socio-economic developments have led to their degradation and pollution. Functions of rivers, particularly those that are vital to sustaining the human community have become impaired (Nienhuis & Leuven 1998). In response, environmental sciences have focused on river condition assessment, system management and rehabilitation measures. Over time, various systemic concepts have emerged in relation to condition assessment, most notably sustainability, ecological integrity and ecosystem health (Callicot et al. 1999).

The ecosystem health concept has emerged as ‘river’ ecosystem health (REH) or river health in the field of river research and management (Karr 1999). REH recognizes that water resource problems involve biological, physical and chemical as well as social and economic issues, and is therefore considered a useful concept for directing integrated assessments of river condition (Norris & Thoms 1999). Furthermore, ‘health’ is found an appealing term for politicians and water managers (Hart et al. 1999; Rogers & Biggs 1999) as it is intuitively grasped by stakeholders (Meyer 1997), making it easy to communicate environmental problems and management measures. As such, bringing back river systems to a ‘healthy state’ and maintaining this state have become important objectives in national and international water management programs (Hart et al. 1999; Karr 1991; Rapport et al. 1999). An important legislative framework to mention in this respect is the European Water Framework Directive (European Commission 2000) that guides developments in European water management today. This directive demands an integrative ecosystem approach, meaning that catchments need to be managed in a holistic way, reflecting the interconnection that exists between the landscape, the water and its uses. This view is also reflected in the concept of ecosystem health, which therefore has good compatibility with the objectives of the Water Framework Directive (Pollard & Huxham 1998).

Within current elaborations of the REH-concept, three different ways of utilisation can be distinguished. Each of them represents a separate dimension of the concept, i.e. meaning, model and metaphor (Pickett & Cadenasso 2002). The ‘meaning’ dimension comprises the conceptual definition. The ‘model’ dimension embodies the specifications (such as elements under study, spatial or temporal limitations) needed to address the actual situations that the definition might apply to. Finally, the ‘metaphorical’ dimension constitutes the use of REH in common parlance, and in public dialogue. The three dimensions are linked, exemplified by the fact that any application of the model dimension of the REH-concept can only be developed based on a conceptual understanding, i.e. the meaning of the concept. However, use of REH has not always been clear and consistent (Norris & Thoms 1999). Often it lacks precise definition in conceptual as well as operational elaborations. This can be partly explained by the fact that the concept is interdisciplinary and evolving, which may cause confusion in conceptualization as well as application.

The present paper critically reviews developments of REH and focuses on the ‘meaning’, ‘model’ and ‘metaphorical’ dimensions of the concept. By doing so, it aims to structure and advance the discussion on ecosystem health and assess the significance of the concept for river management. First, the paper proposes a redefinition of REH within a broader context of River System Health after considering existing definitions and differences with related concepts (i.e. meaning dimension). Secondly, it gives insight in the scientific elaboration and assessment framework (i.e. model dimension). Thirdly, this paper briefly addresses the added value to river management (i.e. metaphorical dimension). The paper concludes with a perspective for future research regarding REH applications in integrated assessments and management of river catchments.

2 Meaningful concept for river functioning

Basic components

For better understanding and insight in the meaning and contents of REH, we will first consider the meaning of its component parts; health, ecosystem and river. This eventuates technical comprehension of the ‘ingredients’ of the concept and facilitates discussion on the question: what defines REH?

The American Heritage Dictionary (Pickett 2000) supplies the following definitions of health: ‘1. The overall condition of an organism at a given time. 2. Soundness, especially of body or mind; freedom from disease or abnormality. 3. A condition of optimal well-being.’ The first entry reveals that health describes the overall state of an organism (human being, i.e. a complex system). Taking into account the third entry as well, which defines health as well-being, it appears that health expresses a wholeness perspective, whereby performance (of the organism) cannot be explained by regarding separate parts. From the second entry it can be derived that health requires normative criteria for its definition. Health refers to a state of 'normal functioning' or 'normality' for multiple parts of an organism, free from disease. The standard for being healthy is 'soundness' (i.e. sound functioning) or, based on the last entry, a generalized state of 'optimal well-being'. This shows that health is a flexible notion since what is considered normal, sound or optimal (i.e. healthy) can vary under influence of different geographical and societal constituents, implying that states of reference are required to distinguish unhealthy from healthy (Figure 1).

The basic definition of an 'ecosystem' by Tansley (1935) encompasses a biotic community or assemblage and its associated physical environment in a specific place. This implicates that the concept of an ecosystem requires a biotic complex, an abiotic complex, interaction between them, and a physical space. This general definition covers an almost unimaginably broad array of instances, as it is neutral in scale and constraint, making it applicable to any case where organisms and physical processes interact in some spatial arena (Pickett & Cadenasso 2002). Over time, various specifications to the basic concept of ecosystem have emerged, using different foci like energy, nutrients, organisms and the inclusion of human sciences. The first and most broadly accepted definitions of ecosystems aimed to understand what physical environmental processes control and limit the transformation of energy and materials in ecosystems. Odum (1969) focused on ecological succession, whereby an ecosystem was considered a unit in which a flow of energy leads to characteristic trophic structure and material cycles within the system. Others focused on the physical template of ecosystems, resulting in the articulation of ecosystem attributes like resilience (e.g. Holling 1973). More recent perspectives have widened the ecosystem concept from 'natural' to 'human-inclusive', thereby acknowledging that humans may be regarded as an integral part of ecosystems. This has resulted in ecosystem models that account for economic flows of goods and services (Costanza et al. 1997) and the development of models that incorporate the full range of human institutions (Pickett et al. 1997; Naveh 2001). Central to all uses of the ecosystem concept is the core requirement that a physical environment and organisms in a specified area are functionally linked.

River systems can be described in five dimensions (Lenders & Knippenberg 2005). The three physical dimensions (longitudinal, transversal and vertical) are key features of river systems (Ward et al. 2002; Van der Velde et al. 2004). These three physical dimensions have been elaborated in terms of ecological concepts such as the River Continuum Concept (Vannote et al.1980), the Serial Discontinuity Concept (Ward & Stanford 1995), the Flood-Pulse Concept (Junk et al. 1989) and the Flow-Pulse Concept (Tockner et al. 2000). The temporal or fourth dimension (Boon 1998; Lenders & Knippenberg 2005; Poudevigne et al. 2002; Ripl et al. 1994) represents short- and long-term changes and is usually elaborated in terms of physical river system processes, such as hydro- and morphodynamics, and accompanying phenomena such as succession and rejuvenation. Finally, the social or fifth dimension includes socio-economic activities as well as issues like cultural identity and various positions humans may hold towards nature (Lenders & Knippenberg 2005).

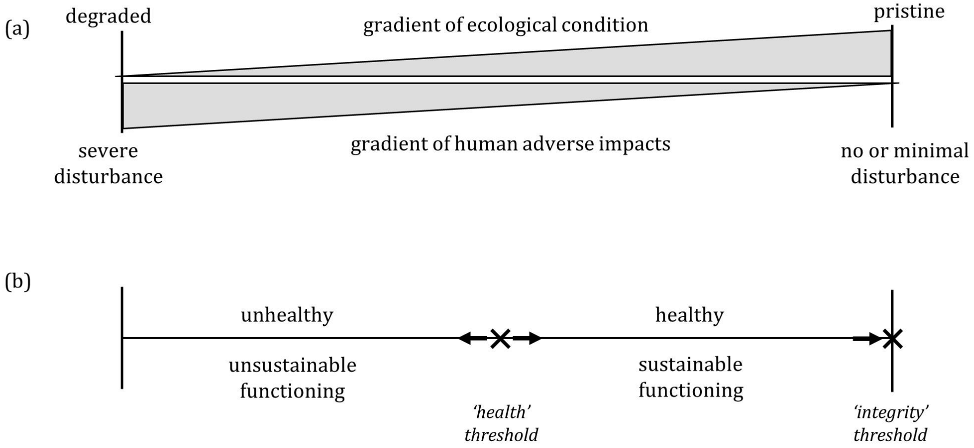

Figure 1

(a) The continuum of human impacts and river condition and (b) the normative valuation of quality in terms of ecosystem health and ecological integrity. Position of thresholds (cross-symbols) is related to valuation of sustainability. Arrows indicate that 'health' threshold is flexible, whereas 'integrity' threshold is rigid. Adapted from Karr (1999).

Key definitions reviewed

Initially, the extension of health to describe ecosystem condition was a response to the accumulating evidence that human-dominated ecosystems became dysfunctional. The health metaphor was used based on the assertion that an ecosystem, like an organism, is built up from the behaviour of its parts (Costanza & Mageau 1999). The first definitions of ecosystem health focused on the crucial parts of system functioning, the vital signs of a healthy system (Rapport et al. 1985), such as primary productivity and nutrient turnover. This was further elaborated by Costanza et al. (1992) who defined health in terms of activity, organization and resilience. Karr (1991) emphasized the system ability of autonomic functioning, stating that a (biological) system could be considered healthy when its inherent potential is realized, its condition is stable, its capacity for self-repair when perturbed is preserved and minimal external support for management is needed. In these definitions of ecosystem health, stability, resistance and resilience are key properties, portraying an ecosystem model according the theoretical presuppositions of Odum (1969), Holling (1973) and May (1977). This reflects a 'natural' system that is deterministic, homeostatic, and generally in equilibrium. Within the concept, health is defined as freedom from or coping with distress, i.e. in the context of maintaining essential functions. A progression from consideration of how human institutions relate to the biophysical environment ('nature') has led to developments in ecosystem models from 'human exclusive' to 'human inclusive', as articulated in the fifth dimension of river functioning (Lenders & Knippenberg 2005). The perspective that ecosystems also provide services for humans (e.g. aesthetic pleasure, timber, water purification), has led to definitions of ecosystem health in the context of promotion of well-being and productivity (Calow 1995), defining it in terms of capacity for achieving reasonable human goals or meeting needs.

The foregoing makes clear that there are divergent meanings given to 'ecosystem health', but the evolution in literature tends to suggest that the full scope of the concept should include ecological criteria as well as (considerations of) human values and uses derived from the system (Boulton 1999; Fairweather 1999; Karr 1999; Rapport et al. 1999). The 'health' concept finds acceptance by an increasing number of researchers (Rapport et al. 1999), but over time there has been scientific debate on whether it is appropriate to use 'health' in an ecological context (Belaoussof & Kevan 2003) and how to define and apply the concept (Lackey 2001). Some abandon the health metaphor, arguing that health is not an observable ecological property, lacks validity at levels of organization beyond the individual and is 'value-laden' (Davis & Slobotkin 2004; Simberloff 1998).

Table 1 summarizes key definitions of ecosystem health, varying from generalized, systemic definitions to narrow, operational definitions. There is no universal conception of ecosystem health, but the table shows that the broad definitions of ecosystem health generally include reference to stability and sustainability. More confusion arises when health is elaborated for a specific system such as a river. Generally, explicit definition of the meaning of REH is avoided, so it is not always clear what constitutes health. Rather, properties and monitoring criteria of the concept are discussed, mainly focused on the elaboration of the concept in terms of criteria for measures (Karr 1999; Norris & Thoms 1999; Boulton 1999; Norris & Hawkins 2000; Bunn et al. 1999). Other studies use REH as an umbrella concept for explaining integrated assessments of river condition using specific indicators (Obersdorff et al. 2002) in specific components (Maddock 1999) or compartments (Maher et al. 1999). Ecological functioning is central in most considerations of REH, but there is general consensus that economic and social functions should be included in the concept (Boulton 1999). However, economic and social functions are often merely considered as conditional but not as integral parts of the system (see e.g. Fairweather 1999; Moog & Chovanec 2000). Economic factors are often stressed as important boundary conditions (e.g. in terms of goods and services to be delivered by the river; e.g. Rapport et al. 1998b), but especially social factors (e.g. sense of belonging, sense of place) are mostly neglected (Kuiper 1998; Lenders 2003).

Overall, inconsistency exists in defined meanings of REH, as well as in the extension of its meaning into models (i.e. elaborations). Reason for this may be a disconnect between the academics discussing the concept of ecosystem health and the aquatic scientists deploying methods in the field to assess condition (Norris & Thoms 1999). Also, a diverse terminology has emerged around REH, due to the extensive scientific and philosophical discussion surrounding its conceptual development (Callicott et al. 1999; Society for Ecological Restoration Science & Policy Working Group (SER) 2004). Table 1 shows that terms like ‘sustainable’ and ‘integrity’ are part of the terminology to define health. However, these terms have own conceptual meanings, adding to the confusion in understanding the concept of health. Therefore, further clarification and demarcation of normative concepts related to REH (i.e. sustainability and ecological integrity) are needed in order to ultimately allow a (re)definition of the health concept for river systems.

Table 1. Examples of ecosystem health definitions

Study	**Ecosystem health definitions**	**System dimensions**	**Specification**	**Approach**
Karr (1991)	Healthy when its inherent potential is realised, its condition is stable, its capacity for self-repair when perturbed is preserved and minimal external support for management is needed.	Conceptual ecosystem; Physical and temporal	System characteristics	T
Costanza et al. (1992)	An ecological system is healthy and free from "distress syndrome" if it is stable and sustainable - that is, if it is active and maintains its organization and autonomy over time and is resilient to stress.	Conceptual ecosystem; Physical and temporal	System characteristics	T
Meyer (1997)	A healthy stream is an ecosystem that is sustainable and resilient, maintaining its ecological structure and function over time while continuing to meet societal needs and expectations.	River ecosystem; Physical, temporal and social	System characteristics	T
Harvey (2001)	Healthy ecosystems are characterized by sustainable turnovers of energy, nutrients, organic matter and water, which remain stable over comparatively long periods of time.	Conceptual ecosystem; Physical and temporal	System characteristics	T
SER (2004)	Ecosystem health is the state or condition of an ecosystem in which its dynamic attributes are expressed within 'normal' ranges of activity relative to its ecological stage of development.	Conceptual ecosystem; Physical and temporal	System characteristics	T
Fairweather (1999)	*Not explicitly defined;* river health can be expressed by holistic measures.	River ecosystem; Physical, temporal and social	Indicators of multiple disciplines	T/B
Bunn et al. (1999)	*Describes properties of river health:* Low rates of GPP and R_{24}, net consummation of carbon ($P<R$).	River ecosystem; Longitudinal, lateral	Physical indicators	B
Karr (1999); Oberdorff et al. (2002)	Health is equated to integrity. Evaluation of health through indicator of biological integrity (IBI).	River ecosystem; Longitudinal, temporal	Multimetric index	B
Maddock (1999)	*Not explicitly defined;* measurements of physical habitat features account for health.	River ecosystem; Lateral	Physical measures	B
Maher et al. (1999)	A healthy sediment ecosystem has an acceptable species abundance and diversity and functions satisfactorily.	River ecosystem; Vertical	Chemical indicators	B
Norris & Thoms (1999)	*Not explicitly defined;* primary needs for a healthy ecosystem are biotic integrity (Karr, 1991) and sustainability.	River ecosystem; Longitudinal, lateral, temporal	Physical indicators in relation to aquatic biota	B
Townsend & Riley (1999)	*Not explicitly defined;* degree of perturbations in physical space account for health.	River ecosystem; Physical and temporal	Multi-scale, multi-temporal measures	B
An et al. (2002)	Health is equated to integrity. Evaluation of biological integrity, habitat conditions and chemical parameters.	River ecosystem; Longitudinal, lateral	Multimetric indices, chemical indicators	B

Note: System dimensions are based on Lenders & Knippenberg (2005): 'conceptual ecosystem': generalized ecosystem, not defined by any spatial scale; 'physical': three dimensions, i.e. longitudinal, lateral and vertical. Approaches can be top-down (T) and/or bottom-up (B). GPP: Gross Primary Production; P: rate of primary production; R: rate of respiration; R24: total respiration over 24 h. Integrity, health and sustainability.

In environmental management and politics, ‘sustainability’ appears to be the most comprehensive concept. Though sustainability has been represented as a scientific concept, it is in fact in its broadest sense an ethical precept, being more a concept of prediction instead of being definitional (Costanza & Patten 1995). In accordance with the Brundtland-commission report ‘Our Common Future’ (World Commission on Environment and Development 1987), this concept highlights three fundamental components to sustainable development: environmental protection, economic growth and social equity. These three components should be in balance to ‘sustain’ them for future generations. Applying the sustainability-concept to river systems implies that river management should set its aims to ecological as well as to economic and social functions (Leuven et al. 2000).

For the ecological subsystem, terms like ecological or biological integrity are often used as either concepts competing with ecosystem health or as synonyms for ecosystem health (Callicot et al. 1999). The common denominator of the integrity and health concepts appears to be the observation that they all bear reference to qualities, i.e. characteristics of the system. Nonetheless, the concepts are distinct in meaning (Mageau et al. 1998; Karr 1999).

Pickett (2000) defines integrity as ‘1. Steadfast adherence to a strict moral or ethical code. 2. The state of being unimpaired; soundness. 3. The quality or condition of being whole or undivided; completeness’. In the entries under 2 and 3, integrity within the context of river management requires a reference. Which river condition can be considered as ‘unimpaired’ and which river state is ‘complete’? The first entry also requires a reference but offers the opportunity to apply one’s own criteria of moral or artistic (aesthetic) values to be taken into account. The entries 2 and 3 predefine these values as state of non-impairment and state of completeness, respectively. This narrows the meaning of integrity to an absolute quality: a river system is integer or it is not, depending on the answer whether or not the system is unimpaired or complete. In everyday practice the ecological or biological integrity concept also refers often to a pre-disturbance or pristine state (Karr 1999), defined as ‘[..] having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region’ (Karr 1991). Apart from the question how to define and to determine this pre-disturbance state, the concept of integrity seems to seek for a maximum exclusion of man and of any influence humans may have (Lenders 2003; cf. SER 2004). Furthermore, integrity appears to appeal above all things to the state of organization of a system, emphasizing structure and pattern as important features of the system, while processes are primarily necessary to attain and maintain these features (Callicot et al. 1999; Lenders 2003).

The above mentioned dictionary entries and conceptual definitions illustrate that health primarily refers to functioning. The acknowledgement that health has been described in terms of performance and capacity to resist and abate stress and disturbances underlies this statement. Furthermore, health refers to a desired (flexible) condition as opposed to the absolute (rigid) condition that integrity refers to. In addition, health can be regarded more of a relative system quality: there are several levels of health possible, each level being determined by different (ecological) criteria. Utilisation of the health concept in river management therefore requires a pre-definition of the desired levels of performance (Costanza & Mageau 1999; Lenders 2003). If this desired condition is defined as a pre-disturbance state (unimpaired, complete), as is often the case in river management thinking, health and integrity become almost synonyms (Figure 1).

When comparing ecosystem health and ecological integrity in relation to their purpose for river management, ecological integrity appears to be rather rigid as a guiding concept for management, referring to an absolute condition and offering few degrees of freedom for other functions (social and economic) within a broader coherent sustainability context. It is therefore a less obvious strategy for densely populated regions of the world where rivers, including their catchment areas and floodplains, have to fulfil a large number of societal functions. We therefore prefer a strategy that aims at ecosystem health as the central concept for sustaining the ecological domain of the river system, whereby the concept of sustainability sets the overarching goals.

Redefinition

Based on the above findings of connotation and scientific meaning, it can be concluded that REH needs to express the ability of the system to function, i.e. to perform and sustain autopoetic processes. Key properties hereby are vigour (throughput or productivity of the ecosystem) and resilience (ability to maintain structure and patterns of behaviour in the face of stress). Self-maintenance of the system depends on system processes in interaction with system structure at various spatial and temporal scales (i.e. organization). Note that health itself is not an ecological property but a societal construct, only having meaning in relation to human beings. The essence of health is an expression of wholeness, self-maintenance and other premises as explained above. However, *qualifications* of health require definition in terms of scientifically-based criteria. Flexibility in defining health status of the ecosystem allows consideration of economic and social functions in a similar fashion as expressed in the concept of sustainability that protects environmental quality within the context of social and economic prosperity. Thus, a healthy status is flexible in definition within the limits of sustainable functioning (Figure 1) whereby societal values drive the level of ecological quality that is attainable within a river system. Capturing the above-made health propositions, REH is redefined as:

> *an expression of a river's ability to sustain its ecological functioning (vigour and resilience) in accordance with its organization while allowing social and economic needs to be met by society*.

From a system perspective, the definition acknowledges that besides the ecological domain, the river system also encompasses a social and economic domain, for which ecosystem health is conditional. This fits a broader conceptual context, here referred to as River System Health (RSH), which considers REH to be a component in the overall health status of the river system. As such, RSH is regarded the integration of ecosystem health and the health of the economic and social systems (Figure 2). RSH expresses that it is not only the ecological component that makes up a sustainable system, but also that ecological qualities should be safeguarded and (re)developed in full accordance with and taking account of social and economic qualities. This means that the three health components are interdependent; the status of an individual health component is conditional for the health of the other two, besides its individual performance. As such, RSH may be considered a holistic representation of people, their activities and their impacts integrated with the ecology and resources of the river system (*sensu* 'coastal health' by Wells 2003). Though the relation between the health components is clarified as such, elaboration of economic- and social system health is beyond the scope of this paper. Having outlined the above conceptual framework and meaning of REH, the next step is to develop a suitable 'model' that enables assessment of its status. Construction of such an operational framework will greatly enhance the applicability of the concept in practice.

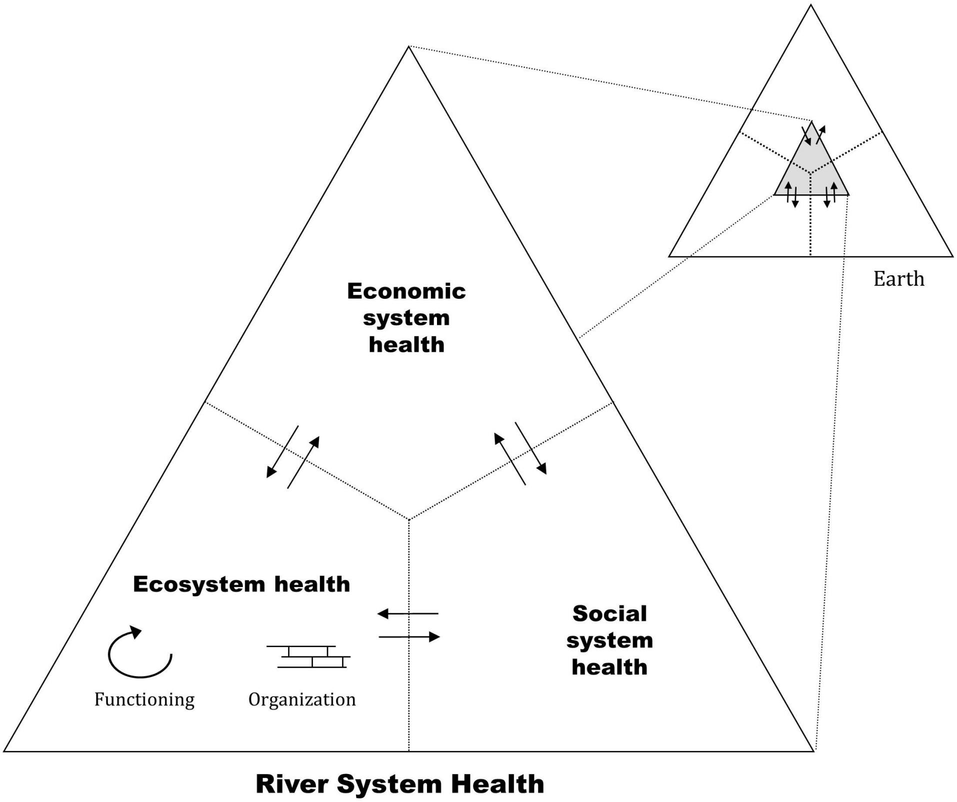

Figure 2

River System Health (RSH) is represented as the overall health status of the ecological, economic and social health components. Ecosystem health is a measure of ecological functioning within the organization of the river system. RSH itself depends on interactions between the river system and the surrounding earth.

3 Assessment framework

REH as an integrative, conceptual notion is not directly measurable or observable, so 'substitute' operational measures (like temperature for human health) are required to enable its assessment. In practice, REH can only be evaluated after ecological endpoints of ‘good’ health are identified for these measures. The assessment framework is required to measure progress towards these endpoints.

Two complementary approaches have emerged to assess ecosystem health, i.e. the top-down and bottom-up approach. The top-down approach provides a holistic basis for studying river ecosystems focusing on macro-level functional aspects without knowing all the details of the internal structure and processes, but rather knowing the primary responses in system performance under stress (Costanza et al. 1992). This approach removes the necessity of first defining all the elements and their mutual relationships before defining the whole ecosystem (Leuven & Poudevigne 2002). Stress effects can be detected by assessing response parameters, using so-called condition indicators. However, this necessitates caution when one evaluates REH, as it is difficult to guarantee that all components of whole system performance are considered in an assessment. The bottom-up or reductionist approach emphasizes the structural aspects of natural systems and focuses on identifying ecosystem health on the basis of accumulated data on simple stressor-effect (i.e. causal) relationships. Hereby a stressor is defined as any biological, physical or chemical factor that can induce adverse effects on an ecosystem (Environmental Protection Agency 1998). Within the context of REH, stressors are mainly understood to arise from human activities and as such pose stress on the natural system. Using the bottom-up approach the current stress status of an area (status assessment) or the progression of river stressor conditions (trend detection) can be assessed. Evaluating REH with this approach involves considerable work to provide information for each spatial and temporal scale, as well as for all the responses of the ecosystem (i.e. changes in structural and functional attributes) to the stressor or set of multiple stressors (Leuven et al. 1998).

Given the restraints of both approaches, a combination of both is suggested to address and link REH status to environmental problems within the river basin (Figure 3), and offering river managers opportunities to counteract these problems. In practice this necessitates the application and aggregation of a suite of indicators to cover REH, representative of the functioning and organization of the system (condition indicators) as well as the constraints that act upon system functioning (stressor and effect indicators). As such, the combined approach demands various dimensions of river functioning (Lenders & Knippenberg 2005) to be considered and multiple disciplines to be integrated in the assessment framework (Belaoussoff & Kevan 2003).

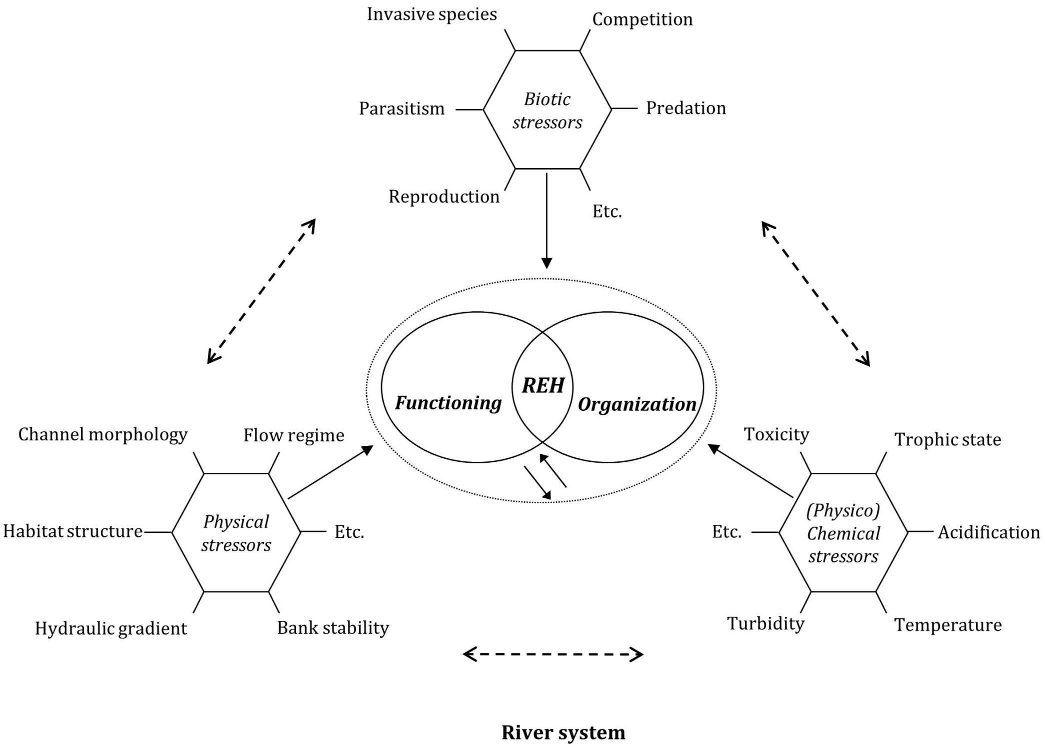

Figure 3

Relation between River Ecosystem Health (REH), condition indicators (functioning and organization) and various stressor indicators. Small opposite arrows signify interaction of river ecosystem with society. Bi-directional broken arrows indicate the interdependence of stressors, i.e. human activities may directly pose either a physical, (physico-)chemical or biotic stress on the river, but most common is a physical change in the system that results in chemical and subsequent biotic stress reactions.

Condition indicators

The system-level attributes vigour, resilience and organization have been traditionally proposed as top-down assessment measures of ecosystem health (Costanza & Mageau 1999; Rapport et al. 1998a; Holling 2001). Applied to REH, maintenance of the first two attributes (vigour and resilience) can be considered capacities of sound ecological functioning. Table 2 summarises available condition indicators that assess system functioning and organization. The table shows that there is a range of condition indicators for ecosystems, but until now relatively few have been developed and tested to assess ecosystem health of river systems. These specific indicators will be shortly described below.

Table 2. Set of condition indicators to assess river ecosystem health

Ecosystem attributes	**Specification**	**Indicators**	**Method**	**Reference**
Functioning	Vigour (activity, metabolisms or productivity)	Gross primary production* (GPP), Standing crop biomass (B), respiration* (R) and ratios (GPP/R*,GPP/B), carbon assimilation ratio	DM	Odum (1985), Xu et al. (2001); Young et al. (2004); Bunn et al. (1999)
		Leaf litter processing rate*	DM	Young et al. (2004)
	Resilience (counteractive capacity of ecosystems to maintain structure and function)	Systems overhead*	NA	Ulanowicz (1986); Costanza & Mageau (1999)
		Ecological buffer capacity^{+}	DM, SM	Jørgensen (1995); Xu et al. (1999, 2001)
Organization	Interactions between processes and structure across space and time (e.g. diversity).	System uncertainty; Shannon's diversity index^{+}	NA; DM	Ulanowicz (1986); Mageau et al. (1998); Xu et al. (2001)
		Exergy and structural exergy^{+}	SM	Jørgensen (1995); Xu et al. (1999; 2001)
Combinations	Combine both functioning and organization aspects	Functional measures of species richness, abundance & morphology, trophic composition (IBI) & habitat preferences *	DM	Karr (1991); Poff & Allan (1995)
		System ascendancy*	NA	Ulanowicz (1986); Costanza & Mageau (1999)

*Note: *: Applied to river ecosystems (including estuaries);*
+: Applied to freshwater ecosystems, easy to adapt for river ecosystem application; DM: Direct measurement; IBI: Index of biotic integrity; NA: Network analysis; SM: System modelling.

Functioning

The vigour of a system is an attribute of system performance that represents the activity, metabolism or primary productivity of the ecosystem. Available indicators can be measured directly and relatively easy, including gross primary production (GPP) and energy flow measures like resource efficiency, system throughput and cycling (Costanza & Mageau 1999). The most commonly used empirical measures are GPP, biomass as well as production and respiration ratios (Bunn et al. 1999; Xu et al. 2001; Vannote et al. 1980). The intensity and dynamic of GPP give expression to system vigour (Costanza & Mageau 1999), by quantifying the magnitude of input (material or energy) available to the system (Bunn et al. 1999). Another measure of system metabolism is the rate of decomposition of terrestrial plant leaves in streams and rivers. It has been suggested for some time as an integrated measure of the effects of human disturbance (Young et al. 2004). Leaf breakdown is potentially an ideal measure because it links the characteristics of riparian vegetation with the activity of invertebrates and microbial organisms, and is affected by natural and human-induced variation in a wide range of environmental factors (Young et al. 2004). Other measures of vigour include resource use efficiency, unit energy flow and system throughput (Xu et al.2001; Ulanowicz 1986; Mageau et al. 1998), as well as system cycling (Finns cycling index; Allesina & Ulanowicz 2004). These indices are part of network analysis, a phenomenological approach that holistically quantifies the structure and function of food webs by evaluating biomasses and energy flows (Ulanowicz 1986).

Measuring the resilience of a system is difficult because it implies the ability to predict the dynamics of that system under stress (Costanza & Mageau 1999). Quantifying resilience therefore often includes modelling techniques whereby resilience is expressed in terms of disturbance absorption capacity (Holling 1987), scope for growth (Bayne 1987) or population recovery time (Pimm 1984).

A suggested proxy measure is system overhead, which is another network analysis index described by Ulanowicz (1986). It quantifies the number of redundant or alternate pathways of material exchange and may be thought of as a systems ability to absorb stress without dramatic loss of function (Costanza & Mageau 1999). Ecological buffer capacity is a measure that has been applied to lakes (Xu et al. 1999). It represents the ability of the system to normalise effects by external variables (i.e. pollution input, acidifying precipitation etc.) through changes in internal variables (plankton concentration, phosphorus concentration etc.). It can be expressed as a ratio between external variables that are driving the system and internal variables that determine the system (Xu et al. 1999; 2001).

Organization

Ecosystem organization relates to the complex of interactions between system processes and structure across space and time. Quantifying organization may be more difficult than functioning because quantifying organization involves measuring both the diversity and magnitude of system components (e.g. river sediment and main stream) and the material exchange pathways between them (Costanza & Mageau 1999). Indicators of organization include the diversity of species and energy flows (i.e. exergy), as well as indirect network analysis measures such as system uncertainty, development capacity, mutual information and predictability (Ulanowicz 1986; Mageau et al. 1998; Turner et al. 1989). The difficulty of quantifying organization in practice is apparent from Table 2, which shows no indicators that have been elaborated for REH. A suggested indicator is system uncertainty or Shannon diversity of individual flows, which may be easily adaptable and applicable for rivers. This network analysis index represents the total number and diversity of input, output and material flows and is a measure of the total uncertainty embodied in any configuration of flows (Mageau et al. 1998). The Shannon index is also applicable to biodiversity; Xu et al. (2001) measured algal species diversity in a lake ecosystem and showed a low diversity index outcome to be related to ecosystem stress. Based on data of wild bee pollinators, Belaoussoff & Kevan (2003) argue that the degree of deviation of diversity and abundance from log normality can be used as an indicator of ecosystem health. Pollinator communities from fields unaffected by an insecticide showed a log normal distribution of diversity and abundance but those fields affected did not. Another measure of organization is exergy, defined as the amount of work a system can perform when it is brought to thermodynamic equilibrium with its environment. Exergy is expected to increase as ecosystems mature and develop away from the thermodynamic equilibrium. It can be expressed as a function of the biomass in the system and the (genetic) information that the biomass is carrying. Structural exergy can be defined as the ability of the ecosystem to utilize available resources and can be expressed as the exergy relatively to total biomass (Xu et al. 1999).

Combinations

There are also measures that combine both functioning and organization aspects. The Index of Biotic Integrity (sic!) incorporates multiple attributes of fish communities to evaluate human influence on a stream and its catchment. It is by far the most used index (in various versions) for assessment of river condition (Karr 1991). The IBI employs a series of metrics based on assemblage structure and function (fish or invertebrate assemblages) that give reliable signals of river condition to calculate an index score at a site, which is then compared with the score expected in the absence of stress. The multi-metric approach has widely found use (Karr 1999), for example by Poff & Allan (1995), who added habitat preference measures to measures of trophic composition and fish morphology. The measure of system ascendancy has been articulated by Ulanowicz (1986), who stated that as an ecosystem network develops through time in a stable environment, it becomes more hierarchical and has fewer redundant links. This means that whereas a mature or non-stressed network has few redundant connections, a polluted, stressed, or frequently disturbed network will have many redundant connections (thus low ecosystem ascendancy). Indeed Costanza & Mageau (1999) found lower ascendancy value for polluted estuaries.

Stressor and effect indicators

Biotic, physical and chemical stressors can affect river ecosystems. As outlined before, the proposed assessment framework can be used to address the current stress status of an area (status assessment) or to express the development of river stressor conditions (trend detection). As a first step, we listed a number of indicators related to the different kinds of stress; biotic, physical and chemical. These indicators can be assessed with methodologies currently in use (Table 3) and presents a list that is not exhaustive, but a representative selection of established indicators.

Concerning biotic stressors, there is sufficient evidence that invasive species may negatively affect the occurrence of indigenous species (Bij de Vaate et al. 2002). The number and abundance of invasive species for fish and macro-invertebrates may be considered a good indicator for the stress caused by foreign biota in a river ecosystem. Species richness (Hill 1973) or a species richness-abundance index, such as the Simpson index (Simpson 1949) may be used to quantify stress of invasive species in river ecosystems. Another biotic stressor indicator is measurement of size-distribution structure. Studies of aquatic systems show that an increase in stress pressures is accompanied by the decreased dominance of large species and an increased dominance of small species. Quantitative estimates of maximum size attained by fish species can be used to calculate shifts in the size distribution of species (Wichert & Rapport 1998).

Table 3. Set of stressor and effect indicators to assess river ecosystem health

Scope	Type	Indicator	Indicator specification	Method	Reference
Biotic	S	Fish, Invertebrates	Invasive species	SR, S (invasive)	Hill (1973); Simpson (1949)
	E		Size-distribution structure	MSD	Wichtert & Rapport (1998)
Physical	S	Flow regime	Quantity and dynamics	RVA, T	Richter et al. (1997); Tennant (1976)
	S	Habitat structure	Depth, width, structure and substrate	QHEI, AQEM	Rankin (1989); Hering et al. (2004)
	E	Connectivity	Fish number and abundance	SR, S (anadromous)	Hill (1973); Simpson (1949)
Chemical	S	Temperature	Temperature change	WQI	Brown et al. (1970); Couillard & Lefebvre (1985)
	S	Trophic state	%DO, BOD, P, NO_3^-, TDS	WQI	Brown et al. (1970); Couillard & Lefebvre (1985)
	S	Turbidity	NTU	WQI	Couillard & Lefebvre (1985)
	S	Acidification	pH	WQI, AQEM	Couillard & Lefebvre (1985); Hering et al (2004)
	E	Toxicity	Toxic stress	msPAF, AQEM	Traas et al. (2002); Klepper et al. (1998); Hering et al. (2004)

Note: Types include S: stressor indicator; E: effect indicator.

Indicator specifications include %DO: percentage dissolved oxygen; BOD: Biological Oxygen Demand; msPAF: multispecies Potentially Affected Fraction of species;

NO3-: Nitrates; NTU: Nephelometric Turbidity Unit; P: Total Phosphates; TDS: Total Dissolved Solids.

Methods include AQEM: integrated Assessment of the ecological Quality of streams and rivers throughout Europe using benthic Macro-invertebrates;

MSD: Maximum size distribution; QHEI: Qualitative Habitat Evaluation Index; RVA: Range of Variability Approach; S: Simpson index; SR: Species Richness;

T: Tennant method; WQI: Water Quality Index.

Physical stressors relate to changes in flow regime and habitat structure. Alternations of flow regimes can play a major role in the destruction of river ecosystems. Richter et al. (1997) developed a Range of Variability Approach (RVA) to assess the influence of human activities on the water budget and dynamics of aquatic systems. A suite of 32 hydrological parameters is defined to characterize hydrological variability before and after an aquatic system has been altered by human activities (Richter et al. 1996). A less elaborative method to assess the hydrological functioning of rivers is the Tennant method. A first picture of the hydrological functioning of a river can be obtained by comparing recommended percentages of the historical average annual flow with the actual monthly hydrographs for winter and summer (Tennant 1976). Apart from water quantity and dynamics, the connectivity of water bodies is of importance for the ecological functioning of river ecosystems, particularly for anadromous fish species. The number and abundance of anadromous fish species may be considered as a good indicator for the stress caused by the lack of connectivity in a river. Species richness (Hill 1973) or a species richness-abundance index, such as the Simpson index (Simpson 1949), for anadromous fish species may be used to quantify the stress due to lack of continuity along rivers. The Qualitative Habitat Evaluation Index (QHEI) was designed to provide a measure of habitat that generally corresponds to those physical factors that affect fish communities (Rankin 1989). The QHEI is based on six interrelated metrics: substrate, in-stream cover, channel morphology, riparian zone and bank erosion, pool/glide and riffle/run quality, and gradient. Another way to assess habitat structure destruction is to use information on species occurrences, which are sensitive towards degradation in stream morphology (Hering et al. 2004).

The third group of indicators reflects chemical stressors. Water quality can be assessed in a relatively straightforward way, by measuring a number of key physical attributes and processes. Various methods aim to integrate these measurements to one comprehensive index (BKH 1994). The Water Quality Index (WQI) of the US National Sanitation Foundation is one of the most widely used of all existing water quality indices, integrating nine water quality parameters, such as pH and Biological Oxygen Demand (Brown et al. 1970; Couillard & Lefebvre 1985). Although the WQI can be applied in a comprehensive way, it lacks the inclusion of a stress index for toxic pollutants. Species are generally exposed to complex chemical mixtures in the environment. Calculation of the combined ecotoxicological effects of mixtures of chemicals on sets of species can be done according to concentration addition rules of calculus for pollutants with the same mode of action and response additive calculation rules between toxic modes of action (Traas et al. 2002). The toxic stress index reflects the fraction of species expected to be (potentially) affected at a given environmental exposure to a mixture of chemicals (Klepper et al. 1998). Another way to address chemical stress is to use information on species occurrences, which are sensitive towards a specific stressor, such as acidification or organic pollution (Hering et al. 2004).

Tables 2 and 3 present a cross-section of indicators required to assess overall REH status through vital properties of the system (vigour, resilience and organization) and lower-level system parameters that are indicative of (potential) stress causalities impairing REH. The list of condition indicators reveals that a limited number of indicators is yet available to assess comprehensive system properties (e.g. resilience) for freshwater systems. The complexity of the underlying processes seems an obvious factor in this. The presented stressor and effect indicators cover the scope of common stresses, but the set is adaptive to specific local circumstances and policy requirements. More explicit than in the current list, measures may be included of ecosystem services ensuring specific social and economic qualities (e.g. stressor measures on harvestable fish species, etc.). Overall, the set of top-down and bottom-up indicators suggests that more integration is required amongst measures to produce practical indices of overall REH. There remains a dilemma in trying to construct a comprehensive evaluation system for REH: on the one hand is the desire to ensure that it truly reflects the defining attributes of REH – on the other, the more complex the system the more information is needed, and time or money may not permit its collection (Boon 2000).

4 Added value of health metaphor

Next to having a conceptual meaning and being elaborated in models, REH has symbolic and informal use in scientific language, and in public dialogue. This is perceived as the metaphorical dimension of REH (Pickett & Cadenasso 2002). In river management the health metaphor has added value in two ways. First, it has scientific value as a structural metaphor that perceives ecosystems as organisms. This provides a simple intellectual framework that allows comprehension of the multi-dimensionality and interrelationships that exist in complex systems. As such it has a generative and creative role for developing concepts of ecosystem condition and structuring research questions. Complementary to this is its socio-political role. Within this role the metaphor generally differs from its scientific use as the precision and narrow focus of scientific terms is generally avoided in favour of richness of connotation and in support of societal important values, for example investing in river rehabilitation (Bennett 2002). As such the metaphor has value in effectively communicating results about the condition of river ecosystems and related environmental problems (Meyer 1997). Humans have intrinsic comprehension of health and can relate to a physician-like approach that involves diagnosis, prognosis, treatment, and prevention. For this reason, it is now widely used in both popular and academic discussions of environmental problems and has widely found public use in policymaking and management objectives.

The strength of the metaphor lies in its potential to mobilize scientists, practitioners and publics by seeing relationships at the level of values. This way it places human beings at the centre of considerations about development, while seeking to ensure the durability of the ecosystem of which they are an integral part. There can be no sustainable development unless interventions take into account both the well-being of human beings and the survival of the ecosystem (Forget & Lebel 2001). Therefore it is necessary to include the human institutions that interact with the river and that control its future condition: laws and their enforcers, management agencies, industries etc. (Meyer 1997). The value of health is recognized by the fact that ‘river health’ has been adopted in various (inter)national monitoring programs and political objectives, for example in Australia and South Africa, Cambodia, Laos, Thailand and Vietnam (Australian and New Zealand Environment and Conservation Council 1992; Hohls 1996; Mekong River Commission 2003).

5 Perspective

Central in river ecosystem health is the ability of the system to function, i.e. to perform and sustain (key) processes that are in accordance with system structure at various scales (i.e. organization). A healthy state is flexible in definition within the limits of sustainable functioning (Figure 1), consequently allowing consideration of economic and social functions for its definition. This fits a broader conceptual context, introduced as River System Health (RSH), which considers REH to be a component in the overall health status of the river system. The framework of RSH extends beyond a separation of a ‘natural’ and ‘societal’ river system and aims to fully integrate human attitudes and social institutions that are a part of a rivers’ societal catchment, meaning the social and economic structures and institutions that directly influence ecological structure and processes (Meyer 1997; Figure 2).

Assessment of ecological health needs integration of measures of multiple, complementary attributes and analysis in a synthesized way. The proposed assessment framework outlines a combined top-down/bottom up approach that combines condition and stressor/effect indicators. For river managers, this poses a framework that is descriptive, i.e. able to evaluate the effects of human interactions on ecological functions, as well as being diagnostic, i.e. indicative of responsible stressors. In order to retrieve an easy-to-use, transparent methodology, efforts need to be directed to define a minimum set of indicators that may reliably represent the scope of REH. The indicators in this paper represent a useful, exemplary selection from a broad range of currently available indicators and are believed to cover the main concept of REH. However, consideration of the latest scientific developments should be combined with cross-comparisons of indicator results in order to optimise the indicator set. Based on findings on the indicative power, mutual relationships and interdependencies of metrics, certain indicators may prove ‘redundant’ while others may be worth including. For example, An et al. (2002) used a biological assessment (IBI) in combination with habitat (QHEI) and chemical measurements to evaluate REH. Habitat quality showed a strong positive relation to species richness. This suggests that the QHEI can be a predictive tool for changes in biological communities. Another study by Miltner & Rankin (1998) showed a negative correlation between nutrients and IBI, detectable when nutrient concentrations exceeded background concentrations.

Benchmarks need to be set for each indicator that enables distinction between “healthy” and “unhealthy” (i.e. intra-valuation; Norris & Thoms 1999). These benchmarks need to be based on reference conditions that illustrate the spatial and temporal dynamics of self-maintaining, sustainable functioning river ecosystems. Appropriate river systems of reference can be identified through expert judgment. For some indicators, the benchmark values assigned could and should be determined by existing guidelines, objectives or standards e.g. contaminant levels in sediments.

Attention should be given to time and spatial scales of measured parameters, e.g. regarding seasonal or long-term natural dynamics of parameter values (Innis et al. 2000). Natural dynamics may cause relative impacts of stresses to change across seasons, i.e. increased solubility of toxics in summer due to higher temperatures. Considerations of scales are not only necessary for evaluating individual indicators, but also for comparing and integrating the results of multiple indicators.

The set of REH indicators suggested in this paper may together be integrated to construct a REH index. Expressing REH in a single index demands the aggregation of multiple indicators and requires use of suitable aggregation techniques. Managers and/or scientists may value the ecological attributes that these indicators measure differently. A process of weighting is required to differentiate between attributes of differing importance (i.e. inter-valuation) (Wells 2003). The values of weighing factors need to be defined, based on validated scientific data and expert judgment. This way a ‘scoring’ or classification system can be developed in which indicators and their metrics are clearly described and the derivation and interpretation of scores can be readily understood. A classification system improves objectivity by ensuring that valuations of health are rigorous, repeatable and transparent (Boon 2000). Multi-optional visualisation and calculation techniques can add to transparency of the weighting, calculation and aggregation process and supply information to managers that is relevant for defined objectives and required information detail. This can provide an effective tool for decision-making that can synthesize knowledge over a range of space and time scales within a nested hierarchy of (sub)systems and be set to multiple levels of assessment intensity, varying from a “superficial” screening to intense diagnostic health assessment.

An index of REH may enable a single judgment of the ecological health status of a river system and evaluation of management objectives. As such, a REH index can support decision-making when a specific health rank is linked with defined policy actions. Such models may be valuable assets in implementation of political frameworks like the Water Framework Directive. In a wider context, the REH concept and its models can provide consistency in ecological assessment approaches, based on flexibility of different scales, hierarchy and information on functioning and organization of the river system. Though the paper has given an assessment framework for managers to work with, practical elaboration will have to be extended on how to relate relevant single effects, values and criteria across fields of impact in a meaningful way and how to make them comparable in order to be able to weight them and trade them off if necessary (Brouwer et al. 2003)

Finally, REH (within the wider context of RSH) has the potential to evolve into a core concept for integrated water management. However, this will require further synchronization with contemporary concepts and methodologies available to achieve the aims set in management, such as restoration, rehabilitation, ecosystem management and adaptive management.

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CHAPTER 3

The duality of integrated water management: science, policy or both?

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1 Introduction

Water systems are of vital importance for human well-being, providing many benefits to society in terms of water related resources and functions. Over time, the field of water management has rapidly evolved and modernized in response to the ever-increasing demands that are being made on finite water resources in many parts of the world (Baron et al. 2002; Vitousek et al. 1997). Over the last two decades, integration and integrated approaches have been increasingly presented as new and superior ways to consider the environment in policy- and decision-making. This development has established integrated water management (IWM)[1] as the mainstream approach for management of water bodies. Its full spectrum refers to a range of management approaches that offer synthesis by analysing, solving and managing water-related issues through a coordinated approach (Biswas 2004; Downs et al. 1991; Gilman et al. 2004).

The diversity of existing IWM approaches results from the societal and scientific context in which water management has to operate today. In comparison to the 1970s when the focus was on well-defined, local environmental problems, water policy these days has to address and accommodate issues that are more complex and less controllable, having a 'mosaic' nature that requires balancing a multitude of interests in and uses of the water system. These issues arise from a variety of human activities on a (supra)national scale and manifest themselves in a multitude of effects over long time periods, across diverse localities. Underlying this complexity are global developments in markets, technology, communication and information systems. Furthermore, socio-cultural developments have led to increased attention for water management and shifted perspectives of its main objectives. Liberalisation and individualisation of citizens, demands for responsibility and accountability by authorities concerning the environment and its management process, characterize a transition from 'government' to 'governance' that underlies water management development as well.

In search of understanding current environmental issues, scientific research has set the challenge to focus on the linkages between social, political, econom-

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[1] Note that the abbreviation IWM will be used throughout the paper as a general denominator to refer to a range of approaches and strategies that have been labelled 'integrated management' and discussed in literature within the context of water systems.

ic, biological, hydrological, chemical, and geological systems (Lubchenco 1998). Thereby it has moved away from individualistic, discipline-driven research to utility-focused research that connects research activity across a number of boundaries. New modes of science, labeled Mode-2, post-academic and post-modern, have been recognized in which research is not solely decided within the academic domain alone, but in negotiation with other actors of various intellectual and social backgrounds (Van Kerkhoff 2005). The emergences of new practical and epistemic perspectives as well as new organizational forms are part of this. The role of science is no longer seen as steadily advancing the certainty of our knowledge and control of the natural world, but is replaced by a view that sees science as coping with many uncertainties in policy issues of risk and the environment (Gallopin et al. 2001).

The imperative of ‘integration’ in both water policy and water-related research has led IWM to become popularized as a political slogan and a fashionable umbrella term for directing research efforts. As such, it has stimulated a wide range of elaborations based on different perspectives. This has however resulted in a diversified meaning of IWM, and has led to ongoing discussions on its meaning, interpretation and implementation. In the scientific field, multiple authors have observed that clear consensus on the scope of the concept is lacking, arguing that IWM has been poorly articulated and elaborated in different competing definitions (Downs et al. 1991; Gilman et al. 2004). Strategic and conceptual, rather than operational and concrete use of IWM seems more common (Biswas 2004). The position of IWM as an ‘inter-cultural’ concept between policy and science (i.e. involving political goals as well as scientific understandings) may underlie difficulties and ambiguities in elaboration of the concept (Hull et al. 2003; Jeffrey & Gearey 2006). Different authors have elaborated on the interactions between these institutions (e.g. Cortner 2000; Hoppe 2005). In these studies the troublesome nature of this relation is recognized, referring to existence of a ‘boundary’ between science and policy, which as such is not considered to be natural but created by social and political processes (Van Kerkhoff & Lebel 2006).

The main objective of this study is to give an academic overview of the scientific rationales behind IWM and explore its fundamental scientific conceptual scope in relation to its strategic scope in a national policy setting. In doing this we take that IWM approaches are determined by the level of (non-) interaction between the institutions of science and policy. The degree and direction of these interactions may differ, resulting in different strategic approaches in terms of scientific support and goal setting. We will not go into elaborating how these relations are shaped specifically, which other authors have done in detail (Hoppe 2005), but take science-policy interactions into account as an explanatory factor for the development of IWM.

The scientific development of IWM is confronted with its policy development in the Netherlands, as an example of national level implementation. The Dutch setting is chosen as IWM has been the adopted approach in water policy in the Netherlands for two decades. Also, the Netherlands has a leading international reputation in water management. Pragmatically, the Dutch case is suitable because documentation on policies was readily available to the researchers. The next two sections address how IWM is understood in the scientific and Dutch policy domain respectively. The scientific elaboration of IWM is discussed in the context of international peer-reviewed research; the policy domain is elaborated by means of Dutch water policy developments during the last 40 years. In the discussion section, possible differences in meaning between and within both domains are discussed. This makes it possible to see whether and how mutual dependency exists between the policy and scientific domain. The article finalizes with shortly stating the main findings.

2 IWM in fundamental science

A scan of scientific publications reveals that it is only recently that the concept of IWM has established as a research topic (Figure 1b). Before the 1990s, publications on the topic have been scarce within the international scientific literature database. Since 1990, the interest in IWM and integrated approaches has been increasing. It should be noted that this claim relates to formal scientific publications (ISI database) only. Semi-scientific (national) publications from research institutes or governmental organisations have not been considered.

Different scientific disciplines are involved in research on IWM. Figure 1a shows how existing publications on ‘integrated management’ and ‘integrated approaches’ are distributed amongst major scientific fields. As a research topic, IWM seems bound to specific scientific fields. Elaborations on integrative approaches in water management are predominantly made in the environmental and natural sciences. About 95 % of all publications in the used dataset are indexed in the ISI SCI-EXPANDED database, which is restricted to publications of the natural sciences. The remaining publications are listed in the Social Sciences and Arts & Humanities indexes. On the basis of the journal publications it can thus be derived that the scientific contribution of social, economic, legal and management fields to IWM is (unexpectedly) small. A negating argument may however be that the social sciences tend to publish more in books instead of journals. Also, the IWM terminology may be less common to the social disciplines. The data in the table do not imply that knowledge of the social sciences is not used in elaborations of IWM. The disciplines themselves may make limited scientific contributions to the concept as such, but social knowledge may be nonetheless applied through elaborations of the environmental sciences, which generally have a broad, multidisciplinary scientific scope.

The dominance of natural sciences in elaborations of water management is also pointed out by Lant (1998) who presented the topical focus of 341 submissions to the Water Resources Bulletin (currently known as the Journal of the American Water Resources Association) in the period 1995-1997. Over three-quarters of the submissions were from the physical sciences, primarily focusing on water quality, hydrology and engineering. A similar result was found in an analysis of Dutch research on IWM. Within an advisory report on knowledge innovation for water management (De Wilt et al. 2000) an analysis was made of the knowledge infrastructure on IWM in the Netherlands. It showed that over 80 % of the studies on integrated management performed at universities focused on the physical system and its different aspects. The remaining studies focused on its management and administration. Up to now, research on social aspects within the explicit context of IWM has been strongly focused on the studying of political and decision-making processes (Endter-Wada et al. 1998). However, increasing attention is given to social aspects like the role of citizens and public attitudes in water management (e.g. Tunstall et al. 2000).

Figure 1a shows that research on integrated management is primarily rooted in the ‘environment’ field of science. This field includes disciplines such as environmental science and (conservation) ecology. The second most number of publications is in the field of ‘Water Resources’, covering applied disciplines such as hydrology and hydraulic engineering, as well as management disciplines. Overseeing literature, the disciplines of ecology and environmental science cover the largest part of contributions to water management concepts. Further analysis and discussion in this section on scientific elaborations of IWM will therefore primarily concern these disciplines, as within these disciplines alone, available literature is extensive.

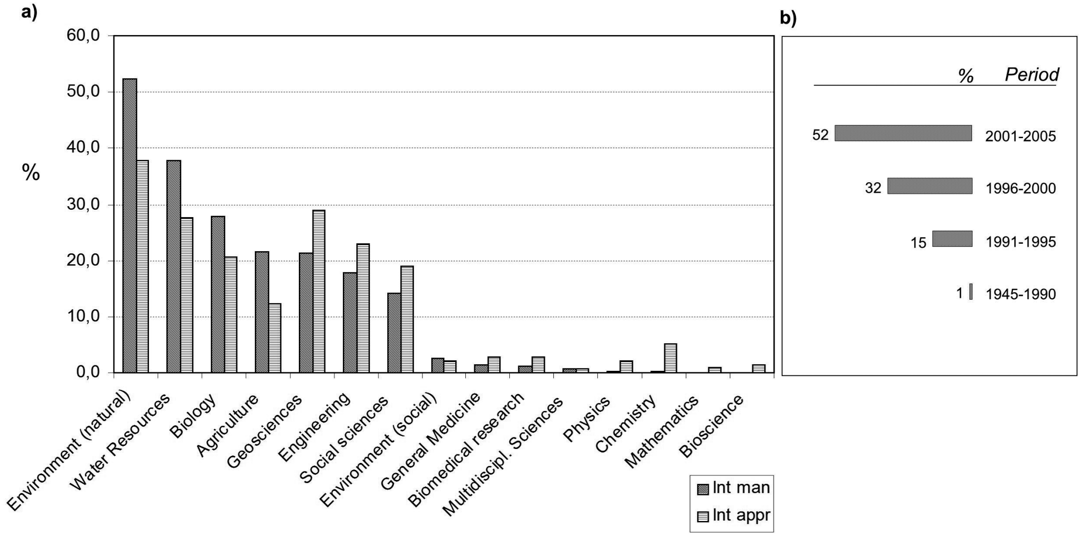

Figure 1

a) Percentage distribution of publications between fields of science for the terms 'Integrated Management' and 'Integrated Approach'. Publications were categorized based on ISI subject categories, which were subsequently generalized to fields of science. Only subject categories that contained a minimum of 1 % of all publications were included. Classes of science fields are derived & adapted from (Glänzel & Schubert 2003).

b) Appearance of integrated management & approaches and their conjugations in scientific literature. Per category, cumulative percentage across all years is 100 %. Data were derived from a general search in ISI Web of Science (http://portal.isiknowledge.com) in the Web of Science databases SCI-EXPANDED, SSCI, A&HCI. Searches performed in publication titles for 'integrated management' and 'integrated approach in relation to the term water, as well as the term river (total N=2751). Online analysis tool was used to generate data.

Key concepts

When considering the rationale behind water management, one cannot ignore the embedded core values that motivate water management; it may be undertaken to meet human needs, the needs of ecosystems, or some combination of the two.

Taking a human-nature dualistic stance, this reveals two basic positions that can be used to distinguish the rationale behind different concepts of integration. The first takes the human needs as a basis, emphasizing resource use, waste production and pollution of the resource and the setting of development priorities. The second takes the needs of the natural system as a basis, emphasizing ecosystem structure and processes that determine the availability and quality of water resources (Endter-Wada et al. 1998). These perspectives coincide with basic value systems (also referred to as 'worldviews', or 'ethical approaches'; Grumbine 1994; Hull et al. 2003).

The human viewpoint takes that goods and services of ecosystems (tangible or intangible, short and long-term) are needed by society and are appropriable to man. It includes the assumption that ecological systems are resilient to resource use. The natural viewpoint considers maintenance of ecological health or integrity as the principal goal (Vugteveen et al. 2006), and generally assumes that human influences are detrimental to ecological systems. All other aspects, including man's use are of secondary consideration.

The aforementioned perspectives have been used to structure Table 1, which presents a list of key concepts and covers the current understanding of IWM in scientific literature. Although a detailed review of the literature on all water management approaches is beyond the scope of this article, the table provides a concise overview of the diversity and characteristics of existing concepts.

It is argued here that the two viewpoints underlie two major lines of research and conceptual development regarding IWM. In this article these lines of research will be referred to by the generic terms *resource management* (human system perspective) and *ecosystem management* (natural system perspective).

Resource management approaches generally focus on water planning and development, in which the different needs and requirements of society (often economic) towards the environment are central. Its conceptualizations are strongly associated with a school of thought that adheres to concepts of sustained yield, reflecting an economic, utilitarian belief that human consumption is the focus of management; the purpose of resource management should therefore be to provide a continuous supply of market-oriented goods (Cortner & Moote 1994). This traditional belief has its roots in the progressive era of industrialization (first half of the 20th century), and places emphasis on human welfare and comfort. The people-

Table 1. Key concepts in literature with relevant aspects

+ & - symbols indicate (degree of) emphasis on either perspective (HV/NV – Human-/ Natural Viewpoint).

Concept	**Reference**	**Aspects**	*Position*	
			HV	*NV*
Co-management	(Carlsson & Berkes 2005)	- deliberation - joint learning - negotiation - governance	++	-
Integrated Natural Resource Management (INRM)	(Gottret & White 2001; Merrey et al. 2005)	- poverty reduction - food security - environmental sustainability - sustainable livelyhoods	++	+-
Integrated Water Resource Management (IWRM)	(GWP 2000; Jønch-Clausen & Fugl 2001)	- coordination - economic efficiency - social equity - environmental sustainability	++	+-
Integrated Environmental Management (IEM)	(Margerum 1999)	- stakeholder collaboration - public involvement	++	+
Interactive Water Management	(Van Ast 1999)	- interactive dialogue watersystem & society - active participation - adaptive approach to ecosystem processes	+	+
Integrated River Basin Management (IRBM)	(Gilman et al. 2004; Jaspers 2003)	- coordination stakeholder interests - maximize (longterm) social & economic goals - maintenance native biodiversity	+	+
Adaptive water management	(Hunt 2000)	- flexible management responses - learning cycle - monitoring ecosystem responses	+	++
Ecologically Sustainable Water Management	(Richter et al. 2003)	- ecological integrity - maintaining intergenerational human needs	+	++
Ecosystem management	(Grumbine 1994; Sparks 1995)	- ecological integrity - maintaining viable populations & ecological processes - accomodation human uses	+-	++
Adaptive Environmental Assessment and Management	(Grayson et al. 1994)	- system dynamics - fundamental variability	-	++

centered approach of resource management explains the broad number of elaborations in the context of developing countries, where it is often linked with a sustainable development agenda and used as an umbrella concept to frame applied technological approaches on hydraulic engineering and technologies for monitoring and remediation, irrigation and drainage. The focus of elaborations thereby lies on incorporating multiple aspects of natural resource use into a system of sustainable management to meet explicit production goals (of farmers e.g.) and other uses (e.g., profitability, risk reduction). As expressed in the Integrated Water Resources Management (IWRM) concept, such goals can be pursued through cross-sectoral planning and involvement of all stakeholders across different management levels (Jønch-Clausen & Fugl 2001). Broader community goals as considered in the Integrated Natural Resources Management (INRM) concept, like food security and environmental quality (Gottret & White 2001), might be best pursued through a livelihoods approach set at the heart of the concept, as Merrey et al. (2005) argue. This latter approach takes improvement of livelihoods and stresses the empowerment of (poor) people, reduction of poverty and promotion of economic growth as basic objectives. In general, the development of resource management increasingly shows acceptance of participatory approaches instead of expert-based approaches. Stakeholder involvement in planning and consideration of local knowledge are examples of current focal issues in resource management approaches. For example, Carlsson & Berkes (2005) consider empowerment of local users to be especially important for solving current resource management problems and therefore propose the use of the concept of co-management, an approach that centralizes partnerships and power-sharing arrangements.

In contrast to resource management, the conceptualizations of *ecosystem management* reflect a natural viewpoint. Thereby the focus is on preserving and protecting the health and/or integrity (see Vugteveen et al. 2006) for notes on these concepts) of the natural system, stressing ecological function and balance. Human use of resources (or ecosystem services) is allowed within the limits of ecological carrying capacity (environmental sustainability). This school of thought is associated with ecological concepts and ecocentric beliefs (see below) and has become increasingly dominant in water-related science with the advent of the environmental movement, when the language and logic of especially ecology began to empower the management agenda (Cortner & Moote 1994; Hull et al. 2003). As defined in the ecosystem management concept, management should integrate scientific knowledge on ecological relationships within a societal (values) framework to protect ecological integrity over the long term (Grumbine 1994). Thereby the preservation of ecological integrity is considered necessary to maintain so-called ecosystem services. The latter represents the natural end of resource use and refers to a wide range of conditions and processes through which natural ecosystems (and the species that are part of them), help sustain and fulfill human life (Daily et al. 1997). A concept such as ecologically sustainable water management (Richter et al. 2003) focuses specifically on how to sustain and protect these benefits. Given the complexity of ecosystems, the procedural approach to attain ecosystem management goals should be adaptive (Hunt 2000). In a conceptual sense, adaptive management recognizes that our knowledge of ecosystems is incomplete and management should be used as an ongoing process to gain further understanding of our impact on complex systems. This is done by viewing projects as a sequence of experimental designs and using the results of each experiment in a learning process to improve subsequent designs (Grayson et al. 1994). Hunt (2000) extends this concept by claiming that managers should adjust their actions not only in response to ecological conditions but to social and economic conditions as well.

The concepts of resource and ecosystem management reflect two major schools of thought on water management based primarily on a distinction between their different viewpoints on human use of the natural system. Though purposefully set apart in the text above for characterizing the existing diversity in approaching water management, the table shows that most concepts do not adhere strictly to either one perspective. In the current scientific arena there is general consensus that best management practices cannot be solely based on optimizing consumptive uses (Cortner & Moote 1994). Furthermore, increased scientific understandings of human-ecological relationships concerning human welfare and sustainability of ecological systems have made it imperative to rethink the ways of managing water resources in accordance with ecological stewardship and social equity. For example, though Gilman et al. (2004) take a natural system perspective by contending that maintenance of native biodiversity should be a prerequisite in Integrated River Basin Management (IRBM) (and not a mere stakeholder interest), they also explicitly state that this should serve to realize human use goals.

The way the relation between society and the natural system is conceptualized (in terms of resource use) is strongly guided by its underlying system perspective, which relates to how systems are thought of in terms of connectedness, i.e. the linkages among the components as well as the context of the entire system. This ‘systems thinking’ has changed over time and has come to include holistic viewpoints, which add that complex systems show emergent properties that can only be understood within the context of the larger whole, arising from the interactions and relationships among the parts (Holling 2001). Thereby the ‘hard’ system (based on physical laws) is a subsystem of the human constructed system definition, the so-called ‘soft’ system (Checkland 2000) that arises from the images and interpretations of reality by members of the system.

The concepts in Table 1 take different system perspectives. Ecosystem management approaches are clearly associated with the eco-centric paradigm. This paradigm is apparent within the field of ecology, where ecosystems are considered the major structural and functional units. This paradigm has been a primary driver for scientific activity in water management, offering a broader, synthetic approach to deal with complex societal issues than the ‘traditional’ reductionist, analytical approaches.

Though concepts such as adaptive water management and IRBM clearly emphasize the conditions in the ‘hard’ system as the basis for management action, they take more to the holo-centric paradigm than the eco-centric paradigm since they recognize the plurality of stakeholder interest (including the interest of the natural system) to define management actions. This is also true for INRM and IWRM. Co-management is a typical example of a concept that fully takes to the holo-centric paradigm. It emphasizes the ‘soft system’, arising from contextual relevance, participation in planning and decision making, responsive and reflexive practice. The holo-centric paradigm has evoked new styles of approaching water management that centralize the consideration of the contributions and perspectives of all users, planners, sciences and policy-makers, and the promotion of communication between different public and private stakeholder groups as well as the wider public (Jeffrey & Gearey 2006). Participatory procedures, defining management as an outcome of ‘dialogues’ between all participants, are main elements in this management approach. An example of such a concept is *interactive water management* (Van Ast 1999). In this concept, the water policy agencies are in a continuous interactive dialogue, both with the water system and the societal system. In a sense, this comes down to combining the concepts of adaptive management and co-management. Similar notions are also articulated in the concept of Integrated Environmental Management (IEM). Margerum (1999) uses the term to refer to a whole array of integrated management concepts, including IWRM and IRBM, arguing that it is the most inclusive term. Like Van Ast (1999), Margerum (1999) also emphasizes the role of interaction and coordination (by stakeholder collaboration and public participation), suggesting that interaction is not just an important part of IEM, but the key operational component for achieving integration.

Overseeing scientific developments, the theoretical framework that supports IWM is broad and fully in development. One-sided ecosystem or resource management perspectives are abandoned and more expression is given to the need to include ‘soft’ relations within the holo-centric paradigm, defining management in the context of social networks. Interdisciplinary disciplines such as conservation biology and ecological economics play an important role in synthesizing natural and social knowledge within management perspectives. Worth mentioning is the current rise of disciplines such as ‘civic science’ (Cortner 2000; Plummer 2006) and ‘public ecology’ (Robertson & Hull 2001). The connotations ‘civic’ and ‘public’ indicate that such disciplines seek to bring science closer to society by integrating policy and scientific dimensions.

The general observation is that no scientific consensus exists on the conceptual rationale behind IWM. Conceptual definitions are not unambiguous and leave ample space for interpretation (and therefore misunderstanding). Multiple authors have observed that the range of opinions on IWM is wide, leading to critical discussions in the scientific community on the meaning and scope of these concepts (Biswas 2004; Downs et al. 1991; Gilman et al. 2004). For example, in a critical paper, Biswas (2004) asserted that the IWRM concept as defined by the Global Water Partnership is currently unusable and not implemental in operational terms as most basic social, economic and environmental goals are implicit in its definition. Overseeing available literature on integrated management concepts, papers generally provide reasoning for integrated approaches and include general conceptual discussions on how to practice integrated management, sometimes including narrative case studies. However, it was found that the category of empirical research that gives context and order to theories in IWM, allowing case studies to be analysed and compared rather than presented anecdotally, is generally lacking. These observations have been made earlier by Margerum & Born (1995) in relation to IEM but apply generally to IWM as well.

3 Development of IWM in Dutch policy setting

After the previous section has shown the scientific scope of IWM to be diversified, this section will look into the framing of IWM in a national policy setting, in this case Dutch water management. The purpose of the section is to show how (thinking on) IWM has developed, indicating the elements of integration that have come to be included in the strategy over time.

We have limited the selection of policy documents to key documents with formal status in order to keep the overview tractable as well as informative. Extended historical overviews of development of water management have been addressed by other authors (e.g. Disco 2002; Van der Brugge et al. 2005).

Key policy documents

Table 2 gives an overview of key policy documents and their primary elements of integration that have contributed to the transition of traditional water management to IWM in the Netherlands. These elements can be attributed to three main aspects, i.e. (i) the physical water system, (ii) societal interests and (iii) control and administration. As shown in the table, IWM development in the Netherlands is captured by six main policy documents. This main strategic framework has been shaped over time by different preparatory documents and given direction by documents that elaborated on focal aspects of water policy.

Overlooking the table it can be seen that different elements of integration have been emphasized or added in policy documents over time. Hereby attention seems to have shifted from a focus on systemic aspects to control and administration. The transition from technical and quantity-oriented sectoral water management to IWM began with the appearance of the First Policy Document on Water Management (1968), which recognized the need for a more coherent water policy, but specified this mainly from a water quantity perspective focused on balancing the interests of public water supply and agricultural use.

The approach in the next Policy Document on Water Management, in 1985, differed significantly from the first and was a response to the growing environmental concern in the seventies (embodied by The Club of Rome report ‘Limits to Growth’, which prompted thinking on the negative impacts of humans on natural systems). Also, it was a response to an unusually hot summer in 1976, in which not only the quantity but also the quality of available freshwater had dramatically deteriorated (Disco 2002). The Second Policy Document gave attention to the coherence between surface- and ground water, as well as its quantity and (physico-chemical) quality, and introduced a system analytic approach to water policy. One could say that turning into the 1980s the awareness of the need for integration was rising, having its main focus on the integration of quantity and quality management. The publication of the policy memorandum “Dealing with water” (V&W 1985b) is generally seen as the turning point in Dutch water management thinking as it defined the basic strategic principles of IWM (De Jong et al. 1995; Van Ast 1999). In this memorandum, ecological aspects were added to the system analytic approach. This resulted in the adoption of the so-called ‘water systems approach’ as a basis for an integrated water policy. As defined in the memorandum, the approach embeds the physical system as the basis for managing the water system, thereby aiming at an integrated consideration of water-related societal functions in accordance with the potentials of the system by means of a fitted technical and legal infrastructure.

As can be seen in Table 2, the memorandum put forth an approach that incorporated aspects of the physical system, societal interest and administrative aspects. Following the strategic elaboration in “Dealing with water”, IWM was established as a policy in the Third Policy Document Water Management (1989). Here, integrated water management was defined as ‘a form of coherent policy and management by the different governmental bodies with strategic tasks and management tasks in the area of water management from the perspective of the water system approach’. With regard to policy, the water system approach referred to internal functional coherences (relations between quantity- and quality aspects of surface and groundwater) as well as external functional coherences (relation between water management and other policy domains like spatial planning). The Third Policy Document elaborated on the performance of IWM in terms of objectives expressed as ‘target images’. The policy document defined these target images mainly in terms of physical-chemical standards for water quality and elaborated on the necessity for horizontal harmonization (i.e. between policy areas) and vertical harmonization (i.e. between tiers of governmental bodies) in administrative control. Explicit in this policy document, the physical object of management changed from single parts of the water system (main bodies of surface water) to include the whole water system as a unit, including relations to groundwater and banks. Demarcation of management objects was no longer based on functional criteria (i.e. relating societal uses) and restricted to mere physical aspects of the water system, but shifted to include ecological criteria extending to physical, chemical and biological aspects of the system. The establishment of the water system approach further meant that the separate tracks within overall water management of demand-oriented water quantity management on the one hand and effect-oriented water quality management on the other were combined into supply-oriented and source-oriented management of quantity and quality altogether. The supplementary Evaluation document (RIZA & RIKZ 1993) to the Third Policy Document extended and refined the set target images and, similarly as the Third Policy Document, in essence related to IWM in terms of being a policy objective.

Internationally, since publication of the Brundtland report (Our Common Future) in 1987, sustainability thinking had started entering environmental policies. With the appearance of the Fourth Policy Document in 1998, IWM was no longer perceived as a policy objective but as a process for planning sustainable measures. Extending the water systems approach, the Policy Document emphasized the catchment approach, referring to region-oriented management that fits with the natural (hydrological) dynamics and boundaries of the water system.

The catchment approach meant a strategic shift. Although management of the water system was first directed at specific uses and basically guided by economic growth, policy now established the recognition that use of the system needed harmonisation of functions within the boundaries of the systems ecological and hydrological resilience. This latter view was a departure from the traditional approach to land and water management (‘heightening dikes’) and had consequences for future spatial planning considerations in the river system. The new approach was prompted by the near floods of 1993 and 1995, an awareness that was further raised by the high water discharges of 1998 (Van Stokkom et al. 2005).

Table 2. Key policy plans in development of water management and their primary elements of integration

Different shadings are used to indicate developments pertaining to the system, interests, and control & administration. European WFD is included since its policies are obligatory for Dutch water policy.

			System			
Year	***Main policy documents***	***Preparatory and/or partial***	System analytic approach	Quality /quantity	Vertical connectivity	Longitudinal connectivity
1968	*First Policy document Water management* [1]					
1975		*Indicative Long-range Programme Water I, II, III* [2]		▨		
1984	*Second Policy document Water management* [3]		▨	▨		
1985		*Dealing with Water* [4]		▨	▨	
1989	*Third Policy document Water management* [5] *INCLUDING:*			▨		
1993	*Evaluation Third Policy document Water management* [6]			▨	▨	
1997		*Room for the Rivers* [7]				▨
1998	*Fourth Policy document Water management* [8]					
2000		*Water Framework Directive* [9]		▨		
2000		*Dealing with water differently* [10]				
2000	*Fifth Policy document Spatial Planning* [11]					
2003		*National Adminstrative Agreement Water* [12]				
2004		*Policy document "Space"* [13]				
2004		*Integration Waterlegislation* [14]				

[1] *Rijkswaterstaat, 1968*
[2] *VROM, 1975-1985*
[3] *V&W, 1985a*
[4] *V&W, 1985b*
[5] *V&W, 1989*
[6] *V&W, 1993*
[7] *V&W & VROM, 1997*
[8] *V&W, 1998*
[9] *European Commission, 2000*
[10] *V&W, 2000*
[11] *VROM, 2000*
[12] *National Administrative Agreement, 2003*
[13] *SER, 2004*
[14] *V&W, 2004*

					Interests			**Control and administration**						
Water system – ecological	(region-oriented) catchment	Ecosystem functioning	Short term-long term planning (sustainability)	Environment, society, economy	User functions	Nature value of water systems	Consideration of social values in planning	Integration across policy domains	Vertically integrated management	water as structuring spatial principle	Participation stakeholders governance	Coherence of measures	Integration among assessment tools	Integration legislative instruments
					■									
						■								
					■	■		■						
		■				■		■	■					
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■			■					■				■		
■	■	■	■				■	■	■	■				
	■	■	■										■	
	■						■		■	■	■			
	■			■						■				
	■		■					■	■		■	■		
			■	■			■		■	■				
														■

As a consequence the policy guideline “Room for the River” (1997) formalized water as a ‘structuring principle’. This policy plan proposed the application of measures for conservation of the winter bedding of the major rivers and the compensation for quantitative changes in the size of the riverbed by creating new room for the river elsewhere. As such it was part of the broader policy to conserve the existing capacity of the rivers to carry water and fitted the call for region-oriented policies, as close interaction between spatial planning and environmental policies is required. Importantly for Dutch water policy, the European Water Framework Directive (European Commission 2000) has added an overarching legislative-administrative dimension to the catchment approach, defining the hydro-geographic catchment as the basic functional unit area for harmonizing Member States’ water policies through so called ‘River Basin Management Plans’.

At the turn of the millennium, the integration of water with land use and spatial planning has become more explicit and a prominent theme in the policy making process (‘room for water’). The Fifth Policy Document on Spatial Planning (2001) headed forth on the policy direction that the Fourth Policy Document had taken, adopting and elaborating ‘water as a structuring principle’ and the region-oriented catchment approach. The policy document ‘Space’ (VROM, 2004) extended the policy intentions of the Fifth Policy Document on Spatial Planning and presented a vision for the ‘integrated spatial development’ of the Netherlands, based on considering different space-demanding functions in relation to social, economic and ecological spatial values. The appearance of this policy document clearly confirmed the political emphasis on spatial harmonisation based on interactive policy strategies. The above-described direction in water management has triggered the call for an institutional and legal infrastructure that is fitted to support the current policy objectives (including EU Water Framework Directive requirements). This is exemplified by current developments of integrating existing Dutch water legislation concerning water quality, water quantity and infrastructural works into a single legislative framework (V&W 2004).

Summarizing, the development of integrated approaches in water management in the Netherlands has focused on the following elements; the water system (surface and groundwater), water quality and quantity, water policy and adjoining domains such as spatial planning, the societal system and different interests, as well as regional/national harmonization. Within this development the step to the 'water systems approach' implied adoption of the holistic eco-centric paradigm. Consequent definition of management in terms of 'serving societal functions of water systems' indicates adherence to a resource management perspective. The internationally anticipated change of future hydrological conditions (climate change) has prompted policy to focus on the spatial eco-hydrological requirements of the whole biophysical water system (catchment), necessitating regional and (inter)national harmonization in planning.

4 Discussion

Following the above analysis, the meaning of IWM at the scientific level is not associated with a single theoretical construct but with a collection of theories and approaches, which can be linked with two major schools of thought, i.e. resource management and ecosystem management. Though initially associated with system thinking and ecological functionality, integration efforts tend to be more and more aimed at including 'soft' relations, defining management in the context of social governance networks. Its practice needs learning and participation by all interests groups (Pahl-Wostl et al. 2008)

In contrast to the scientific level, IWM at a policy level was found to be foremost associated with a planning process that is multi-objective and adaptive to the political agenda, instead of being a fixed procedural framework with set principles. Different orientations towards integration over time seem related to (sudden) shifts in political focus, or political urgency (Table 2). This has been called the effect of so called 'shock events'(Wiering & Driessen 2001). For example the earlier mentioned drought in 1976 (Disco 2002) triggered political attention to water quality issues, next to the traditional attention for water quantity. Also the severe flooding events in 1993 and 1995 in the Netherlands drove the water management agenda to its current focus on spatial planning in relation to quantity management, and established a general political awareness about the issue of climate change. Currently water quality is prominent in the agenda as well because of implementation of the EU WFD. IWM at the policy level thus serves as a dynamic and functional concept for rationalizing the political changes in the management process.

Comparing the rational framing of IWM in science and Dutch policy, it shows that some basic understandings are shared, primarily concerning (ecological) systems theory. The rational framing of water management in policy made a significant change in the 1980s with the recognition of the eco-centric water systems approach and the catchment approach in policy documents (see Table 2). Making functional use of these systemic understandings, policy-makers were able to formulate co-ordinated, synthetic management objectives. Although systems thinking is a paradigmatic frame for policy as well as science, substantive understandings of system theory (i.e. what are system boundaries, what are the essential systems functions, etc.) are still evolving and debated at the scientific level (e.g. Holling 2001). Overseeing the current conceptualizations of IWM, it is apparent that the theoretical development has shifted its focus from natural system dynamics to include social dynamics, human perspectives and values. Central to this reasoning is the need to consider humans as part of ecosystems and linking ecological and social systems. Governance issues receive increasing attention, exemplified by such approaches as co-management. At the policy level in the Netherlands, the importance of involving stakeholders and creating an open policy process has been acknowledged but is still very much a ‘learning process’ according to Witter et al. (2006).

Next to holding rational claims, IWM is undeniably value-laden as it involves how we as a society deal with the natural resource of water. The analysis at the scientific level brought forward that resource management and ecosystem management hold different embedded values towards the position of humans in relation to nature. The attachment of normative, ethical claims to IWM at the scientific level, does raise interesting questions about the value perspectives (‘worldviews’) in the scientific community and how science should relate to policy. Traditionally, scientific culture is characterized by adherence to objective, value-free science, preference for technical solutions, and advancement of scientific rationality as preferred logic (Cortner 2000). This however complicates inclusion of non-quantifiable information and non-expert opinions, moving beyond technical questions, and integrating larger questions of values (e.g. ecological integrity, equity), aspects which all lay in the domain of social science.

Together, the above notions bring forward some important research issues to consider in the further advancement of IWM. This article was able to show that IWM is framed differently in science and policy but importantly, the different roles of science and policy in the framing process of IWM need further consideration. This needs a more specific definition of science and policy than taken in this article, taking into account the full institutional arena with different actors. Questions need to be directed on how to connect the sciences to policy in the pursuit of IWM, for example through civic science (Cortner 2000; Plummer 2006)). More specifically, research issues involve how knowledge should be transferred between science and policy domains as well how knowledge utilization needs to be shaped in the policy process (Hoppe 2005). Other suggestions relate to considering the practice and nature of science itself.

Exploring the literature base on IWM showed that the environmental and natural science disciplines are the main contributors to IWM concept development, especially (system) ecology. But although the importance of social dynamics is recognized from a systems perspective, it will need social science to understand and assess these dynamics. Importantly, social sciences need to be increasingly involved and challenged to contribute to IWM strategies, for example through social analysis approaches (Endter-Wada et al. 1998). As such, the social sciences can contribute to elaboration of the rising holo-centric paradigm in which water systems are regarded as the product of eco-social dynamics. Interdisciplinary collaboration between natural- and social scientists can help to further develop IWM in the light of this paradigm.

5 Summarizing conclusions

When contrasting IWM elaboration in both science and policy, it becomes apparent that IWM has a different standing in both domains; i.e. being a comprehensive systemic understanding for linking research in science versus being an adaptive approach for unifying policy objectives at the policy level. This corresponds with differences in culture between science and policy whereby the rational–analytical model dominates science and policy is driven by a bargaining-conflict containment mode (Cullen et al. 1999). At the scientific level, IWM is mainly elaborated in terms of system thinking and ecological functionality, but shifting to inclusion of social dynamic relations. At the policy level, IWM is foremost functional for framing multiple objectives and driving changes in the management process. Altogether, differences within science in dealing with the value-laden character of IWM may complicate development of the IWM knowledge base. Also difference between science and policy in framing IWM may complicate the input of scientific knowledge into the policy process. Further, advancement of IWM depends on consideration of the practice and nature of science itself and greater involvement of social scientific disciplines.

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CHAPTER 4

Stakeholder value orientations in water management

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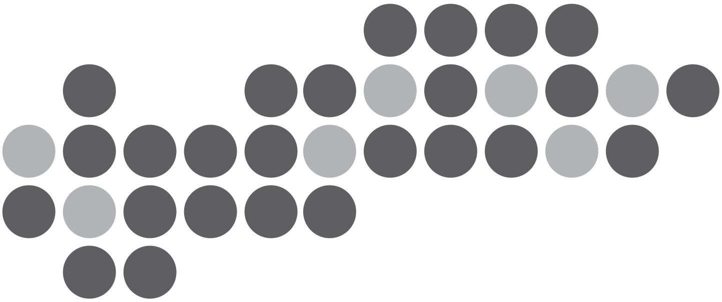

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1 Introduction

Integrated water management (IWM) is a common term for labeling strategies in water management that take into account the ecosocial complexities of the water system through a coordinated, coherent and comprehensive approach (Vugteveen & Lenders 2009).

In IWM the definition of the water system is generally broader than just referring to the biophysical system, also including the social and economic dimensions. Notions of system complexity and uncertainty (Holling 2001) and the inclusion of the “human dimension” (Lenders & Knippenberg 2005; Redman 1999) have triggered scholars in water management to propose participatory and adaptive management approaches (Blatter & Ingram 2001; Leuven et al. 2000).

The issues that water management has to deal with are complex and characterized by factual uncertainty, relating to the limits of scientific knowledge, and value uncertainty, relating to the policy process of making subjective choices. IWM approaches are trying to accommodate both, resting as such in the science-policy interface (Vugteveen & Lenders 2009). On the “factual” side, different authors have observed that, in practice, managers struggle to overcome the traditional engineering approach focused on end-of-pipe solutions, using “certain” science (based on physics, for example). Management is still inclined to take a technical “predict and control” approach, rather than a “holistic approach,” which also includes social sciences to deal with the growing (scientific) uncertainties, different stakeholder perspectives, and growing interdependencies that are characteristic of today’s resource management issues (Jeffrey & Gearey 2006; Pahl-Wostl 2002).

These observations are relevant to, for example, the Netherlands, where the supporting knowledge infrastructure for IWM was recently assessed to be still rather technocratic (NRLO AWT & RMNO 2000). Also, it has been noted that many technical experts focus exclusively on their area of expertise and pay less attention to communication and cooperation with other actors in the process (Mostert 2006). Furthermore, in line with international calls for effective integrated management processes (World Water Assessment Programme 2009), the Dutch National Commission on IWM Commissie Waterbeheer (2000) recommended involving more social sciences in research to fill the gap between policy development and policy implementation and to support truly participative policy making, as such acknowledging that beyond factual competence, good water management decisions must also be competent with regard to the existing range of values.

Thus, there is a challenge to bring facts and values together in developing and informing IWM approaches. At the scientific level of IWM, this requires scientists to bring understanding of the value orientations underlying IWM into the development of methodologies and techniques supporting IWM.

The construct of “values” has been defined in numerous ways by different authors across various paradigms; for reviews see, for example, Rohan (2000) and Hitlin & Piliavin (2004) on values in sociology and Dietz (2005) on environmental values. Following Schwartz (1999), values can be taken to be desirable trans-situational goals that serve as guiding principles in the life of a person or other social entity. They are given varying importance by people and based on these priorities, people have different sets of conscious beliefs, that is, orientations, about actual or potential realities relating to the world. Value orientation then fits what Rohan (2000) defines as a “world view”.

The main purpose of this study is to examine in what way associations of value types (value orientations) differentiate themselves among a group of different stakeholders in water management and to assess implications for the scientific support and policy context of integrated approaches. Thus, the research does not focus on developing a value typology as such, like for example, Schwartz & Bilsky (1987) have done, but aims to see how basic value types are organized into priorities relevant to the context of IWM.

To elicit these value orientations, a Q-methodology study was performed in the Netherlands; this method provides an inductive, yet systematic way of assessing the viewpoints and values of subgroups of people (Steelman & Maguire 1999). Conventional survey methods underlie much of the empirical work on values towards natural resources and these methods often use categories that the investigator imposes on the responses (Keeney et al. 1990; Satterfield 2001). In contrast to this R-type analysis, Q-methodology determines categories that are expressed operantly, that is, are communicated by the participants, and it allows analysis of the individual participant’s subjective value priorities as a whole rather than the characteristics of a population that are associated statistically (Barry & Proops 1999; Robbins & Krueger 2000).

This study adds to the few Q studies in the context of water management that so far have focused on Dutch flood management (Raadgever et al. 2008), cooperation and participation in planning (Colorado Institute of Public Policy 2006; Webler et al. 2003), waterfront aesthetics (Gabr 2004), and adverse impacts of human activities and natural events (Focht 2002).

Here we specifically focus on identifying the main existing value orientations of stakeholders within the context of IWM and how these orientations can be characterized in terms of the distinct value types that are expressed. Developing understanding of these orientations can increase awareness of existing views on IWM and as such stimulate reflection about the scientific support needed for underpinning IWM. Finally, we address the implications of our findings for the policy process of IWM.

2 Methods

Q-methodology (Brown 1980; McKeown & Thomas 1988) was used to identify stakeholder orientations and to identify latent similarities in value orientations between individuals about water issues in the Netherlands. Its application results in a taxonomy of different value orientations based on intercorrelations of individual belief patterns. Q-methodology is based on an ontology that assumes that subjectivity has a measurable internal structure that is observable in behavior, in this case the Q-sorting process. Subjectivity is conceived as the internal reference frame that a person calls upon to understand the world. Measuring subjectivity then requires responses to be collected “in the moment” when a subject expresses a viewpoint on an actual issue, a stimulus or situation (Robbins & Krueger 2000). When performing a Q-procedure, a participant maps his / her viewpoints with respect to an issue of personal importance. The research subject is presented with a set of statements about the issue, called the *Q-sample*, which he / she arranges into a quasi-normal distribution along a ranking scale ranging from, in this case, ”most agree” to “least agree.” This set of sorted statements forms the *Q-sort*. The data from the Q-sorts represent each participant’s subjective orientation of values. Hence, methodologically it “represents subjectivity.” Statistical analyses are performed on all Q-sorts in order to correlate the sorts of different participants, identify groups of participants who sort the statements in similar ways, and construct composite Q-sorts that capture the essence of groups of similar individual Q-sorts. Q-analysis differs from conventional (R-type) analysis in that the participants are the “variables,” meaning that participants are clustered instead of the statements. Finally these typical Q-sorts need to be interpreted to develop coherent interpretations of the value orientations about the issue.

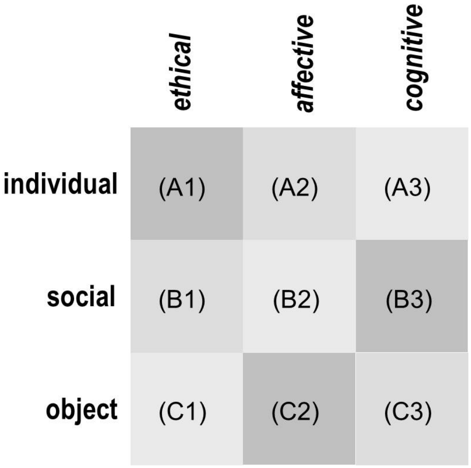
Participants

The study was performed in the context of Dutch water management, specifically freshwater management. The study population (P set) consisted of persons affiliated with different stakeholder organizations (i.e., that affect or are affected by management decisions) in the strategic arena of the management of national water bodies. Participants were purposefully sampled in order to ensure adequate representation of all stakeholder groups and cover the expected diversity of value priorities regarding IWM as such. Selection was therefore directed at obtaining a broad representation of stakeholders from different water management sectors, such as the government, different interest groups and industries. In total, 200 potential participants were approached by e-mail. Out of the positive responses we selected 56 persons for our sample based on the selection criteria mentioned earlier (18 % women, 82 % men; age range 33 to 66 years). Their organizational background included government policy bodies (national, regional and local; 10 participants), government management bodies (3 from water boards and 3 from the Department of Waterways and Public Works), universities and research institutes (8), expert consultancies (8), a civilian deliberative body on flood protection (1), cultural (2), recreational (4) and environmental organizations (7), and water-related industries, including utility companies (10).

Q-sample

For composing the Q-sample we gathered a broad range of representative statements that reflected the positions and sentiments in the Dutch discourses surrounding water systems: the *concourse* in Q-methodology jargon. The statements were derived from conference proceedings, professional literature from the scientific as well as policy arena surrounding Dutch water management, government documents, and advisory reports in which claims were made about human values and preferences towards water systems. The original Q-sample was stated in Dutch and statements were translated for this study.

The selection of statements to be incorporated in the Q-sample was guided by a 3 × 3 theoretical matrix that represented nine distinct value domains (Figure 1). The matrix aimed to ensure that our set of statements represented the broad range of possible value positions in the communication on IWM. Using the matrix this way does not predefine the outcome of the sorting process since the supposed a priori meaning of the statements does not necessarily enter into the Q-sorter's considerations when evaluating them; participants inject statements with their own understandings (Brown 1980).



	ethical	**affective**	**cognitive**
individual	(A1)	(A2)	(A3)
social	(B1)	(B2)	(B3)
object	(C1)	(C2)	(C3)

Figure 1. Matrix of value domains

To generate the Q-sample statements were categorized by linking communicated value expressions to three basic universal value types that convey the classical, philosophical questions: what is right, what is beautiful and what is true? These relate to three fundamental ways in which the environment can be perceived and appreciated, namely ethical, affective and cognitive. The ethical perspective relates to moral justifications for certain choices in water management. For example, this includes the statement “dealing with nature in a respectful way is important to me.” The affective view relates to aesthetic motives, whereas the cognitive view concerns rational, i.e. reasoned, motives (Swart et al. 2001). An example of an affective-laden statement is “I feel connected to water, it is part of me,” and a cognitive example is “people are in control of global environmental issues.” Furthermore, statements were categorized after considering the form in which values are expressed, namely at the individual or social level, or assigned to objects in the perceived experienced world of the subject (Lockwood 1999).

After defining nine value domains, four statements were selected from the concourse to represent each cell roughly equivalently. This produced a Q-sample of 36 items (4 × 3 × 3); the statements are presented later in Table 3.

Sorting

Each participant was personally visited and asked to sort and arrange the 36 items in a quasi-normal distribution grid (Table 1) according to the following instruction: *“Sort the following statements about how you see the aims and values of underlying Integrated Water Management from those most in accordance with your viewpoint (+5) to least in accordance with your viewpoint (-5).”*

The result of the sorting was a personal Q-sort, which was then recorded by the researcher along with basic descriptive data (including gender, age, highest level of formal education, affiliation, job title). Adherence to the distribution stimulated participants to express their priority views.

Table 1. Rank score distribution

	Least in accordance with my viewpoint										*Most in accordance With my viewpoint*
Rank score	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
Nr. of statements	2	2	3	4	4	6	4	4	3	2	2

Although each participant was encouraged to follow this distribution, participants were allowed to deviate from it if adhering to the distribution would misrepresent their perspective. As Brown (1980) explains, deviations from the prescribed distribution structure have no adverse impact on the statistical analysis of the data. In the present study, 11 participants deviated from the suggested distribution, most of them skewing to the positive side, placing more cards in the +1 and +2 categories. Everyone kept to the prescribed number of cards in the extreme categories (+/-4, +/-5).

After performing the Q-sort, participants were asked to formulate keywords that they personally associated with integrated water management. In addition they were asked to state what they thought to be the most important societal values of water systems. The individual answers were recorded and served as a check for the validity of factor interpretations by allowing us to compare verbally expressed views to the ones expressed through sorting.

Analysis

Five factors (i.e., specific groupings of similar subjective representations) were extracted after analyzing the 56 Q-sorts by using the software PQMETHOD. Principal components analysis and Varimax rotation were applied to determine the factors (PQMethod 2.11 2002). The five-factor solution represented the most clear and meaningful picture of the perspectives at issue after taking into account the Kaiser criterion (retaining factors with eigenvalues larger than 1), scree test and, importantly, the extent to which the solution was interpretable.

The degree to which individual Q-sorts correlate with each of the five factors (Table 2) is referred to as the amount of “loading” in Q-methodology. A significant loading indicates that the sort has a statistical probability of occurring greater than the sort occurring by chance. In our case a significance level of α=.001 was used. This meant Q-sorts with a factor loading above .55 on a factor, based on the statistical rule, *loading* $>3.29/\sqrt{n}$ *items* (where the number of items is the number of statements in the Q sample; see tutorial PQMethod v. 2.11 2002). To keep the factors as “clean” as possible, only pure loading Q sorts were selected as representative for a factor. Pure in this case means that a Q sort has a significant loading on one and only one factor, as well as having more than half of its total variance accounted for by that factor. These rules to “flag” pure sorts were based on the algorithms of PQ Method. In total, 35 Q-sorts (63%) had pure loadings on one of the five factors identified (Table 2).

Table 2. Factor matrix with factor loadings for all participants

Subject	Factor					Subject	Factor				
	1	2	3	4	5		1	2	3	4	5
1	**0.65**	-0.03	0.12	0.23	0.50	29	0.12	0.34	0.21	**0.72**	0.27
2	0.34	0.53	0.30	0.23	0.33	30	0.28	0.20	0.38	**0.59**	0.27
3	0.29	0.15	**0.60**	0.44	0.07	31	0.05	**0.74**	0.33	0.33	0.17
4	0.31	0.30	-0.04	**0.74**	0.29	32	0.29	**0.64**	0.02	-0.01	0.34
5	0.46	0.06	**0.64**	-0.16	0.37	33	0.49	0.18	0.43	0.15	0.45
6	0.13	0.09	0.31	0.03	**0.72**	34	**0.66**	0.17	0.28	0.47	0.17
7	0.23	0.23	0.28	0.42	**0.62**	35	0.23	0.38	0.37	0.30	0.39
8	0.21	0.25	0.12	**0.60**	-0.01	36	-0.04	**0.68**	0.44	0.19	0.25
9	-0.07	**0.71**	0.12	0.26	-0.23	37	**0.69**	0.07	0.33	0.44	0.10
10	0.41	0.27	0.36	0.28	0.39	38	0.42	0.46	-0.12	0.34	0.40
11	**0.59**	0.04	0.31	0.42	0.26	39	**0.77**	0.26	0.02	0.04	0.24
12	**0.66**	0.04	0.35	0.05	0.46	40	-0.02	0.24	**0.69**	0.17	0.25
13	0.41	0.10	0.20	0.36	**0.56**	41	0.28	0.42	**0.58**	0.09	0.06
14	0.22	0.15	0.53	0.32	0.39	42	0.32	0.25	0.47	0.51	-0.12
15	0.38	0.15	0.02	0.33	**0.74**	43	0.35	0.18	0.30	0.24	**0.65**
16	0.24	0.55	0.07	0.36	0.29	44	**0.62**	0.41	-0.06	0.47	0.14
17	0.49	0.33	0.16	0.41	0.50	45	0.17	**0.66**	0.26	0.41	0.20
18	0.50	0.15	0.10	0.11	0.67	46	0.41	0.32	0.28	0.55	0.27
19	0.25	-0.07	**0.63**	0.28	0.35	47	0.22	0.25	0.40	0.47	0.37
20	**0.76**	0.17	0.31	0.13	0.22	48	0.22	0.53	0.51	0.10	0.06
21	0.32	0.12	0.26	0.34	0.54	49	0.42	0.43	**0.59**	0.33	-0.10
22	-0.11	0.36	0.52	0.30	0.35	50	0.25	0.27	0.53	0.16	0.40
23	0.26	0.46	0.19	0.41	0.28	51	**0.71**	0.17	0.20	0.17	0.27
24	-0.11	0.35	0.32	**0.62**	0.40	52	0.25	0.16	0.29	0.34	**0.69**
25	0.42	0.45	0.25	0.07	0.26	53	0.27	0.02	0.14	**0.73**	0.44
26	0.39	0.37	0.04	0.18	0.55	54	**0.83**	0.02	0.10	0.24	0.24
27	0.16	0.30	0.34	**0.74**	0.25	55	0.43	0.32	0.15	0.13	0.48
28	0.54	0.43	0.13	0.40	0.32	56	**0.58**	0.02	0.14	0.54	0.41

Note: Statistically significant pure loadings (p<0.001) indicated in bold.

3 Results

The factors were interpreted based on the contents of the Q-sorts and the relationships among the statements. The goal of interpretation is to describe and understand the views or beliefs revealed to be held in common by persons whose Q-sorts load on a given factor. In order to determine the meanings of the factors, a "factor array" or model Q-sort was created for each factor. The factor array is a composite Q-sort calculated as the weighted average of the pure-loading Q-sorts associated with that factor, using their factor loadings as weights (Brown 1980; McKeown & Thomas 1988). The factor array represents aspects that are similar among the Q-sorts that underlie that factor. The factor arrays for all five factors are provided in Table 3. The factor analysis revealed that significant overlap in factor arrays exists, as high correlations were shown between factor scores (.42 – .72). Though participants thus gave similar rankings to a number of statements, interpretation of these factor arrays yielded five distinct value orientations, as their description and comparison will show. When referring to statements in the text we will use the following notation: #35=+4* is short for statement 35 rank ordered at "+4", and asterisks, if added, are indicative of the significance level (see Table 3).

Table 3. Factor arrays for five factors

For each statement the corresponding value domain is given in code between brackets (cf. Figure 1).

Statement		**Factor**				
#		*1*	*2*	*3*	*4*	*5*
1	From an ethical viewpoint, natural resources should be conserved, even if this means that people have to do without certain products (A1)	1	-2**	1	3	2
2	Nature has value, even if we do not use it (C1)	2	2	2	2	5**
3	If you ask me, water management is more sociology than ecology (A3)	0	-1*	0	1	-2*
4	We can never let emotional arguments play a decisive role in decisions on management measures (B3)	-3	3**	-3	0*	-2*
5	The various use functions of water should be guiding in water management control (C3)	-1	5	-1	5	-1
6	The decision-making process surrounding water should take future generations into account (C1)	4	5	5	5	3
7	The societal goal for the conservation of nature does not really appeal to me (B1)	-3	-2	-4	-3	-5
8	The river landscape possesses inspirational beauty (C2)	2	0	-1	0	2
9	We, the Dutch people, are connected to water (B2)	2	3	0	2	1
10	As a community we should stand for the equal division of the goods and services that nature offers to us (B1)	-1	0	0	2	1
11	Dealing with nature in a respectful way is important to me (A1)	3	2	3	2	5*
12	It is important that water management takes the increasingly complex field of societal processes and actors better into account (C3)	5	4	2	3	1
13	The river landscape offers people the possibility to experience personal growth (C2)	0*	-5**	-1	-1	-1
14	We should practice the ethics of stewardship towards our rivers (B1)	-1	-1	2	4**	0

15	I sometimes hear that other people go into nature, like river areas, to experience its beauty. This does not apply to me (A2)	-2	-3	-3	-2	-3
16	The fact that rivers have spiritual function is not recognized enough in water management (C3)	0	-5**	-2	-2	-1
17	I personally think that nature should be recognized in terms of a monetary value within water management (A3)	-2	2	4	-1	2
18	Being able to experience peace and quiet in nature is important to me (A2)	1	0	0	1	4**
19	I personally do not feel the obligation to protect the environment (A1)	-4	-2**	-5	-5	-4
20	As society we may be proud of the river landscape that, also by our activities, has been formed (B2)	4	0	3	-2*	0
21	It is fact that that we in general see water as a commodity in service to humans (B3)	0	1	4*	-1	-1
22	A river is most beautiful when there is nothing that reminds you to the inhabited world (C2)	-2	-2	-2	-1	0**
23	I feel connected to water, it is part of me (A2)	2	2	1	0	3
24	People are in control of global environmental issues (B3)	-2	-1	-2	-2	-3
25	Community spirit is not important when talking about the challenges that face water management (B2)	-3	-3	-5*	-4	-2
26	Water management that is focused at nature conservation is important from the perspective of biological diversity (C3)	1	1	0	4	4
27	I know for sure that technological knowledge is able to solve most of the environmental problems (A3)	-5	4	3	-3	-4
28	The environment should be protected because it is vulnerable (C1)	0	0	-1	1	3
29	It is better to speak of an individual responsibility towards environmental problems than a collective responsibility (B1)	0**	-4	2**	-3	-2
30	I have the conviction that we are safe from high water because the dikes have proved to be solid enough (A3)	-4	-3	-3	-4	-3
31	I feel part of a shared cultural identity that is connected to the landscape (B2)	3**	-1	-2	0	0
32	It is necessary to conserve some landscape parts because of the cultural-historical value that they possess (C1)	3	3	5	1	0
33	I share the viewpoint that we as a society do not need to adjust ourselves to the natural environment (B3)	-5	-4	-4	-5	-5
34	When I find myself in the river landscape I feel a sense of freedom (A2)	1	0	0	0	0
35	A river is fascinating because it is such a dynamic system (C2)	5**	1	1	0	2
36	I value a fair sharing of the joys and burdens within water policy (A1)	-1**	1	1	3*	1

Note: Statements were originally in Dutch.
*Asterisks indicate distinguishing statements for that factor. * (p<0.05); ** (p<0.01).*

Factor 1 – "Holists"

The first factor was defined by 11 Q-sorts with pure loadings (see Table 2). A rational attitude seems prevalent in this orientation as cognitive-type statements are ranked highly. This coincides with the organizational background of participants in this group, who are mainly from research- and consultancy organizations (Table 4). Persons in this factor group are labeled here as *Holists* because they value water as a physical eco-social entity at a systemic level. The dynamics of the system make the landscape fascinating (#35=+5**). The interplay between natural and social processes in shaping the landscape is part of these dynamics. This is in line with the participants' verbal characterization of IWM; participants mentioned that a systems approach to water, coherently considering water quantity and quality is central, and that the societal value of water systems lies in water being necessary for human existence (Table 4). People in this group are proud of the river landscape that is partly shaped by human activities (#20=+4), and it is part of their cultural identity (#31=+3**). Furthermore, participation of stakeholders was verbally expressed as a key aspect of the decision-making process and in agreement with the statement that water management needs to better take into account the increasingly complex field of societal processes and actors (#12=+5). There is general disagreement that technological knowledge is able to solve all environmental problems (#27=-5), which is quite striking considering the professional affiliations in this group: expert consultancy agencies and research institutes.

Factor 2 – "Technocrats"

Factor 2 had five Q-sorts with pure loadings. Factor representatives are linked to consultancy agencies (in engineering and spatial designing) and economic and recreational use organizations. Persons adhering to this value orientation expressed a technocratic, non-emotional attitude towards water systems and their management (Table 4). There is general trust in technology for solving problems associated with water (#27=+4). Emotional arguments in water management are rejected (#4=+3**) and there is denial that the quality of the river landscape offers an environment conducive to personal growth (#13=-5**). Also, they rejected the statement that spiritual functions of water systems are not recognized enough in the management process (#16=-5**). Technocrats seem to approach water management in terms of the human uses water provides (#5=+5). This was confirmed by the post-sorting questions, as participants generally expressed the view that guaranteeing multiple use functions is the principal goal of IWM and that a good weighting process is the basis of IWM. Furthermore, fulfilling primary needs of humans (like drinking water) and water as a resource were mentioned as important societal values. This utilitarian point of view was mildly supported by the fact that in relation to the other factors, “Technocrats” disagree that “natural resources need to be conserved” (#1=-2**).

Factor 3 – “Producers”

Six persons had pure loadings on factor 3. Economic sectors linked to production functions (agriculture, drinking water, fisheries) and policy representatives from governmental agencies (municipalities and province) are the main representatives in this factor group (Table 4). Their discursive position expresses appreciation of the multifunctionality of water systems with an emphasis on the production function of nature. It acknowledges that society sees water as a commodity in service to humans (#21=+4*) and that nature should be recognized as a monetary value in water management (#17=+4). Keywords associated with IWM emphasized the need for regarding functions in a coherent way and the importance of communication in this process. A main societal value of water systems was verbalized as the water cycle regulating and producing services for human life being conditional for direct water uses and attached economic values. Participants focused on the social aspects of water systems in their orientation. For example, community spirit was found important in order to tackle water management issues (#25=-5*). Nevertheless, this group expresses that responsibility for action towards environmental problems is expected to lie at the individual level (#29=2**). Parts of the landscape of cultural-historical importance should be conserved (#32=5).

Factor 4 – “Accountable managers”

Seven Q-sorts had pure loadings on factor 4. This factor group expressed a value orientation emphasizing ethical and cognitive values. Amongst factor representatives are persons from organizations directly responsible for managing and maintaining Dutch waters (water boards and the Department of Waterways and Public Works). This orientation acknowledges the functional benefits of the water system (#5=5), taking the ethical standpoint that these benefits should be equally shared and require good stewardship. This follows from agreement with the statement that “we should practice the ethics of stewardship towards our rivers” (#14=+4**) and that there should be “a fair sharing of the joys and burdens within water policy" (#36=+3*). Participants replied to the post-sorting questions that IWM is a process of weighing interests in a coherent way, for which responsibility and cooperation are key, and that the aim of water management is guaranteeing water(systems) of "good quality" for society. Part of this is maintaining biological diversity (#26=+4).

Factor 5 – "Environmentalists"

This factor is defined by six participants loading purely, expressing a value orientation that centers on individual ethical values towards nature. Main representatives of this group were affiliated with environmental nongovernmental organizations (NGOs), as well as governmental representatives from the Ministry from Agriculture, Nature and Food Quality and a water board as well. People in this group, labeled *Environmentalists*, feel a strong personal bond with nature in general. The intrinsic value of nature is acknowledged, independent of our use of it (#2=+5**). A respectful attitude towards nature is regarded as highly important (#11=+5*), as is being able to experience peace and quiet in nature (#18=+4**). Nature conservation is an important societal goal (#7=-5) from the perspective of maintaining biological diversity (#26=+4). Sustainability and multidisciplinarity were mentioned as key principles for IWM, and multiple participants mentioned that non-anthropogenic, ecological values should be the point of departure for management. This was also expressed by the denial that water management is more sociology than ecology (#3=-2**).

Consensus amongst factors

Some statements did not distinguish significantly between any pair of factor groups, thus expressing consensus amongst factors. Consensus was shown amongst all participants that as a society we need to adjust ourselves to the natural environment (#33). Furthermore, although less characteristic (i.e., lower ranking of the statement), all participants disagreed that society is in control of current global environmental issues (#24). This belief is related to participants' disagreement with being safe from high waters because the dikes have proven solid enough to prevent flooding (#30). At another level, recognition of the value of nature was demonstrated by the consensus statement that people like to go into nature to experience its beauty (#15).

These statements together indicate a consensus that, due to lack of control over current environmental changes and their potential consequences (like flooding), people need to alter their behavior to accommodate or counter these changes.

Table 4. Overview of factor group arrangements

A Dominant value types in matrix as shown in Figure 1 - indicated in dark grey and considered dominant if the average rank score for four statements was larger than 3;

B. Organizational background - intra-factor percentages (sums to 100% within a factor) based on pure loading participants ($\%^{in}$), inter-factor percentages (sums to 100% over all factors) ($\%^{it}$) are based on dominant loadings (sign. + non-sign.);

C. Verbally expressed IWM keywords and associated societal values, mentioned more than once.

	Holists (n=11)		**Technocrats** (n=5)		**Producers** (n=6)		**Accountable Managers** (n=7)		**Environmentalists** (n=6)	
A. ***Et* *Af* *Co*** ***Ind*** ***Soc*** ***Obj***	□□■ □□■ □□□		□□□ □■□ ■□■		□□■ □■■ ■□□		■□□ □□□ □□■		□■□ □□□ ■□□	
B.	$\%^{in}$	$\%^{it}$	$\%^{in}$	$\%^{it}$	$\%^{in}$	$\%^{it}$	$\%^{in}$	$\%^{it}$	$\%^{in}$	$\%^{it}$
Experts (n=16)	**73**	**56**	60	31	0	0	14	6	17	6
Env. NGO's (n=7)	18	43	0	0	0	0	0	0	**33**	**57**
Policy (n=10)	9	20	0	0	**33**	**40**	14	20	17	20
Management (n=6)	0	0	0-	17	0	0	**43**	**67**	17	17
Economic users (n=10)	0	0	20	20	**50**	**40**	29	20	17	20
Recr/cult users (n=6)	0	0	20	33	17	17	0	0	0	50
C.	- systemic coherence - quality/ quantity - stakeholder involvement - water is condition for human life		- weighing of interests - safety - use functions - goods & services		- managerial accordance - communication - condition for use		- good quality - responsibility - cooperation - weighing of interests - functional use		- multi-disciplinary - sustainability - non-anthro./ ecology values	

Note: Part B, the one participant of the civilian deliberative body was not included as it presented a single case stakeholder representative.

4 Discussion and conclusions

This study relied on Q-methodology to elicit stakeholder perspectives instead of more commonly used survey techniques such as questionnaires. The approach is mixed in the sense that it combines a qualitative way of studying subjective perspectives with the statistical rigor of quantitative research techniques.

The method allows replicability even with the relative small sample size used. If the same operational instructions are followed during repeated application of the Q-method with other individuals from the same study population, then the factors identified after analysis of the Q-sorts should be similar and provide an accurate reflection of the broad spectrum of discursive positions that exist within a larger population (Doody et al. 2009).

Q provides statistically significant results from a relatively small sample size (56 in this study) in comparison to an R-type analysis that requires (larger) statistically representative sample sizes of the population of interest in order to generalize. The results of a Q-methodological study are used to describe a population of viewpoints emphasizing individual subjectivity, whereas R describes the percentage of the general population that adheres to any of these viewpoints.

Using the theoretical matrix (Figure 1) for structuring selection, we were able to retrieve a set of statements covering the valuation discourse on (the management of) water systems in nine basic value dimensions. We did this by using an elementary scheme with basic value distinctions (Lockwood 1999; Swart et al. 2001) that was shown to be well applicable to structure the concourse, enabling a manageable and relevant Q sample for exploratory study.

In our study we were able to identify five value orientations that represent characteristic ways of valuing and viewing water systems and their management by stakeholders. Table 4 shows that the expert-dominated group of *Holists* was directed at the ecosocial aspects water systems in terms of their dynamics and associated landscape. In contrast, *Technocrats* adhered to a “traditional” view on water management with a focus on user functions and technical control of the water system. The group of *Producers* comprised stakeholders from different economic sectors who especially emphasized the use value of nature that can be exploited economically. On the other hand *Accountable Managers*, including governmental managing bodies, put more emphasis on the social-policy aspects of water systems and management, highly valuing a fair division of responsibilities and stewardship. Finally, the *Environmentalists* show a clear orientation emphasizing a personal relation with nature and expressing an ethical “protective” standpoint to dealing with nature, based on an intrinsic value of nature. Though more characteristic of this factor group, an ethical position expressing care for nature and the ideal of sustainability (#11, #6) was shared in all factors. This ethical stance, along with an awareness of the need for an adaptive strategy in management (see consensus statements), is in line with the observed “ecological turn” in Dutch water management (Disco 2002) and reflects the current shift in thinking about water management changing from “fighting water” to “accommodating water” (Van Stokkom et al. 2005). Preferences regarding the outcome may differ, however, between stakeholders due to divergent value orientations, as exhibited for example by the contrasting beliefs of Technocrats and Environmentalists. Findings of Raadgever et al. (2008) are in line with this observation, as they found a prevalence of technocratic thinking in terms of flood prevention by engineering still present amongst expert stakeholders, despite the mentioned “ecological turn.”

Compared to other studies regarding environmental attitudes, for example Schultz (2001) and Gagnon Thompson & Barton (1994), our analysis involved a scope of values extending beyond environmental values in a strict sense, relating to beliefs about technological knowledge and cultural identity, for example. As such the perspectives are more akin to “world views” (Rohan 2000), considering a broader range of human values. An advantage of Q is that it explores the association among values instead of the levels of agreement or disagreement with single values (Robbins & Krueger 2000). Such an analysis has added value in the field of environmental management studies as understanding discursive positions of stakeholders, and especially the assocation between value priorities enables decision makers to bring more nuance in negotiating management solutions.

Our study showed the elicitation of ethical and affective value priorities in terms of different orientations. For example, *Holists* and *Technocrats* differed in their beliefs about the role emotional arguments should play in water management. Furthermore, *Environmentalists* differed from the other groups in their explicit recognition of the intrinsic value of nature.

Such understandings of how associations of value types by stakeholder groups form their perceptual framing of issues and problems are relevant for the technical “factual” development of IWM approaches. Bringing facts and values together could help the advancement of IWM by producing problem solutions in which value assumptions are made more explicit and as such are more socially robust. Substantiating IWM then calls for support from scientific fields such as sociology, psychology and philosophy to bring understandings about value orientations underlying IWM into development schemes for methodologies and techniques supporting IWM. Also, the development of IWM approaches calls for initiating multidisciplinary efforts by natural scientific as well as social scientific research areas that have up to now developed rather independently with little exchange among them (Lenders & Knippenberg 2005).

At the policy level, the type of analysis used here might be useful in developing planning scenarios. For example, in a project that involves divergent stakeholders, different scenarios acknowledging the different value orientations that are present may accommodate discussions and the decision making process. In general, Q-methodology may prove valuable in the demand for morally resonant and narrative-style elicitation techniques that enable articulation of a broader range of values, such as ethical and affective values, to deploy in collective decision making (Dietz et al. 2005; Satterfield 2001) through approaches such as social learning (Doody et al. 2009; Pahl-Wostl et al. 2008). Overall, it is believed that IWM decision makers can tackle policy conflicts more successfully when not only being considerate of the divergence of value orientations among stakeholders but extending this with understandings of how value priorities are actually associated within such orientations.

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CHAPTER 5

Cross-disciplinary patterns in river science

P. Vugteveen, H.J.R. Lenders, P.A.A. van den Besselaar

This chapter has been submitted

1 Introduction

During the last decades, views on river management have significantly changed in many parts of the world moving away from a deterministic, engineering paradigm of controlling nature toward an ecosystem perspective that includes nature and the people that are part of it (Brierley & Fryirs 2008). With increasing pressures on the environment, it is generally recognized that rivers should be managed as riverine landscapes in which ecosystem values and human needs are both taken into account (Vugteveen et al. 2006). This has promoted the development of interdisciplinary approaches to coordinated and holistic management, focusing on the delivery of sustainable outcomes. It requires understanding of the systemic nature of the riverine landscape with its ecological, social, political, economic and cultural dimensions (Lenders & Knippenberg 2005; Thorp et al. 2007). The extensive range of current approaches to integrated water management (IWM) recognizes relationships between surface and ground water, water quantity and quality, land and water resources, different socio-economic uses and societal actors at multiple political and hydro-geographic scales (Medema et al. 2008; Saravanan et al. 2009; Vugteveen & Lenders 2009).

Environmental issues are typically complex, containing numerous parameters and uncertainties. Research approaches to articulate environmental problems in all their dimensions do not emerge ready-made in the middle of existing research specialties. Therefore a wide cross-disciplinary knowledge base is required to understand and solve these problems (Brierley & Fryirs 2008; Thorp et al. 2007). Recognition of system complexities and societal developments has challenged scientific research to move away from traditional discipline-driven research and reductionist disciplinary approaches to socially relevant and utility-focused research that connects research activity across societal and scientific boundaries (e.g. Gallopin et al. 2001; Kates et al. 2001)). This refers to the interaction of academics with other stakeholders to develop new understandings and multiple forms of knowledge production and with other scientists to bridge different disciplinary perspectives (Van Kerkhoff 2005).

There is widespread recognition that cross-disciplinary efforts in environmental science in general, and more specifically in water management yield substantial benefits (e.g. Benda et al. 2002; McCulloch 2007; Naiman 1999; Palmer

& Bernhardt 2006; Wear 1999). The bridging of disciplinary perspectives figures prominently on the research agenda in newly promoted fields like hydroecology, ecohydrology, eco-hydromorphology and eco-geomorphology. It has been suggested that these fields might extend beyond ecology, geomorphology and hydrology into other contributing fields (e.g. civil engineering, economics, social sciences) (Hannah et al. 2004; Thoms & Parsons 2002; Vaughan et al. 2009). Similar developments take place in other water research fields, such as coastal research (Merkx & Van den Besselaar 2008).

However, it is also apparent that interdisciplinary integration in practice is still relatively uncommon (e.g. Bond 2003; Hannah et al. 2004; Hillman 2009; Rice et al. 2010). This has been attributed to the "turbulent" boundaries among different disciplines, a qualification that is related to mutual misunderstandings of disciplinary cultures and lack of effective communication (Boulton et al. 2008). Interdisciplinary efforts tend to be perceived as being more complex for participants than traditional intra-disciplinary collaborations because participants have different paradigms and approaches (Benda et al. 2002; Cullen 1990; Petts et al. 2006).

The aim of this paper is to map the landscape of river science, and assess the extent to which river science represents a cross-disciplinary endeavor. We use the term cross-disciplinarity as a generic term for research that combines, integrates or transgresses knowledge, methods or concepts from different disciplinary origins (Merkx & Van den Besselaar 2008). Cross-disciplinary research as such covers three different types of research, i.e. multidisciplinary, interdisciplinary and transdisciplinary. Multidisciplinarity is the combined contribution of research findings from a number of monodisciplinary investigations while interdisciplinarity aims at a theoretical merging of elements of individual disciplines. Finally transdisciplinarity refers to the integration of scholarly (general) knowledge with local (application context specific) knowledge (Merkx & Van den Besselaar ; Tress et al. 2005a).

We use bibliometric approaches to describe and analyze the knowledge base of current river science, in terms of the relative positions of its contributing scientific fields, as well as the knowledge flows between those fields. We assess cross-disciplinarity in river science by drawing on a range of bibliometric indicators.

Firstly, we map river science in terms of the network of contributing research fields, by analyzing the citation relations between the relevant journals. River science may have become an (inter)discipline of its own, indicated by a set of journals with similar citation patterns. Alternatively, river science journals may be cross-disciplinary because they are found to belong to different relevant disciplines.

Secondly, river science may be cross-disciplinary because river science journals heavily cite journals belonging to different disciplines, as this indicate that river research necessitates inputs from other fields. We therefore map cross-disciplinary knowledge flows as flows of citations in this journal network.

Thirdly, we map the topical structure of the research front in river science at the paper level using similarity in terms of title words and references. Clusters of papers representing specific river research topics may be published within different disciplines, indicating that those topics are studied in more than one of the relevant disciplines. We also compare the disciplinary and topical structure of river science. We then conclude our study by discussing what the findings tell us about the development of cross-disciplinarity in river science and its meaning for integrated river management.

2 Methods and data

Document set

Science can be viewed as a communication network. Journals as well as the scientific publications in journals allow us to map these communication systems. Research fields can be represented in a variety of ways, depending on the level of aggregation (Van den Besselaar & Heimeriks 2006). Journals can be used for mapping the more global scientific landscape in terms of research fields, whereas journal papers can be used for mapping the research fronts, i.e. leading topics, within a research field. A variety of bibliometric techniques are available for this and will be used in this study. Figure 1 presents a flowchart of the methodological steps, which are briefly outlined below.

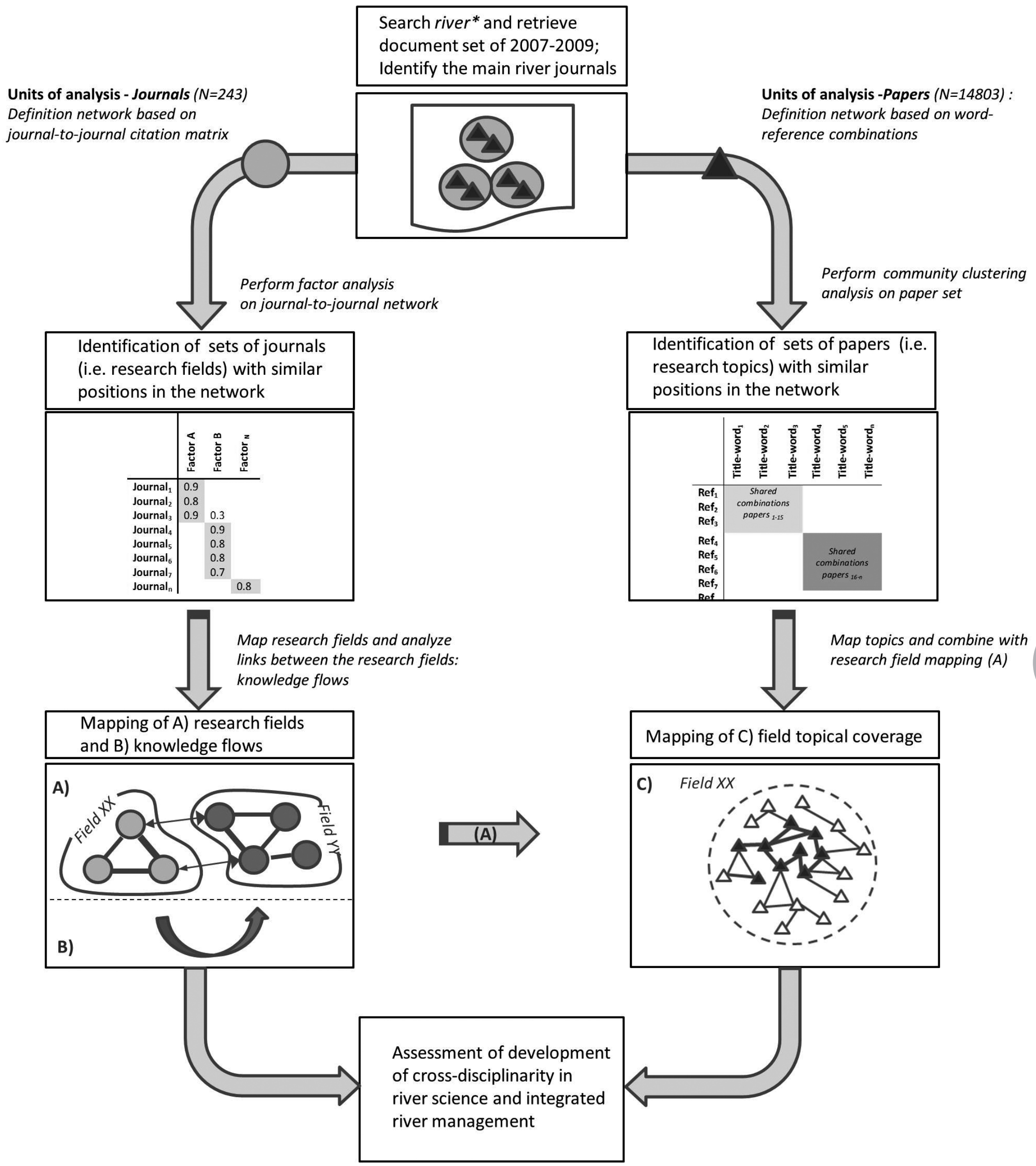

Figure 1. Flowchart of methodological steps in study

A) Mapping of research fields (Figuur 2);

B) Analyzing knowledge flows between fields (Figuur 3);

C) Mapping of topical coverage (Figuur 4).

In order to map current river research we started by using ‘*river*’* as a search term and identifying all papers indexed in the Web of Knowledge with *river** in title, keywords or abstract.[1] The search was restricted to so-called citable items: articles, reviews and proceedings papers (we use the commonly used term ‘papers’ to refer to all these document types for the remainder of the article). We searched multiple years (2007-2009) to avoid incidental citation relations. By using the simple generic search term river* we aimed for a high recall (but consequently a lower precision) of papers.

The resulting document set (N=31,869) was used to identify the core river science journals by considering those journals with the highest shares of river related papers. Table 1 shows a listing of the journals in the set that are the most strongly focusing on rivers. Core journals are defined as i) having more than 35% of their total paper output in the 2007-2009 period belonging to the *river** document set and ii) having an absolute number of at least 100 papers in the document set.[2]

Mapping research fields

Journal citation networks can be used for mapping research fields that are relevant for international river research. Using data on citations between journals research fields can be delineated as clusters of journals with similar citation behavior. The approach uses the notion that researchers in a field share a set of research questions and methodologies and refer to a largely overlapping literature. They use a common knowledge base, which is reflected in their selection of references. Con-

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[1] The use of river* may lead to a bias towards large, non-wadeable river systems and may partly exclude literature on the wadeable parts of the river system more commonly associated with terms such as ‘streams’. To test, deploying ‘stream*’ as search terms resulted in a set documents that hardly overlapped (some 10%) with the river* set. This is to a large extent because the term stream* has a much wider meaning. When restricting the stream* papers to the relevant subject areas (e.g., Environmental Sciences, Ecology, Water Resources, Marine Freshwater Biology, Oceanography, Biodiversity, Conservation, Physical Geography), the overlap increases to about 50% of the papers.

[2] Bibliometric journal maps of research fields use thresholds in order to focus on the core of the field, leaving out many marginal journals. Thresholds are also needed to keep data analysis manageable, and to avoid unreadable visual representations. However, many of the journals that are below the threshold are included in the analysis, as they do belong to the citation network of the core journals.

sequently, journals belonging to the same research field exhibit similar aggregated citation patterns and the identity of this field can therefore be mapped in terms of sets of journals with similar citing patterns. Using these citation-based communication patterns, we can retrieve the position of river science within the overall scientific landscape (Van den Besselaar & Heimeriks 2001; Van den Besselaar & Leydesdorff 1996).

Table 1. Entrance journals for the citation analysis with river research papers (2007-2009)

	Source title	River papers in document set		
		(%) share	(#) papers	(%) repres
1.	River Research and Applications	96	246	0.8
2.	Ecology of Freshwater Fish	59	108	0.3
3.	Transactions of the American Fisheries Society	48	206	0.6
4.	Journal of the American Water Resources Association	48	168	0.5
5.	North American Journal of Fisheries Management	44	192	0.6
6.	Hydrological Sciences Journal	42	105	0.3
7.	Geomorphology	41	379	1.2
8.	Estuaries and Coasts	41	119	0.4
9.	Earth Surface Processes and Landforms	41	187	0.6
10.	Hydrological Processes	40	411	1.3
11.	Hydrology and Earth System Sciences	39	163	0.5
12.	Water Resources Management	38	155	0.5
13.	Freshwater Biology	37	211	0.7
14.	Journal of Hydrology	35	474	1.5
15.	Continental Shelf Research	35	191	0.6

Note: *For each journal the table presents:*
i) the share (%) of river papers across all published papers in the journal concerned,
ii) the total number of papers and iii) the representation (%) of the journal output across the total document set.

The analysis is based on the journal network of the 15 journals with the most river research papers (Table 1). We used the 2008 CD-Rom version of the Journal Citation Reports to compile the network.[3] The network was constructed with all journals citing or being cited by the top 15 journals of Table 1. Since we were interested in structure and not in incidental citations, we removed the “noise” by discarding those journals that contributed less than 0.5% to the citations over 2008.

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[3] This is the last CD Rom version available.

A factor analysis of the matrix of 243 x 243 journals resulted in 23 factors,[4] each representing a research field. The analytical question we pose is whether one of the factors represents river science, and the other factors do represent fields that are relevant for river science, or whether the core river science journals are distributed over a variety of fields. In other words, is river science a single field or is river research cross-disciplinary and distributed across a set of distinct research fields.

Mapping knowledge flows

The next question is how the relevant river science research fields are related. Do these fields depend on each other, and how strongly? Numbers of citations between the different research fields (as represented by the factors) were calculated using the same journal-journal citation matrix. These citation relations are an indicator for knowledge flows and cross-disciplinary knowledge exchange, which can be analyzed in terms of their direction, their magnitude, and network configuration. For example, the more substantively a field is citing a range of heterogeneous other fields, the more cross-disciplinary it is considered to be.

Mapping research topics

To map the research topics within river science we selected from the initial 3-year document set only those documents (N=14,803) that were published in the journals included in the factor analysis. Researchers simultaneously select (title) words to describe their research subject and references to relate to the tradition in which they work. These title words acquire their specific meaning within the context of the cited references. We used word-reference similarities between papers (Van den Besselaar & Heimeriks 2006) to map and analyze the topical structure of river research. The more combinations of title words and

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[4] Though appearing in the factor analysis as a separate field we exclude Science Magazine, Nature and the Proceedings of the National Academies of Science from most of the further analysis of river science. These three journals have an explicit broad multi-disciplinary scope and are heavily cited by all fields, and that puts them together in a factor. However, they cannot be considered as representing a distinct research field.

cited references are shared between papers, the more similar they are. For the analysis title words were reduced to their stem, which increased the accuracy of the clustering.[5] We used the Saint tool (Somers et al. 2009) and a fast community detection algorithm (Blondel et al. 2008) to reveal 1340 clusters of topical similar papers, of which 108 have a reasonable size (defined as at least 15 papers over three years). For research topics with a social science nature we set a minimum of 5 papers.

In the final step the disciplinary structure and the topical structure of river science were compared by a superposition of the topics map on the field map. This shows the level of cross-disciplinarity of the research topics.

3 Results

Mapping research fields

The 15 entrance journals have overlapping citation environments and together span a network of 243 journals. The factor analysis of the journal citation network reveals 23 factors, representing research fields that constitute river science as well as several related research fields that provide knowledge input for river research (see Appendix, Table A1).

The factors are labeled according to the focus of the journals loading on that factor. The journal network consists of fields belonging to biology, geochemistry, environmental science (including environmental management), hydrology, and water resources research. Generally, journals load on one factor and have only a very low loading on other factors, indicating their mono-disciplinary nature. Journals that show a relatively high loading on different factors are cross-disciplinary, filling the space between the disciplines. For example, *Global Planet Change* loads 0.46 on oceanography, 0.34 on general environmental ecology, 0.47 on quaternary science, and 0.46 on climatology. *River Research and Applications* shows a typical multidisciplinary behavior as it loads moderately on more factors: 0.61 on limnology

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[5] The nodes of the network are papers and the ties between papers are based on shared word-reference combinations: Title word A, B to N are combined with cited reference 1, 2 to x to form A1, A2, …. Ax B1, B2, ….., Bx ... Nx. Similarity between papers depends on the number of shared combinations.

and 0.40 on fisheries & fish research. On the other hand, the ecology journals and the hydrology & water resource journals hardly load on a second factor, indicating that these research fields have a strong disciplinary identity.

Table 2. Core fields in river science 2007-2009

Rank	Label	(%) share	# river papers	(%) mass
1.	Limnology	37.6	1493	10.1
2.	Fisheries & fish research	27.6	1456	9.8
3.	Hydrology & water resources	27.1	2532	17.1
4.	Geomorphology	26.2	850	5.7
5.	Sediment geology	19.6	210	1.4
6.	Geochemistry	16.4	813	5.5
7.	Quaternary science	14.2	538	3.6
8.	Environment pollution	13.7	1676	11.3
9.	Marine & estuarine biology	12.1	1112	7.5
10.	Environmental management	10.8	232	1.6
11.	Water science & technology	10.5	550	3.7
12.	Soil science & agricultural water	9.6	388	2.6
13.	Geology	7.8	313	2.1
14.	Oceanography	7.8	733	4.9
15.	General environmental ecology	7.3	62	0.4
16.	Ecology	7.0	860	5.8
17.	Aquaculture	7.0	248	1.7
18.	Climatology	6.8	221	1.5
19.	Evolutionary ecology	5.9	193	1.3
20.	Remote sensing	4.2	158	1.1
21.	Microbiology	3.3	126	0.9
22.	Behavioral ecology	0.7	39	0.3
		SUM	14.803	100

Note: Document set 2007-2009 from journals drawn in the factor analysis. For each field the share (%) and absolute number of river papers across all published papers in the subsequent field journals is presented, as well as the mass (%) of the field across the river science document set.

The fifteen major river science journals (Table 1) are not concentrated in one factor but are distributed across multiple fields. Hydrology & water resources contains six of the entrance journals, fisheries & fish research three, limnology and geomorphology each contain two, and marine & estuarine biology and oceanography each include one. The citation analysis thus shows that river science does not represent a separate discipline but a multidisciplinary endeavor. Based on their share of river related papers, i.e. the degree to which the research fields contribute to river science, the first four of these five fields can indeed be considered as core fields for river science (Table 2). Based on absolute numbers of papers, hydrology & water resources ranks, as expected, highest as a major contributor to river science. Environmental pollution is also a significant field as it has a large contribution to the document set in absolute terms. River systems may be a major object, but are not not core object of research in environmental pollution, which is reflected in the relatively low amount of river papers compared to its total output. Limnology and fisheries & fish research are also among the major contributors as well as marine & estuarine ecology, the latter adding significantly to the number of river related publications.

Document set 2007-2009 from journals drawn in the factor analysis. For each field the share (%) and absolute number of river papers across all published papers in the subsequent field journals is presented, as well as the mass (%) of the field across the river science document set.

Figure 2 presents a visualization of the results of the factor analysis, and shows the way the research fields are positioned in and around river science.[6] The nodes represent journals while the thickness of the links is a measure of the degree of similarity in citation behavior between two nodes. Research fields are represented by so-called (factor analysis-based) groups of journals within the larger network. The denser the network is (and the thicker the lines), the stronger the disciplinary orientation of a research field. Figure 2 reveals groups of related fields with similar citation patterns, which may be called meta-fields:

(i) Ecological sciences, situated on the right side of the map. Ecology is in the middle, and it is surrounded by different river science fields: limnology, marine and estuaries biology, with fisheries & fish research and aquacultures clustering at the far right. Also general environmental ecology, and evolutionary ecology are in this part of the map;

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[6] Please note that this is a two dimensional map of a multidimensional space. The projection influences the distances between the fields on the map.

(ii) Geosciences, at the left of the map, including geology, sedimentology, quaternary sciences and climatology;

(iii) Environmental Pollution & Water science & technology, in the left-bottom corner;

(iv) Hydrology & Water resources, center bottom the map. The map shows that this field has a strong own citation identity; separated from the other fields and having a dense network structure.

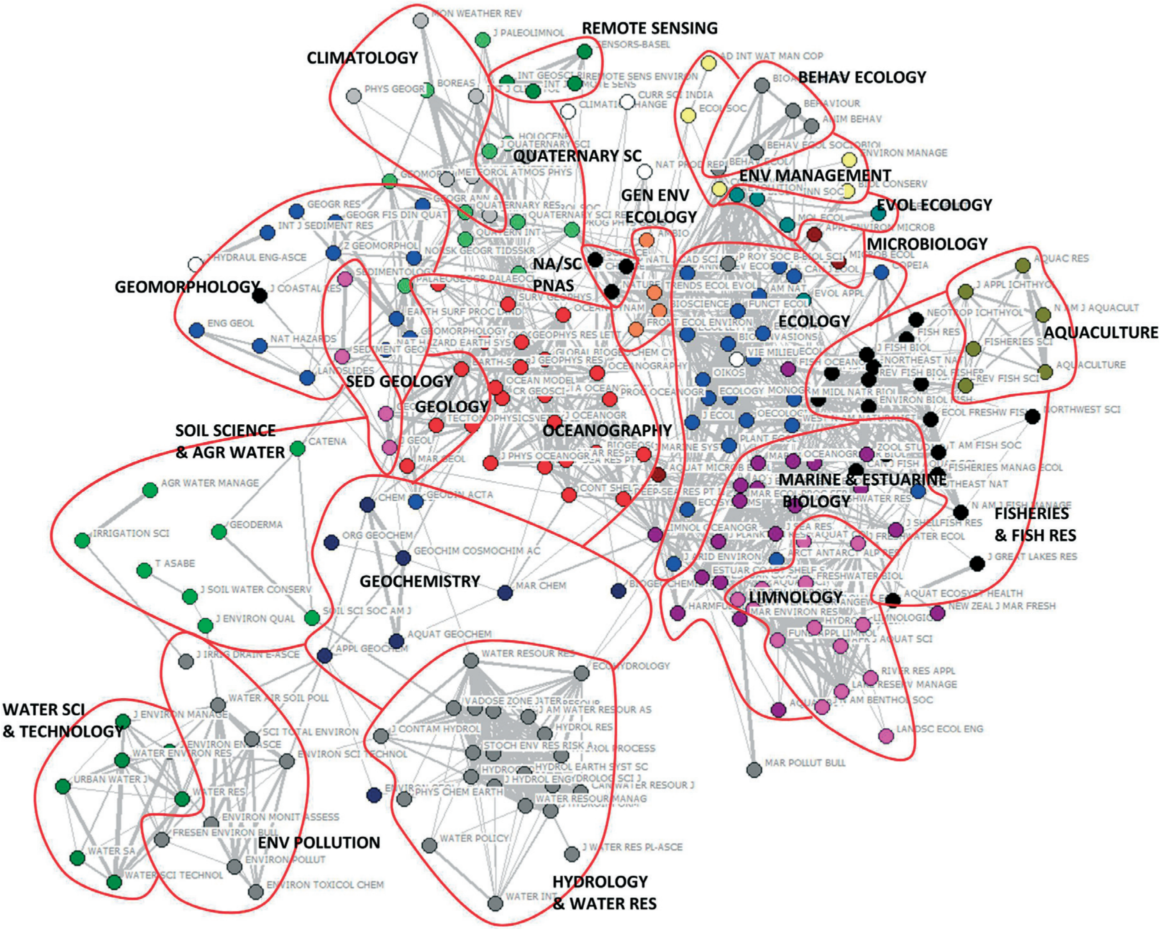

Figure 2. River science 2008 journal network

The nodes represent journals. Dense and thick links between nodes represent high similarity in citing behavior.

Several other fields that are relevant for river science can be found on the map. Geochemistry is in the center of the map, between geosciences and hydrology. At the edges we find microbiology, and behavioral ecology. In the right top, close to the Geosciences, we find remote sensing. Finally, Environmental management is in the lower middle of the map.

Concluding, river science does not constitute one coherent interdisciplinary field, but consists of a few fields in which river research has an important position. River research and main journals publishing about it are distributed across hydrology (six journals), the various ecology fields (seven journals), and geosciences (two journals).

Mapping of knowledge flows

The various research fields have mutual citation relations whereby the more field A cites field B, C, D etc., the more it depends on other research fields. The observed meta-fields that compose river science present themselves clearly when considering the knowledge flows (citation relations) between the fields. Figure 3 presents a visual representation of these relations, and Table A2 in the Appendix supplies the underlying data.

The *ecosciences* meta-field includes ecology and more specialized fields such as human environmental ecology, ecological genetics, evolutionary- and behavioural ecology. Environmental management has the strongest citing relations with ecology. The meta-field further includes aquatic ecology & biology fields such as limnology and marine & estuarine biology, and fisheries & fish research and aquaculture. Within the ecosciences the field of ecology is central and presents a so-called reference field for other eco-fields as it is being cited substantively, as well being cited by other fields throughout the whole network. Furthermore there is an *environmental pollution and water science & technology* grouping consisting of hydrology and soil science & agricultural water field and also a *geosciences* meta-field including a subgrouping of oceanography and climatology. The geosciences meta-field is quite separate from the ecosciences meta-field in which oceanography and geology present reference fields. Finally, we found *hydrology and soil water* as a fourth meta-field.

One may classify a field as cross-disciplinary when it is substantively citing a range of other fields belonging to different meta-fields. From inspecting the knowledge flows across these meta-fields it appears however that the citation relations *within* the four meta-fields are rather tight, whereas the cross-disciplinary exchange *between* the four meta-fields is much more limited. For example the environmental pollution and water science & technology meta-field does show citation relations to the eco- and geosciences meta-fields but to a very limited extent only.

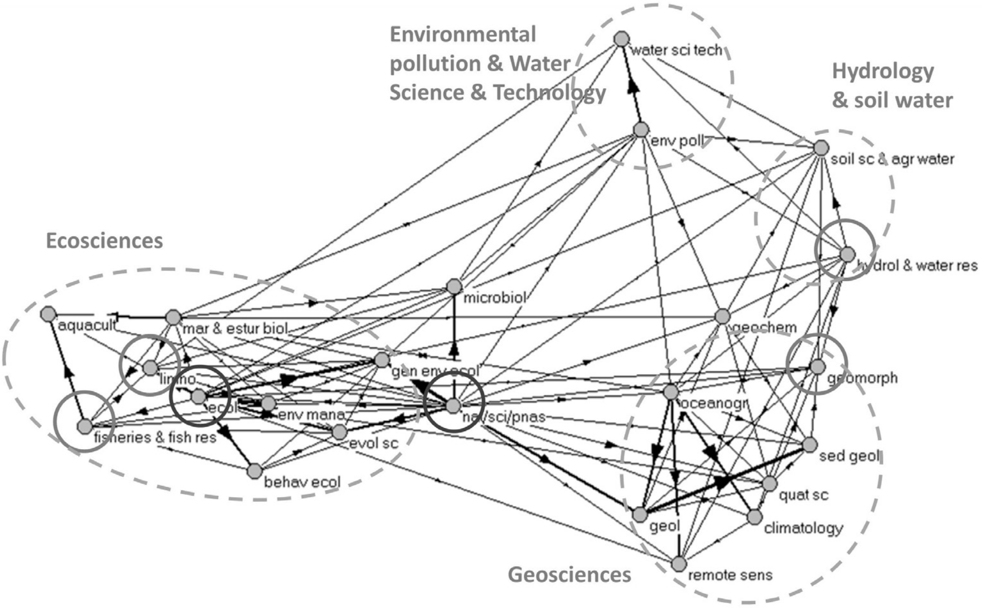

Figure 3. Knowledge flows between research fields

The nodes represent the fields. The dashed circles indicate meta-fields. Thickness of the arrowhead and distance between fields express the strength of the flows. The closer together, the stronger the mutual knowledge flows. The light gray circles indicate the four fields that include the core of river science. The dark grey circle in the center of the map indicates Science Magazine, Nature, and the Proceedings of the National Academies of Science. As expected, these journals are cited by (almost) all other fields, and therefore get a position in the center of the map. The second dark circle is the ecology field.

We have identified river science as a multidisciplinary activity within hydrology & water resources, limnology, fisheries & fish research and geomorphology. When we consider these core fields (light grey circles in Figure 3), hydrology & water resources presents a distinct research field that is mainly self-citing (60%) and has links to both the environmental pollution meta-field as well as the meta-field of geosciences. The most substantial mutual citing relation is shown with soil science & agricultural water. The citation relations with the other three mentioned core river science fields are small or absent. Limnology and fisheries & fish research belong to the same grouping – but hardly cite hydrology & water resources and geomorphology. Finally, geomorphology heavily cites hydrology & water resources (and not the other way around) but does not cite fisheries & fish research and limnology (see Table S2 for further details). In other words, the different river research fields are not strongly connected in terms of knowledge exchange.

Mapping of research topics

So far we mapped river science on a high level of aggregation: as a network of research fields, based on the relevant journals. Using the published papers as unit for mapping we now proceed by producing a more detailed map of river research. Clustering papers through *title word-cited reference similarity* we derived the main research topics in river science over the last few years, i.e. the research front. Table 3 gives an overview of the 38 largest topics out of 108 main research topics we identified in the document set.

The research topics cover fish, climate, river evolution and pollution issues. Specifically, the distribution and diversity of fish assemblages in relation to habitat changes presents a large topic in the set, followed by hydrological modeling in the context of climate change. Table 4 also shows that many major topics in river science are focusing on different forms of environmental pollution. Furthermore, topics focuses on fish migration, sediments multiple topics address systemic relations, specifically ecological and geomorphological cycles as well as hydrological interactions and dynamics.

Table 3 shows the contributing fields to the topics. It can be seen that most of the topics are the research domain of multiple fields indicating cross-disciplinary research endeavors. Some topics are explicitly the object of study for a single field, for example in environmental pollution (e.g. nos. 7 & 14), hydrology & water resources (e.g. nos. 2, 12) and fisheries & fish research (e.g. nos. 22, 24). Above, we observed that fields like hydrology & water resources and environmental pollution show high self-citing behavior suggesting mono-disciplinarity. But also the topics that have cross-disciplinary orientation remain within a single meta-field. These findings suggest that cross-disciplinary interaction across broader scientific meta-fields is limited. This is in line with the analysis of knowledge flows.

Table 3. Major river science research topics having at least 50 papers

Per topic the contributions (%) of metafields and single fields to the topical paper set (third column) is presented.

Nr.	Topics	Nr. of papers	Meta-field* (%)			
			Ecol Science	Geoscience	Hydr & Soil	WST & Poll
1	fish assemblages - habitat effects	1436	**83**	3	6	8
2	hydrol modeling - climate change	1349	5	21	**67**	7
3	river flow - fish & vegetation effects	714	**64**	15	16	5
4	salmon trout - population genetics	474	**98**	1	0	1
5	holocene river evolution	464	5	**91**	5	0
6	river sediments	318	14	**70**	11	5
7	heavy metal pollution	263	6	28	9	**57**
8	dissolved organic carbon	246	29	29	15	27
9	estuarine phytoplankton-nutrient dynamics	227	**71**	14	2	14
10	river basin weathering	200	3	**77**	14	7
11	river sediments – organic matter	186	19	**69**	2	9
12	groundwater-surface water interactions	186	20	9	**64**	7
13	river bed – transport	168	4	**57**	38	2
14	mercury contamination	166	16	17	3	**64**
15	estuarine plume modeling	152	23	**67**	7	4
16	flow modeling - artificial neural network	148	7	4	**80**	8
17	nitrogen phosphorus effects	142	**40**	19	33	8
18	polycyclic aromatics & hydrocarbons distr.	127	9	8	3	**80**
19	food web - trophic levels isotopes	105	**87**	4	0	10
20	nutrients - agricultural loading	105	16	12	**47**	25
21	groundwater – isotopes	100	7	**49**	42	2
22	salmon trout – habitat	96	**97**	2	0	1
23	wastewater treatment - pharm occurrence	81	2	0	5	**93**
24	sturgeon, green - habitat use	79	**97**	0	0	3
25	eel migration	76	**97**	1	0	1
26	water quality assessment – pollution	75	4	5	25	**65**
27	salmon trout, atlantic - migration & survival	74	**97**	0	0	3
28	river sediments – transport	72	6	33	**51**	10
29	salmon, pacific - migration & spawning	70	**97**	1	1	0
30	mekong delta - arsenic pollution	65	0	**62**	14	25
31	wastewater treatment – hormones	58	3	0	3	**93**
32	river - estuary interaction - tidal circulation	56	30	**59**	2	9
33	carbon fluxes	56	**50**	41	7	2
34	fish otolith chemical composition	54	**96**	2	0	2
35	integrated water management - social learning	53	25	0	**58**	17
36	leaf - litter decomposition	53	**91**	0	0	9
37	polychlorinated & brominated substance distr.	50	0	0	2	**98**
38	pesticides distribution	50	4	0	6	**90**

Most contributing field	Share (%)	All contributing fields (5%)**
limnology	37.7	5; 7; 9; 13; 14; 15
hydrology & water res	61.8	3; 13; 21
limnology	29.6	5; 9; 11; 13; 14
fisheries & fish res	31.9	1; 5; 8; 9; 14; 15
quaternary science	43.3	4; 11; 18; 20
oceanography	24.8	4; 11; 13; 15; 17; 18; 20
env pollution	51.7	7; 10; 21
env pollution	20.7	7; 10; 13; 14; 15; 17; 22
mar & est biol	49.3	7; 14; 15; 17
geochemistry	47.5	4; 7; 10; 13; 17
geochemistry	32.3	7; 10; 15; 17
hydrology & water res	61.3	7; 13; 14
geomorphology	44.6	11; 13; 20
env pollution	62.0	7; 10
oceanography	58.6	13; 15; 17
hydrology & water res	78.4	13
soil science	16.9	5; 7; 10; 13; 14; 15; 16; 21
env pollution	74.8	7; 15; 22
mar & est biol	45.7	5; 7; 9; 14; 15
soil science	23.8	7; 10; 13; 14; 17; 21; 22
hydrology & water res	42.0	10; 13; 18
fisheries & fish res	59.4	5; 9; 14
env pollution	65.4	7; 22
fisheries & fish res	54.4	1; 9
fisheries & fish res	55.3	9; 14; 15
env pollution	44.0	7; 10; 13; 22
fisheries & fish res	64.9	1; 9; 14; 15
hydrology & water res	43.1	7; 11; 13; 21
fisheries & fish res	45.7	5; 6; 8; 9
geochemistry	56.9	7; 10; 13
env pollution	81.0	7; 22
marine & estuarine biology	50.0	13; 15; 17
oceanography	35.7	7; 10; 15; 17
fisheries & fish res	55.6	9; 15
hydrology & water res	56.6	6; 13; 22
limnology	66.0	5; 7; 14; 15; 16
env pollution	98.0	7
env pollution	84.0	7; 21; 22

Note:

** Meta-field definition follows from identified factors (Figure 2) and knowledge flows (Figure 3). The meta-field with the highest share is shown in bold.*

*** Fields contributing 5% to the topic paper set are presented as well as the most contributing field and its respective share. Identification of contributing fields, i.e. research field representation, is based on the journal affiliations of topic papers and their respective identified factorial research fields.*

1= aquaculture;
2= behavioral ecology;
3= climatology;
4= geology;
5= ecology;
6= environmental management;
7= environmental pollution;
8= evolutionary ecology;
9= fisheries & fish research;
10= geochemistry;
11= geomorphology;
12= general environmental ecology;
13= hydrology & water research;
14= limnology;
15= marine & estuarine biology;
16= microbiology;
17= oceanography;
18= quaternary science;
19= remote sensing;
20= sediment geology;
21= soil science;
22= water science & technology

Table 4. Major social issues research topics having at least 5 papers

Per topic the contributions (%) of metafields and single fields to the topical paper set (third column) is presented.

Nr.	Topic	Nr. of papers	Meta-field* (%)			
			Science	Geoscience	Hydr & Soil	WST & Poll
1	integrated water management - social learning	53	25	0	**58**	17
2	integrated water management – allocation	24	4	0	**88**	8
3	conservation planning	19	**84**	0	5	11
4	integrated water management – governance	14	0	0	**86**	14
5	coping with floods	10	10	**70**	10	10
6	water sharing - disputes & cooperation	10	0	0	**100**	0
7	water resources – economics	8	25	0	**50**	25
8	virtual water trade	7	0	0	**71**	29
9	stakeholder water demands	7	14	0	29	**57**
10	integrated urban management: systems approach	7	0	14	29	**57**
11	planning under uncertainty	7	0	0	**86**	14
12	balancing water needs	7	14	14	**57**	14
13	EU Water Framework Directive	6	17	33	17	33
14	trading discharge permits	6	17	0	**50**	33
15	water markets	6	0	0	**100**	0
16	recreation management	5	**80**	0	0	20
17	flood vulnerability: informing policy	5	0	20	20	**60**

Despite the discussions on the relevance of social research (such as planning, management, economics) for river research and management, the fields map (Figure 2) only included one such field: environmental management. The topics list (Table 3) does not show any social science topics. By investigating the presence and nature of 'societal' research topics in river scientific output in detail, more insight is gained in the position of social science within river research. Using a title word search[7], a total of 38 different topics were identified of which Table 4 shows the major ones. These topics relate to integrated water management, planning, system approaches, water sharing & trade, and user/stakeholder perspectives.

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[7] We used an automated search on the following search terms and derivatives: agencies, cost, decision, development, economic, institution, learning, management, participant, place, planning, policy, public, social, socio, stakeholder, strategy, sustainability, user. The remaining topics were manually and visually checked.

Most contributing field	Share (%)	All contributing fields*
hydrol & water res	57	6; 7; 13; 21; 22
hydrol & water res	83	6; 13; 21; 22
env mana	58	5; 6; 14; 21; 22
hydrol & water res	86	13; 22
geomorph	70	6; 11; 13; 22
hydrol & water res	100	13
hydrol & water res	50	5; 13; 22
hydrol & water res	71	13; 22
water sci tech	57	13; 14; 22
water sci tech	57	3; 13; 22
hydrol & water res	71	13; 21; 22
hydrol & water res	57	10; 12; 13; 22
geochem	33	6; 7; 10; 13; 22
hydrol & water res	50	6; 7; 13; 22
hydrol & water res	83	13; 21
env mana	40	1; 6; 9; 22
water sci tech	60	3; 13; 22

Note:

** Meta-field definition follows from identified factors (Figure 2) and knowledge flows (Figure 3). The meta-field with the highest share is shown in bold. Social topics were identified based on “socially-relevant” title words. See legend of Table 3.*

The focus is on (integrated) water management and related topics, with clear policy relevance. Over half of the social topics are related to the field of hydrology & water resources and are published in the more general water resource (management) oriented journals such as *Water Resources Management* and *Water Policy*. Other societal topics are within environmental management and in water science and technology. Interestingly, although societal issues are being discussed in the river research literature, there is no significant reference to social science literature as no factor with social science journals was found.

Tables 3 and 4 show that some topics predominantly belong to a single research field whereas most topics are researched by a variety of fields. Differences and similarities in topical relations of research fields are further visualized in Figure 4 representing a topics map based on similarities in terms of word-reference combinations. This means that papers of similar topical scope are clustered. Related

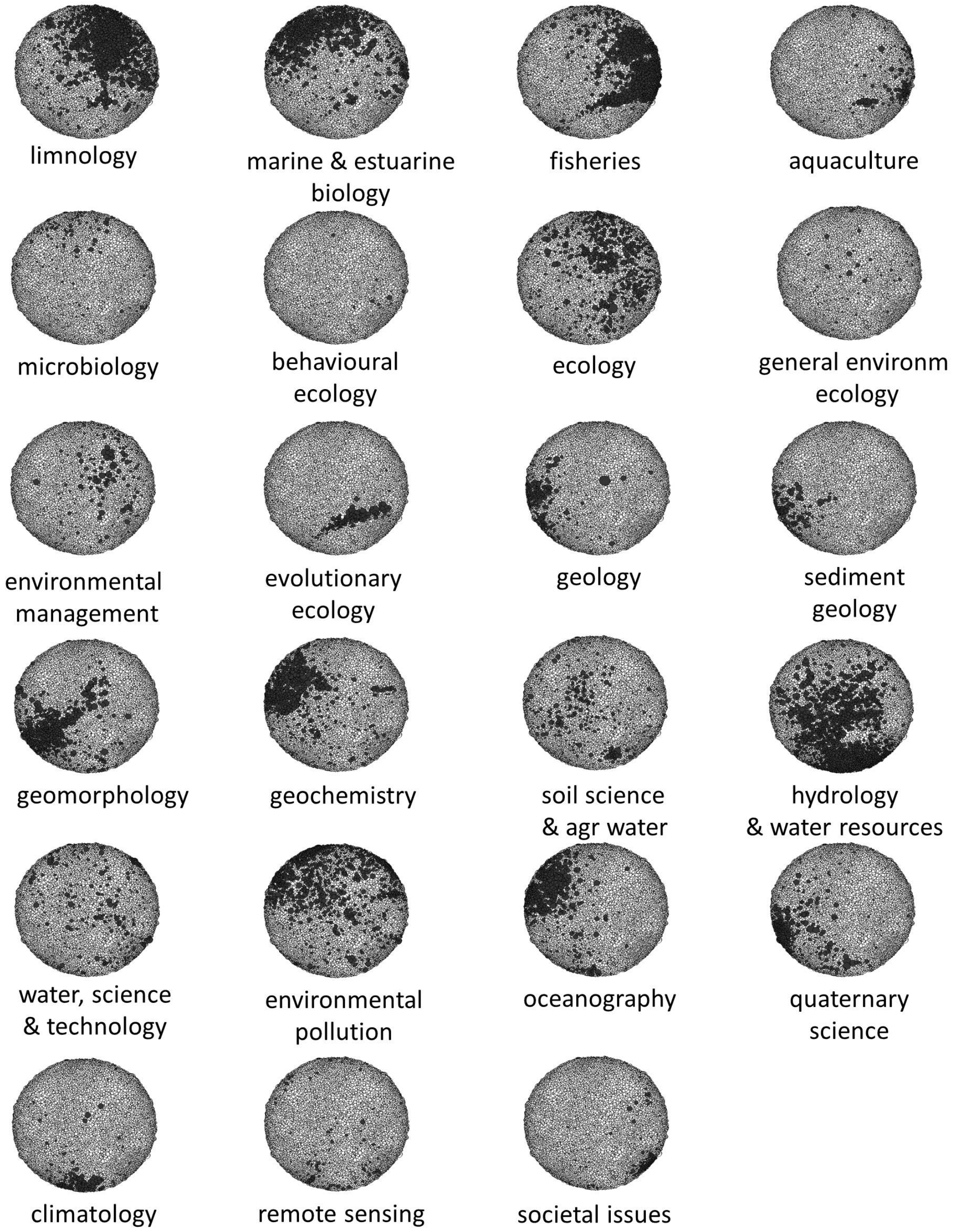

Figure 4. Topical scope of all river research fields (including societal issues)

Nodes in the figures represent papers whereby the relations between articles are based on similarity in terms of word-reference combinations. The mapping has been partitioned and colored in separate 'layers' according to the research field affiliation of the individual papers.

topics are close to each other, whereas unrelated topics are farther apart. A so-called ‘spring model’ algorithm fitted all articles into a 2D visualization, using the BibTechMon visualization tool (Kopcsa & Schiebel 1998).

On this topics map a field map was superimposed. For clarity reasons we partitioned the mapping and produced separate maps for each research field. For each field (= a set of journals) all papers belonging to the field are colored. This way of presenting and visualizing allows for comparisons between fields and it reveals that the topical scopes of research fields differ in range and structure. In some field maps, papers are concentrated indicating a more homogeneous topical structure of the field. This is true for smaller fields like evolutionary ecology and climatology. Other fields show a more heterogeneous topical structure like ecology and environmental pollution. Multi-disciplinary topics (Table 3) are indicated where colored areas in field maps show overlap. For example limnology and marine & estuaries biology partly cover the same topics.

Overviewing the complete field-configuration of the topics mapping, the previously observed division in meta-fields is recognizable again; the upper half of the mapping presents the ecological sciences with aquatic ecological science positioned at the edge and general ecology lying more to the center. Hydrology & water resources is concentrated at center-bottom and the geosciences are found at the lower left. Environmental pollution is more spread out across the ecological sciences region. As can be expected, core fields like limnology and fisheries & fish research cover a large part of the topics map of river science, along with marine & estuarine biology. Ecology itself is more heterogeneous and spread out, indicating a wide topical scope. Water science & technology and soil science are heterogeneous fields as well. Soil science and hydrology & water resources have shared topics. The link between these fields is also apparent from their mutual citation streams (Figure 3). The core field hydrology & water resources field covers a broad topical scope of research issues. Part of the field shows shared topical interest with ecology and environmental management, and geomorphology. This latter field overlaps with ecology as well. Furthermore Figure 4 makes clear that the fields of oceanography and geochemistry have considerable topical overlap. This concerns fluxes and loading of organic carbon and nutrients from river basins into oceanic systems as can be derived from the main topics in which both fields are involved (see also Table 4). Finally, the societal topics are presented in a separate visualization and it can be seen that they cluster quite strongly in a specific part of the hydrology & water research meta-field.

4 Discussion & conclusions

In this study the current scholarly output of river science was analyzed using bibliometric techniques with the aim to investigate claims and calls for cross-disciplinary research endeavors (McCulloch 2007; Palmer & Bernhardt 2006). Such a quantitative evaluation of river research seems timely given the growing body of literature expressing the need for scientific research crossing traditional academic boundaries in support of understanding and managing the social-ecological complexity of rivers (Brierley & Fryirs 2008; Hillman et al. 2008; Surridge & Harris 2007; Vugteveen et al. 2006).

Some limitations of our study are addressed here. The availability of extensive publication databases makes river science amenable to bibliometric indicators, and enables to investigate its dynamics. That leads to a study based only on research output published in peer reviewed scientific journals. Differences exist in publication traditions between scientific disciplines. In the social sciences and humanities, also books provide an important publication format whereas technical fields intensively use conference proceedings. In water related research this is about 25% (Van den Besselaar & Horlings 2010). Nevertheless, as journals are the dominant form of communicating research in river science, our analysis results in a valid representation of the field. However, including other publication types such reports, may add the application part of river science in a more detailed way. This we may address in a next study.

Secondly, this paper presents a bibliometric mapping of river science using recent data. We did not include an evolutionary perspective on river science but for this paper choose to focus on its actual state and dynamics. A longitudinal study would be needed to put our findings in the context of temporal dynamics and changes. We performed a preliminary explorative analysis in order to investigate whether important changes did take place. We factor-analyzed the 1998 journal citation network in a similar way as presented for 2008. Though slight deviations in structure there appear to be no meaningful changes between 1998 and 2008 with respect to the position of river research in the scientific landscape.

Based on tried bibliometrical indicators we found that river science is composed of four core fields: limnology, fisheries & fish research, hydrology & water resources, and geomorphology. Overall this structure confirms what other authors identified as the main components of a scientific framework for studying the biophysical functioning of rivers, i.e. river ecology, hydrology and fluvial geomorphology (Dollar et al. 2007; Mika et al. 2008; Poole 2002; Thoms & Parsons 2002).

Closer examination of disciplinary orientations and cross-disciplinary patterns showed a division of river science in distinct clusters of fields, i.e. meta-fields broadly covering biological and ecological sciences, environmental sciences, the geo- and geochemical sciences and the hydrological sciences (Figure 1; Table 3). The knowledge flows were shown to be much stronger within than between these meta-fields. This suggests that traditional disciplinary divisions between the biological, environmental and physical dimensions of river system research are still prominent. Furthermore, despite calls for cross-disciplinary fields such as eco-geomorphology, hydroecology or hydromorphology (Hannah et al. 2004; Thoms & Parsons 2002; Vaughan et al. 2009) the map of river science does not show the arrival of these fields.

Ecology was identified as a primary research field in the river science citation network and is found to be the most cited across all fields (Table 4). This suggests that the field of ecology has established itself as an authoritative knowledge reference field underlying river scientific efforts. This observation fits with an observed shift in river (management) approaches away from an engineering-based to an ecosystem-based water management paradigm (Brierley & Fryirs 2008). Indirectly substantiating this claim our observation that hydraulic engineering did not show up as a separate field in our mapping but apparently, based on a quick scan of the citation environment of hydraulic engineering journals, constitutes a citation network adjacent to what defines river science in this paper.

In a second step research topics were analyzed in order to provide deeper understanding of the research front of river science. This analysis demonstrated that although river science operates in a ‘traditional’ disciplinary mode as indicated by the field mapping, various research topics represent a combined contribution of mono-disciplinary research, which implies multi-disciplinary research efforts at the operational research level. Major topics address (Table 5) the interface of hydrology & water resources, geomorphology and ecology (Dollar et al. 2007; Poole 2002;

Thoms & Parsons 2002) and concern the study of systemic cycles, interactions and dynamics at the interface of these disciplines.

The complex societal context of riverine management issues not only asks for understanding from the natural sciences but also from the social sciences including psychology, sociology, geography, political science, economics and policy studies (Brierley & Fryirs 2008; Hillman 2009; Lenders & Knippenberg 2005; Pahl-Wostl et al. 2007; Surridge & Harris 2007; Vugteveen et al. 2006). Thorp et al (2007) - in their presentation of the International Society for River Science (ISRS) - mention social science, economics, management and policy as relevant to river science next to hydrology & water resources, geomorphology, ecology and chemistry. We analyzed whether current river science includes research beyond natural science. We did find planning and management issues to be part of river science research, through the presence of an environmental management field, and through several management related research topics mainly within the hydrology & water resources field (Table 5). The cross-disciplinary orientation of this latter field can be attributed mainly to the water resource journals, which have a broader scope than the hydrology research journals, and consider water resources in their societal context. However, river science research literature does hardly refer to social science literature, suggesting that one is reinventing the wheel instead of using what is available.

Finally, our analysis did not confirm that research on river issues in their societal context produces the type of knowledge referred to by Hillman (2009) as *phronesis*; i.e. contextual and place-dependent knowledge derived from practical experience and values at the local level and applied in a particular socio-political setting. This type of (transdisciplinary) knowledge is considered necessary to advance river management next to *techne* or applied “know-how”, as in art, craft or technology and *episteme* or “know-why”, scientific knowledge that is universally applicable. Our results thus support Hillman’s observation that claims for a paradigm shift based on the full inclusion of the three mentioned knowledge types in river management must be treated with considerable caution (Hillman 2009). Qualitative approaches to the development of river science (Van Hemert 2008; Van Hemert & Van der Meulen 2011), based on interviews and document analysis, often sketch a picture where wishes and aims dominate, and not so much the *de facto* trends in a research field. The advantage of the quantitative approach in this study is to deliver the latter.

Summarizing, when considering the dynamics of river science at the field level we see that river science presents a multi-disciplinary endeavor but does not express theoretical merging and integration of knowledge bases from individual disciplines, i.e. inter- or transdisciplinary research efforts (Tress et al. 2005b). The map of river science indicates that there is only a modest exchange of knowledge, i.e. fields hardly inform themselves with knowledge from fields outside their direct scientific domain, thus stimulating disciplinary theory development. There are however shared topics to which multiple fields contribute.

When considering the dynamics of river science at the field level, it is found that cross-disciplinary behaviour is restricted to combined mono-disciplinary contributions into joint topics. For example, the core field of hydrology & water resources emerges as a strongly mono-disciplinary field with strong self-citing and weak citing relations with environmental quality sciences, geosciences, and the ecological field. But at the same time, hydrology & water resource shares many of the identified topics with other fields (Figure 4). This signals multi-disciplinary research activities in river science.

Finally, the local and practical integration of river science in everyday engineering and social interventions may not proceed through paper based communication of research results, as we noted earlier. Other forms of interaction may be relevant here as well, such as co-researching and collaboration between researchers and river professionals and policy makers. Future research on these collaborative relations may reveal this in more detail.

Acknowledgments

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APPENDIX

Table A1. Factor analysis of the river science journal-citation environment based on ISI Data from 2008

The entrance journals are underlined with rank numbers given between brackets. Factor 12 was broken down into two smaller factors. The journals within factor 12b are different from those in 12a in that they also have moderate high loading on factor 4. Factor 7b (Science, Nature, PNAS) was separated from 7a (general environmental ecology) because the latter factor consists of journals that also load high on factor 1, whereas Science, Nature and PNAS are high level broad multidisciplinary journals.

Journal	FACTOR	ecology 1	hydrology & water research 2	marine & estuarine biology 3	oceanography 4	limnology 5	fisheries & fish research 6	general environmental ecology 7	geomorphology 8	quaternary science 9	environmental pollution 10	behavioural ecology 11	geology 12	water science technology 13	aquaculture 14	climatology 15	geochemistry 16	evolutionary ecology 17	remote sensing 18	soil science & agricultural water 19	environmental management 20	microbiology 21
ECOLOGY	**1**	0.911																				
OECOLOGIA	**1**	0.911																				
PLANT ECOL	**1**	0.899																				
OIKOS	**1**	0.898																				
ECOL MONOGR	**1**	0.876		0.306																		
J ECOL	**1**	0.873																				
WEST N AM NATURALIST	**1**	0.813					0.301															
ECOL LETT	**1**	0.808						0.37														
AM MIDL NAT	**1**	0.802																				
J ANIM ECOL	**1**	0.801										0.306										
BIOL INVASIONS	**1**	0.781																				

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
FUNCT ECOL	**1**	0.737										0.37										
ECOSYSTEMS	**1**	0.736				0.368																
ECOL APPL	**1**	0.693																			0.367	
J ARID ENVIRON	**1**	0.659																				
AM NAT	**1**	0.657										0.371						0.415				
CAN J ZOOL	**1**	0.629										0.475										
J APPL ECOL	**1**	0.619																			0.368	
ARCT ANTARCT ALP RES	**1**	0.573								0.379												
ANNU REV ECOL EVOL S	**1**	0.533						0.47				0.347						0.493				
COPEIA	**1**	0.512																				
SOUTHEAST NAT	**1**	0.459					0.379															
FOREST ECOL MANAG	**1**	0.443																				
WETLANDS	**1**	0.389				0.314																
ECOL MODEL	**1**	0.358																				
J HYDROL ENG	**2**		0.938																			
STOCH ENV RES RISK A	**2**		0.931																			
J HYDROL (14)	**2**		0.924																			
WATER RESOUR RES	**2**		0.918																			
J HYDROINFORM	**2**		0.903																			
HYDROLOG SCI J (6)	**2**		0.89																			
ADV WATER RESOUR	**2**		0.886																			
HYDROL PROCESS (10)	**2**		0.873																			
HYDROL EARTH SYST SC (11)	**2**		0.865																			
HYDROGEOL J	**2**		0.84																			
HYDROL RES	**2**		0.828																			
GROUND WATER	**2**		0.824																			
WATER RESOUR MANAG (12)	**2**		0.817																			
CAN WATER RESOUR J	**2**		0.781													0.303						
J AM WATER RESOUR AS (4)	**2**		0.764																			
VADOSE ZONE J	**2**		0.729																	0.343		
ECOHYDROLOGY	**2**	0.435	0.705																			
WATER INT	**2**		0.623																			

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
J CONTAM HYDROL	**2**	0.617								0.476											
PHYS CHEM EARTH	**2**	0.557																			
WATER POLICY	**2**	0.554																			
J WATER RES PL-ASCE	**2**	0.461																			
J IRRIG DRAIN E-ASCE	**2**	0.4																	0.365		
ENVIRON MODELL SOFTW	**2**	0.383																			
MAR ECOL-PROG SER	**3**		0.928																		
AQUAT BIOL	**3**		0.92																		
J SEA RES	**3**		0.91																		
J EXP MAR BIOL ECOL	**3**		0.908																		
MAR BIOL	**3**		0.907																		
OCEANOGR MAR BIOL	**3**		0.862																		
ESTUAR COAST SHELF S (8)	**3**		0.853																		
B MAR SCI	**3**		0.81			0.34															
ESTUAR COAST	**3**		0.753																		
J PLANKTON RES	**3**		0.712		0.423																
MAR ENVIRON RES	**3**		0.679							0.528											
ICES J MAR SCI	**3**		0.632			0.474															
MAR FRESHWATER RES	**3**		0.61		0.493	0.338															
HARMFUL ALGAE	**3**		0.597																		0.349
J SHELLFISH RES	**3**		0.566											0.426							
FISH OCEANOGR	**3**		0.513			0.492															
LIMNOL OCEANOGR	**3**		0.491	0.404	0.413																0.349
AQUAT BOT	**3**		0.475																		
ZOOL STUD	**3**		0.42																		
NEW ZEAL J MAR FRESH	**3**		0.41																		
OCEAN DYNAM	**4**			0.865																	
J OCEANOGR	**4**			0.862																	
J MAR RES	**4**			0.839																	
ACTA OCEANOL SIN	**4**			0.838																	
OCEAN MODEL	**4**			0.826																	
DEEP-SEA RES PT I	**4**		0.361	0.815																	

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
PROG OCEANOGR	**4**			0.322	0.809																	
J GEOPHYS RES	**4**				0.798																	
J PHYS OCEANOGR	**4**				0.788																	
GEOPHYS RES LETT	**4**				0.775											0.358						
J MARINE SYST	**4**			0.577	0.715																	
SURV GEOPHYS	**4**				0.711																	
CONT SHELF RES (15)	**4**			0.322	0.711																	
DEEP-SEA RES PT II	**4**			0.531	0.645																	
OCEANOGRAPHY	**4**			0.331	0.614			0.542														
GLOBAL BIOGEOCHEM CY	**4**				0.61			0.334														
BIOGEOSCIENCES	**4**				0.579			0.362														
J GLACIOL	**4**				0.486																	
COAST ENG	**4**				0.385																	
LIMNOLOGICA	**5**					0.932																
FUND APPL LIMNOL	**5**					0.928																
AQUAT ECOL	**5**					0.898																
AQUAT SCI	**5**					0.879																
INT VER THEOR ANGEW	**5**					0.871																
LAKE RESERV MANAGE	**5**					0.852																
HYDROBIOLOGIA	**5**			0.32		0.851																
INT REV HYDROBIOL	**5**			0.319		0.83																
FRESHWATER BIOL (13)	**5**	0.362				0.829																
AFR J AQUAT SCI	**5**					0.769																
J FRESHWATER ECOL	**5**	0.33				0.718	0.456															
J N AM BENTHOL SOC	**5**					0.656																
RIVER RES APPL (1)	**5**					0.607	0.395															
AQUAT CONSERV	**5**			0.472		0.505															0.313	
LANDSC ECOL ENG	**5**					0.494													0.435			
T AM FISH SOC (3)	**6**						0.884															
N AM J FISH MANAGE (5)	**6**						0.808															
ECOL FRESHW FISH (2)	**6**						0.801															
CAN J FISH AQUAT SCI	**6**					0.305	0.775															

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
FISHERIES MANAG ECOL	**6**						0.772															
FISHERIES	**6**						0.772															
ENVIRON BIOL FISH	**6**						0.739															
REV FISH BIOL FISHER	**6**			0.382			0.735															
J FISH BIOL	**6**			0.332			0.676								0.375							
FISH RES	**6**			0.352			0.662															
FISH B-NOAA	**6**			0.498			0.659															
ADV MAR BIOL	**6**	0.314		0.463			0.594					0.358										
NORTHEAST NAT	**6**	0.493					0.584															
FISH FISH	**6**			0.477			0.544											0.436				
AQUAT ECOSYST HEALTH	**6**					0.511	0.515															
NORTHWEST SCI	**6**						0.514															
J GREAT LAKES RES	**6**					0.302	0.478															
NEOTROP ICHTHYOL	**6**						0.457															
SCIENCE	**7b**							0.809														
P NATL ACAD SCI USA	**7b**							0.785														
NATURE	**7b**							0.784														
BIOSCIENCE	**7a**	0.372						0.743														
TRENDS ECOL EVOL	**7a**	0.512						0.626										0.402				
FRONT ECOL ENVIRON	**7a**	0.433						0.609													0.351	
AMBIO	**7a**	0.327						0.515													0.329	
GEOMORPHOLOGY (7)	**8**								0.853	0.308												
GEOGR FIS DIN QUAT	**8**								0.837													
Z GEOMORPHOL	**8**								0.779													
EARTH SURF PROC LAND (9)	**8**		0.331						0.778													
LANDSLIDES	**8**								0.768													
GEOGR ANN A	**8**								0.752	0.366												
NORSK GEOGR TIDSSKR	**8**				0.311				0.669							0.304						
ENG GEOL	**8**								0.633													
NAT HAZARDS	**8**								0.546													
GEOGR RES	**8**								0.537												0.484	
GEODIN ACTA	**8**		0.438						0.494				0.487									

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
NAT HAZARD EARTH SYS	**8**				0.398				0.45													
INT J SEDIMENT RES	**8**		0.3						0.388													
PERMAFROST PERIGLAC	**8**								0.361													
J QUATERNARY SCI	**9**									0.898												
QUATERNARY SCI REV	**9**									0.872												
BOREAS	**9**									0.865												
QUATERNARY RES	**9**									0.862												
HOLOCENE	**9**									0.829												
QUATERN INT	**9**									0.814												
GEOMORPHOLOGIE	**9**								0.609	0.634												
J PALEOLIMNOL	**9**									0.616												
PALAEOGEOGR PALAEOCL	**9**									0.546			0.541									
GLOBAL PLANET CHANGE	**9**				0.461			0.348		0.467						0.463						
PROG PHYS GEOG	**9**	0.34						0.382	0.368	0.448									0.396			
ENVIRON POLLUT	**10**										0.91											
SCI TOTAL ENVIRON	**10**										0.875											
WATER AIR SOIL POLL	**10**										0.853			0.319								
ENVIRON TOXICOL CHEM	**10**										0.81											
ENVIRON SCI TECHNOL	**10**										0.807											
ENVIRON MONIT ASSESS	**10**										0.764											
FRESEN ENVIRON BULL	**10**										0.554			0.492								
MAR POLLUT BULL	**10**			0.458							0.514											
ANIM BEHAV	**11**											0.918										
BEHAVIOUR	**11**											0.914										
BEHAV ECOL SOCIOBIOL	**11**											0.907										
BEHAV ECOL	**11**											0.894										
BIOACOUSTICS	**11**											0.797										
P ROY SOC B-BIOL SCI	**11**	0.392						0.448				0.604						0.445				
HORM BEHAV	**11**											0.492										
J EXP BIOL	**11**											0.333										
J GEOL	**12a**												0.775				0.366					
GEOL SOC AM BULL	**12a**												0.728									

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
SEDIMENT GEOL	**12a**												0.667									
SEDIMENTOLOGY	**12a**												0.649									
EARTH-SCI REV	**12b**				0.488					0.313			0.685									
GEOLOGY	**12b**				0.456			0.32					0.648									
TECTONOPHYSICS	**12b**				0.489								0.619									
EARTH PLANET SC LETT	**12b**				0.458								0.549				0.412					
CR GEOSCI	**12b**				0.41			0.35					0.531									
MAR GEOL	**12b**				0.311					0.339			0.474									
WATER SCI TECHNOL	**13**													0.923								
WATER ENVIRON RES	**13**										0.32			0.89								
URBAN WATER J	**13**													0.821								
WATER RES	**13**										0.47			0.772								
J ENVIRON ENG-ASCE	**13**										0.45			0.754								
J ENVIRON MANAGE	**13**										0.359			0.669								
WATER SA	**13**		0.337											0.614								
AQUAC RES	**14**														0.955							
AQUACULTURE	**14**														0.944							
N AM J AQUACULT	**14**														0.885							
J APPL ICHTHYOL	**14**						0.381								0.764							
REV FISH SCI	**14**			0.372			0.44								0.63							
FISHERIES SCI	**14**			0.409											0.589							
BFPP-CONNAISS GEST P	**14**					0.337	0.395								0.537							
METEOROL ATMOS PHYS	**15**				0.375											0.792						
INT J CLIMATOL	**15**															0.786						
J CLIMATE	**15**				0.375											0.774						
B AM METEOROL SOC	**15**				0.546											0.708						
J HYDROMETEOROL	**15**		0.392		0.344											0.704						
MON WEATHER REV	**15**															0.647						
PHYS GEOGR	**15**								0.473							0.532						
GEOCHIM COSMOCHIM AC	**16**																0.857					
AQUAT GEOCHEM	**16**																0.85					
CHEM GEOL	**16**												0.373				0.823					

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
APPL GEOCHEM	**16**										0.531						0.67					
ORG GEOCHEM	**16**																0.573					
MAR CHEM	**16**				0.382												0.565					
ENVIRON GEOL	**16**		0.354						0.317		0.366						0.384					
BIOGEOCHEMISTRY	**16**																0.364			0.359		
MOL ECOL	**17**																	0.854				
CONSERV GENET	**17**																	0.827				
BIOL J LINN SOC	**17**	0.321										0.352						0.775				
EVOLUTION	**17**	0.308										0.331						0.711				
EVOL APPL	**17**						0.455											0.69				
REMOTE SENS ENVIRON	**18**																		0.936			
INT J REMOTE SENS	**18**																		0.924			
INT GEOSCI REMOTE SE	**18**				0.329														0.903			
SENSORS-BASEL	**18**																		0.868			
AGR FOREST METEOROL	**18**																		0.342			
SOIL SCI SOC AM J	**19**																			0.737		
GEODERMA	**19**																			0.662		
J SOIL WATER CONSERV	**19**																			0.624		
T ASABE	**19**																			0.621		
AGR WATER MANAGE	**19**																			0.586		
IRRIGATION SCI	**19**																		0.313	0.553		
J ENVIRON QUAL	**19**										0.462									0.551		
CATENA	**19**								0.493											0.548		
ENVIRON MANAGE	**20**																				0.627	
CONSERV BIOL	**20**	0.464																			0.578	
BIOL CONSERV	**20**	0.483																			0.551	
ECOL SOC	**20**							0.465													0.508	
AD INT WAT MAN COP	**20**																				0.326	
MICROB ECOL	**21**																					0.791
APPL ENVIRON MICROB	**21**																					0.764
AQUAT MICROB ECOL	**21**			0.56																		0.618

Table A2. Knowledge flows in 2008

Flows are expressed as share of citations between research fields (%).

2008 citing	nas	gee	evo	eco	man	beh	lim	mar	fis	aqu	mic	wat	poll	hyd	soi	gch	geol	sed	qua	geom	oce	cli	rem
nat/sci/pnas	77,9	27,2	16,6	9,7	10,3	14,6	4,1	6,0	4,4	3,2	17,9		4,4		2,7	9,4	15,7	8,2	14,1	4,7	9,9	6,4	5,8
gen env ecology		12,7	5,0	4,2	6,2	3,1	2,6																
evol ecology		5,0	37,0	3,7	3,0	6,3			3,5														
ecology	4,7	24,9	18,1	55,6	30,9	19,3	19,0	11,7	13,5	3,0	3,4		3,8	3,4	5,4				4,8	2,6			6,7
env management		4,8	3,1	3,9	29,1		2,4																
beh ecology		5,5	10,2	4,9		50,0			3,9														
limnology					3,2		28,1	3,8	4,6			2,8											
mar & est biology		3,2	2,9	4,4	3,3		14,9	45,9	14,0	15,5	12,4		6,7			4,5					7,0		
fisher & fish research			4,0	2,6	3,8	2,6	12,0	8,2	44,4	16,3													
aquaculture									3,2	50,5													
micro biology							2,6				52,0	9,1	3,3										
water sci technology											2,5	46,3	5,8		2,7								
env pollution		3,4						3,0			2,6	19,8	50,8	3,9	8,4	8,6							
hydrol & water res												6,9	3,6	60,0	13,6	5,1		2,5		12,5		4,1	5,9
soil science												2,9	3,9	6,2	47,9	3,1				5,7			
geo chemistry													6,1	3,0	4,6	40,7	10,1	7,1	4,8		2,8		
geology																10,0	33,6	27,3	10,6	7,9	4,0		
sed geology																	6,0	34,1	5,0	7,4			
quat science																	5,7	8,0	38,1	11,0			
geomorphology															3,1			2,7	3,6	31,6			
oceanogr	4,4							7,3					3,5	4,8		7,2	23,4	8,1	7,6	8,7	58,2	24,7	16,8
climatology														3,3					3,0		6,5	59,5	4,9
remote sensing															2,6								49,7

Note: Data indicate research field A (column) citing research field B (row). Columns add to 100% Values lower than 2.5 percent are not shown. Substantial mutual citing relations are highlighted: research field A cites research field B and vice versa.

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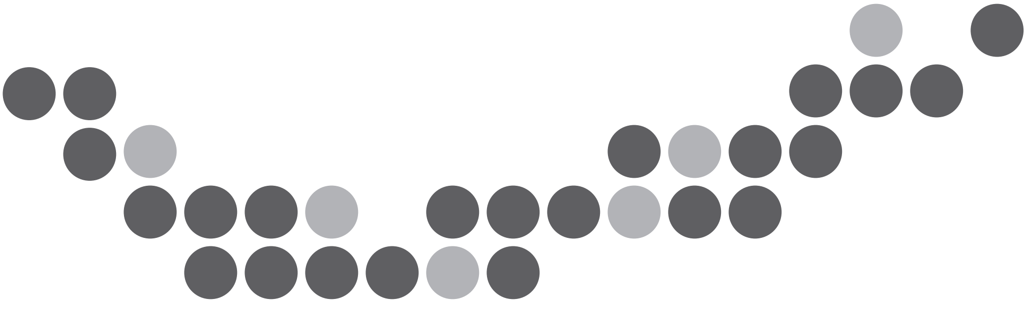
CHAPTER 6

Community structure and collaboration in river science in the Netherlands

P. Vugteveen, W. de Nooy, H.J.R. Lenders



This chapter has been submitted

1 Introduction

River science involves multiple disciplines and is a dynamic knowledge domain that focuses on complex eco-social problems related to societal developments (Thorp et al. 2007; Vugteveen et al. submitted). Recognition of system complexities (Holling 2001) and calls for integrative and adaptive water management approaches (Medema et al. 2008; Saravanan et al. 2009; Vugteveen & Lenders 2009) have led to the commonly accepted view that fragmented science can yield only partial solutions and that cross- disciplinary scientific efforts in water management are likely to yield substantial benefits (e.g. Benda et al. 2002; Boulton et al. 2008; McCulloch 2007; Naiman 1999; Palmer & Bernhardt 2006; Wear 1999). This has resulted in an increasing call for cross-disciplinary research the last decades in order to develop and support systemic approaches.

The traditional model of science where research is conducted by individual researchers has evolved into a model where large collaborative scientific teams, research institutions and formal knowledge networks are encouraged (Klenk et al. 2009). In addition to interacting with other scientists to bridge different disciplinary perspectives, academics have also been challenged to interact more with other stakeholders. Moving to socially relevant research should lead to developing new understandings and multiple forms of knowledge production (Van Kerkhoff 2005). Despite these developments Hillman (2009) observed a reluctance to apply the full range of scientific and experiential knowledge to river management strategies in a range of case studies.

Following a broad analysis of 1250 projects in Dutch water management the supporting knowledge infrastructure was assessed to strongly emphasize a technical-scientific approach that focused on the physical water system and included limited knowledge from the human sciences (De Wilt et al. 2000). Furthermore it has been noted that many technical experts focus on their area of expertise and pay less attention to communication and cooperation with other actors in the process (Mostert 2006; Vugteveen & Lenders 2009). Similarly for the related field of coastal research it was found that broader societal, managerial and policy aspects were being addressed, although substantial contributions from social research did not seem to be involved (Merkx & Van den Besselaar 2008).

Although scientific and policy paradigms advocating cross-disciplinary scientific collaboration are prominent in integrated water management (IWM) strategies, difficulties in progressing IWM through cross-disciplinary collaboration have been associated with social factors like (a lack of) organizational structure, collaboration arrangements and cognitive factors like differences in knowledge bases (Lowe & Phillipson 2009; NRLO AWT & RMNO 2000; van Rijnsoever & Hessels 2011; White et al. 2004). Scientific knowledge does not exist in a vacuum. Researchers often work collaboratively to produce new knowledge. Knowledge generation and validation requires a social infrastructure consisting of the relationships between scholars and the organizations and institutions they are affiliated with, such as university departments, research centers, and research institutes (Börner et al. 2012).

In this study we want to gain better understanding of the role of collaboration in IWM-supporting river science by considering its social structure. This structure can be understood as a network that consists of a set of people or groups (“nodes”) each of which has connections (“ties”) of some kind to some or all of the others (Newman 2003). A social network study of river science can greatly advance the understanding of the cognitive structure in terms of the knowledge-creation process and the flows of knowledge.

Social Network Analysis (SNA) has developed a set of well-proven methods and theories that have been frequently and commonly employed to investigate (academic) collaboration (Borgatti et al. 2009; Glänzel & Schubert 2005; Sonnenwald 2007). It includes analytical and graphical measures of network structure to explore the connections between individuals or organizations, and how linkages affect aggregate behaviour or information flows (De Nooy et al. 2011).

In this study we aim to analyze and explain the topology of Dutch river science using exploratory and statistical techniques from SNA. We consider the networks of organizational affiliation, collaboration and citation behavior of the research community of river science whereby we specifically wish to determine whether and which institutional arrangements foster or hinder scientific collaboration and the exchange of knowledge within this community. Collaboration can thereby be defined in terms of co-authorships. Such co-authorship networks among researchers are a particularly important part of the collaborative social structure of science (Mali et al. 2012) wherein co-publishing is a driver for the (cross-disciplinary) exchange of knowledge. Co-authorships as a proxy for joined intellectual activities constitute a rather objective and tractable measure and has been well-documented (Glänzel & Schubert 2003; Newman 2001). But although analysis of co-author networks may provide a window on patterns of collaboration within science, they have received far less attention than have citation networks for analyzing cognitive structures (Newman 2004).

In our study the nodes in the networks represent individual river researchers that are affiliated with an institute based in the Netherlands. The ties between them represent their affiliation, collaboration and citation relationships. Thereby we expect that co-affiliations at lower organizational levels affect collaboration and knowledge exchange more because there is direct contact and a stronger shared identity. As we are considering network relationships we acknowledge that there are mutual associations and dependencies among collaboration, shared knowledge bases, and the productivity of researchers. We expect that collaboration through co-publishing is a driver for the (cross-disciplinary) exchange of knowledge between researchers. Similarly, it can also be expected that collaboration between researchers of similar disciplinary backgrounds are more easily established.

We focus on the case of river science in the Netherlands. This presents a suitable case since, lying in the delta of the Rhine, Meuse and Scheldt rivers, the Netherlands historically have had a strong water management structure as well as a strong national knowledge infrastructure focused on river related research. In support of policy developments several large research programmes have been launched over the last decades (Van Hemert & Van der Meulen 2011). Integrated water management policies have been implemented in the Netherlands since the mid-eighties and the need for cross institutional collaboration and knowledge exchange has been formally recognized and organized by major research institutes (Alterra et al. 2002; NCR 2012; NRLO AWT & RMNO 2000).

First the method is further explained in the following section. Then we present the results of the statistical analysis with visualizations to support interpretation. Finally we synthesize and discuss our findings in the wider context of scientific support for IWM strategies.

2 Methods

Case

In this study we constructed the collaboration network of the Dutch river science community from bibliographical data that were extracted from the ISI Web of Science. It included a five year publication range (2005-2009) and we searched all document types that are citable items: articles, reviews, proceedings (i.e. conference) papers, editorial materials, notes and letters (from now on called 'papers'). To define the Dutch research community the search query was set to only contain papers that included "(The) Netherlands" in the address field. A topic search (in title, abstract and keywords) over all indexes (ISI: SCI-EXP, SSCI, A&HCI) was performed using a selection of keywords in a number of steps. Keywords included *"river*"* and more specific river-related keywords derived from online river management glossaries (see Appendix, Table A1). Keywords were cross-checked and expanded based on suggestions of several river researchers. The initial keywords were found especially suitable to select relevant and a manageable number of publications from the extensive natural science domain.

The contribution of social sciences and humanities to environmental management has been argued to be important for developing IWM (Endter-Wada et al. 1998; Ison et al. 2007; Vugteveen et al. 2010). To ensure capturing the social scientific efforts in the analysis we put additional effort in retrieving and including relevant publications from the social & management sciences. We therefore additionally performed a topic search in the social & humanities index (SSCI and A&HCI) using the term "*water*", "*flood(s)*" and "*flooding*". Using generic terms like "*river**" and "*water*" aimed for a high recall of papers but the consequence was a relatively low precision in the document set. In the next step we therefore manually checked all the data and cleaned the document set for irrelevant publications.

This combined approach ultimately left a total of 977 publications in the document set with immediate relevance to river systems and their management and/or policies. All data were then imported in a Microsoft Access database using the SAINT tool box (Somers et al. 2009).

The organizations responsible for the major part of the output of Dutch river science are presented in Table 1. Universities show the largest output and are responsible for the majority of the publications. This primarily includes the VU University Amsterdam, Wageningen University, Delft University, Utrecht University, Radboud University Nijmegen, University of Amsterdam, Erasmus University Rotterdam, and UNESCO-IHE Institute for Water Education Delft. Other main institutes include Alterra, the National Institute for Public Health & Environment (RIVM), the Institute for Inland Water Management and Waste Water Treatment (RIZA), the Netherlands Organization for Applied Scientific Research (TNO) and WL-Delft Hydraulics. These five organizations explicitly profile themselves as institutes for knowledge development in support of freshwater management practices and the implementation and evaluation of water policy (Alterra et al. 2002). In this study TNO especially concerns the unit Geological Survey of the Netherlands. Other main institutes of geoscience involve the International Institute for Geo-Information Science and Earth Observation (ITC) and the Royal Netherlands Meteorological Institute (KNMI). Finally, the Netherlands Institute of Ecology (NIOO-KNAW) is directed at basic and strategic ecological research and has separate marine (CEME) and limnological (CL) research departments at different locations.

Table 1. Main research organizations

Based on the number of papers (co-)authored by the organization's researchers. Scope, abbreviations and acronyms of organizations are explained in the main text.

	Organization	Count		Organization	Count
1.	Delft University of Technology	177	11.	University of Amsterdam	37
2.	Utrecht University	145	12.	WL-Delft Hydraulics^{+}	37
3.	Wageningen University*	132	13.	ITC	34
4.	VU University Amsterdam	126	14.	TNO^{+}	32
5.	UNESCO-IHE	111	15.	RIVM	24
6.	Radboud University Nijmegen	81	16.	Deltares^{+}	23
7.	Alterra*	60	17.	KNMI	20
8.	University of Twente	55	18.	NIOO-KNAW CEME	16
9.	RIZA^{+}	52	19.	NIOO-KNAW CL	15
10.	Wageningen UR*	46	20.	Erasmus University Rotterdam	14

*Note: *Wageningen UR presents a formal collaboration between Wageningen University and different research institutes, including Alterra. Wageningen UR appears as a separate affiliation because authors did not always specify their affiliation to either the university or one of the research institutes. Note that papers co-authored by researchers from different organizations are counted for more than one organization.*

+ Parts of the organizations RIZA, TNO and WL-Delft Hydraulics have been reorganized and split in 2008 into a new organization called Deltares.

Definitions and operationalizations

The bibliographic information about the papers includes the authors, their addresses, cited references, and titles. All networks that we analyze are constructed from this information.

Co-author network

The network of co-authorships is central to our analyses. We consider co-authorships as documented in ISI indexed papers as a proxy for collaboration (Melin & Persson 1996). The collaboration network based on co-authorships consists of the 1253 researchers who appeared as authors of the selected papers and who included at least one Netherlands-based organization in their address information.

All of the authors listed on a single paper are assumed to be fully and mutually connected via the work, and the date of publication is taken as the year the collaboration occurred, as it is generally not specified when the actual research work has been performed. The value of their tie in the collaboration network is calculated as the number of papers co-authored by two researchers.

The network consists of 87 components, i.e. groups of researchers that are connected within their group but who are disconnected from other groups. Most of these components only included a few individuals who published a few articles with one or a few colleagues. This often concerned collaboration within one organization. The largest and core component in the collaboration network links 839 researchers (67%). In addition, 114 researchers (9 %) wrote only single-authored papers, so they are isolates in the collaboration network.

Knowledge sharing networks

We considered the citation network based on references included in the document set to determine how Dutch authors use the knowledge of their peers. When considering citing behavior we make an analytical distinction between shared citations amongst authors who are part of the Dutch community in the period under study, so one ‘Dutch’ author citing another, and ‘Dutch’ authors citing external researchers, that is, researchers outside this community, either working abroad or having worked in The Netherlands only in the past.

The number of times an author cited another author in the selected papers is the value of the directed tie (arc) from the citing to the cited author. References among authors in co-authored papers were omitted from the calculation of shared references. The directed network of references among Dutch authors was symmetrized by taking the maximum value within the pair. For example if researcher A cites researcher B 5 times while researcher B cites researcher A 8 times, then the undirected tie value is set to 8.

In addition to this network of direct citations within the Dutch community, a network was constructed from references to work by researchers outside the current Dutch community. Two ‘Dutch’ researchers are connected by a line in this network if they cite the same ‘external’ researchers. The number of shared cited external researchers yields the tie value. The line value is normalized by dividing it by the lowest number of external researchers cited by a member of the pair because this is the maximum number of ‘external’ references that the two researchers can share.

Author addresses and network of institutional affiliation

The authors’ addresses from the article records are used to determine author affiliations. ISI addresses generally contain information on main organization, sub-organizational units like faculty and department, as well as city, and country. We cleaned and standardized the data by checking for spelling variants and correcting for typographical errors etc. We had to deal with the complication that authors not always detail their complete affiliations, so information was sometimes missing. Incomplete addresses with missing organizational units were complemented by comparing and reconstructing the hierarchical organization structure top-down.

We are interested in evaluating the impact of being affiliated to the same organizations on collaboration and knowledge sharing. Researchers can be co-affiliated, that is, members of the same organization, at different organizational levels. We considered co-affiliation at 4 organizational levels being the i^a) *supra-organizational* level, i.e. formal inter-organizational cooperation, i^b) whereby the Netherlands Center for River Research (NCR) was analyzed as a separate institution because it aims to play a coordinating, exploratory and stimulating role as regards to river-related research in the Netherlands; ii) *multi-site* level with multiple locations and addresses;, iii) *establishment* level, i.e. one location address, and the iv) *centre/departmental* level. These levels differ with respect to important dimensions such as physical proximity, specialization level, and experienced identity.

For each level, a network was constructed with lines linking pairs of researchers that are co-affiliated to at least one organization at that level. Note that lines have no values; they are either present (coded as 1) or absent (coded as 0). Table 2 presents descriptive data of the affiliation networks. From this table it is evident that researcher are especially linked at the level of establishments, meaning that they are working in the same building or complex of buildings at one address, and multi-site organizations, mainly universities. The average number of colleagues with whom a researcher is co-affiliated, i.e. degree, is highest for the NCR. Each NCR-member is linked to the other 412 members (413 * 412 / 2 = 85,078 NCR lines in total) and all non-members are isolated, so the average degree over all researchers is about 68 (= 85,078 / 1253).

Table 2. Organizational affiliations

Affiliation is defined as a unique combination of organizational units across 4 levels. Specifications per organizational level concern the number of organizational units, authors and co-affiliations involved. Average degree is the average number of co-affiliations per researcher.

Org. level	# Org units	# Linked authors	# Co-affiliations (# lines)	Average degree
i^a) Supra	12	517	44,248	35,3
i^b) NCR	1	413	85,078	67,9
ii) Multi-site	42	1,018	58,418	46,6
iii) Establishment	159	1,158	40,697	32,5
iv) Centre/Department	191	363	5,598	4,5

The affiliation networks allow for researchers to have more than one affiliation. If a researcher is working for several centres, s/he is linked to each colleague in each of the centres in the affiliation network for centres/departments. For visualization and exploratory network analysis, each researcher was also attributed to a single organization, namely the organization where the researcher published most of his/her articles in 2005-2009. We label this the researcher's main organizational affiliation.

Shared research topics

We assessed the topical scope and current research front of the river science network in the Netherlands based on the papers in de document set. The development of the research front can be seen as an evolving paper system in which knowledge is produced by combining and extending the existing set of papers, and new knowledge is related to previous research through the citation of references. We used the word-reference approach by (Van den Besselaar & Heimeriks 2006) in which research topics are defined as sets of papers that are similar in terms of title word-reference combinations (Vugteveen et al. submitted). This revealed 51 clusters of papers sharing similarity covering 895 papers (92%) out of the document set, i.e. 51 research topics varying from 2 to 159 papers. We identified the major research topics from the total of 51 identified topics. We set a minimum of 5 papers over five years to represent a substantial, i.e. major research topic. This criterion left the research front of river science in the Netherlands to consist of 23 major topics (Table 3).

Table 3. Major topics in Dutch river science 2005-2009

The number of included papers is based on the word-reference analysis.

	Topic	#		Topic	#
1.	Hydrological river catchment modelling	159	13.	Water footprints	12
2.	Flooding effects on floodplain species	117	14.	Rainwater & irrigation management	10
3.	Heavy metal toxicity and pollution in floodplains	105	15.	Invasive species - gammaridean species	9
4.	Rhine-Meuse delta palaeo – sediments	94	16.	Fish migration - silver eel	8
5.	River basin management policies	83	17.	Channel flows - experiments & simulation	7
6.	Climate change - river basin hydrological regimes	62	18.	Flood modelling approaches	7
7.	Estuarine biogeochemical dynamics	35	19.	Genetic diversity - riverine plant species	7
8.	Sediment transport and sorting	32	20.	Water quality monitoring and sampling	6
9.	Flood risks in the Netherlands	15	21.	Hormonal activity and contamination	5
10.	Remote sensing - water productivity	14	22.	Arctic rivers - organic matter	5
11.	Delta sediments - Red River	13	23.	Climate change – flood risks & vulnerability	5
12.	Soil erosion catchment modeling	13			

From the research topics assigned to the papers, a network of shared research topics was constructed. Per pair of authors the number of publications in non-common topics was subtracted from the number of publications in common topics. The resulting number is the value for the line between the two authors. A positive number then indicates that pairs predominantly publish on the same topics while a negative number represents mostly different topics.

Statistical method

We use multiple regression analyses to establish partial correlations, i.e. the effects while controlling for other predictors. Thus, we establish the net contribution of organizational structure on collaboration if we control for shared knowledge and vice versa.

Within our network approach the units of analysis are pairs of researchers. Researchers are affiliated to the same organization (or not), they collaborate, they share knowledge. Pairs of researchers are not independent, i.e. if researchers A and B belong to the same organizational unit as well as researchers A and C, then researchers B and C are more likely to be co-affiliated. Therefore, we cannot assume independent observations, which is required for ordinary regression analysis. Instead, we use a MRQAP regression model (Dekker et al. 2007) as implemented in R (Butts 2006).

Three regression models are estimated: a model with collaboration (co-authorship) as the dependent variable, and two models with knowledge sharing as the dependent variable. The other networks are used as predictors. We also included a control variable for the productivity of pairs of researchers, which is calculated as the number of papers of the least productive researcher in the pair. This variable controls for the sheer probability that two productive authors are more likely to cooperate, to cite each other, or share references to external authors.

For the analysis some variables were transformed. To reduce skew, the natural logarithm was taken of the number of co-authored articles, the number of internal references among ‘Dutch’ researchers, and the number of shared references to ‘external’ researchers.

For additional interpretation of the statistical results we describe and visualize the networks of collaboration and knowledge sharing. Visualizations and network analyses are performed with Pajek software for network analysis (Pajek 2.04

2011). One of the alluring aspects of this program is the ability to visualize the networks and use the power of network graphs to facilitate the understanding of network structure.

3 Results

Table 4 presents the results of the three regression models ; a model with collaboration (co-authorship) as the dependent variable, and two models with knowledge sharing as the dependent variable.

Tabel 4. Regression results (MRQAP)

For independent variables range and standard deviation (SD) are given; N = 784,378.

			Model 1		Model 2		Model 3	
Dependent variable			Co-authors		Internal Refs		External Refs	
Independent variables	Range	SD	b	b*	b	b*	b	b*
(Intercept)			0.000	.	0.002*	.	0.006***	.
Co-affiliation: NCR	0/1	0.311	0.000	.001	0.004***	.013	0.004***	.038
Co-affiliation: Supra-organization	0/1	0.231	0.006***	.021	0.001	.002	0.000	-.003
Co-affiliation: Multi-site organization	0/1	0.263	-.007***	-.029	-0.003**	-.009	0.000	-.003
Co-affiliation: Establishment	0/1	0.222	0.027***	.097	0.013***	.031	0.006***	.041
Co-affiliation: Centre	0/1	0.084	0.055***	.076	0.042***	.037	0.011***	.027
Co-authors (ln)	0-3.33	0.061	.	.	0.111***	.071	0.097***	.179
Internal References (ln)	0-3.50	0.095	0.045***	.071	.	.	0.059***	.170
External references (ln)	0-0.69	0.033	0.558***	.302	0.835***	.290	.	.
Pairwise productivity (ln)	0-3.50	0.377	0.008***	.047	0.027***	.106	0.005***	.052
Shared topics	-79-50	4.967	0.001***	.062	0.001***	.077	0.001***	.081
R^2				.11		.10		.16

Note: b is the unstandardized regression coefficient, b is the standardized regression coefficient. $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ (based on 1,000 simulations).*

Model 1 predicts the (log) number of times the researchers co-authored a paper. We see that shared external references has clearly the largest predictive power (*b** = .302) meaning that Dutch researchers who have more similar citing patterns with respect to external researchers are much more likely to co-author papers. References in co-authored papers were omitted from the calculation of shared references, so this effect is not confounded by references from co-authored papers that are shared by definition. Collaboration between researchers hinges on shared knowledge as expected.

Also internal references among authors within the Dutch system have a sizable predictive effect (b^* = .071) on the probability to co-author papers. Again, references within co-authored papers were disregarded. Shared topics has a predictive effect that is of comparable size to the effect of internal references (b^* = .062). Researchers working on similar topics co-author more papers if we control for knowledge sharing, i.e. shared internal and external references, and organizational co-affiliations.

The estimates for the predictive effects of co-affiliations directly address our research question. Co-affiliations at several organizational levels have predictive effects on the number of co-authored papers, that is, on scientific collaboration. The largest effects are found at the lowest levels, i.e. the centre and the establishment levels. This indicates that physical proximity is more important to collaboration than being affiliated through large organizational structures, e.g. multi-site organizations such as universities. Both multi-site and the supra organization level have very weak predictive effects on collaboration when we control for co-affiliations on lower organizational levels. This implies that researchers of the same university (multi-site organization) who are not in the same department or centre are not more likely to cooperate than researchers at different universities. In fact, the negative sign of the effect indicates that they are less likely to co-author papers. As mentioned before the NCR aims to play a coordinating, exploratory and stimulating role as regards to river-related research in the Netherlands. This level shows no effect, which means that shared membership of this organization does not enhance or hinder collaboration if we control for co-affiliations at lower organizational levels, shared knowledge base, specialization, and productivity. Although tentative, it is noteworthy that an organization designed to accommodate interdisciplinary exchange does not seem to cause additional collaboration.

The positive predictive effects of the lower organizational levels imply that collaboration across organizational boundaries is less likely to occur. Even though Model 1 only explains 11% of the variance in the number of co-authored papers, meaning that there is a lot of random variance or variance related to other predictors, the tendency to collaborate within institutional boundaries produces a clearly structured network of co-author relations, especially if we disregard co-authorships that occurred only once in the period under investigation. We can see this when we consider the structure of the network as presented in Figure 1. The figure shows the main component of the network. The colours of the nodes refer to the organization where the researcher published most of his/her articles in 2005-2009.

The co-author network consists of a ring-shaped structure with two main clusters of researchers. The main research organizations (Table 1) form the core component for the most part except for the marine oriented NIOO-KNAW CEME institute. The cluster on the right side includes Delft University of Technology and UNESCO-IHE including links to the University of Twente and ITC (part of the University of Twente compound). UNESCO-IHE is based in Delft and focuses on international higher water education and has close formal collaboration with Delft University whereby researchers work for both institutes. Their research profile has a strong focus on hydrology and civil engineering. The other cluster on the left side of the figure is comprised mainly of Radboud University (RU), the Utrecht University (UU) and NIOO-KNAW CL. Water-related research by these institutes has an environmental ecological and geomorphological focus.

Authors from the VU University Amsterdam and of Wageningen University form ties bridging between the RU/UU and Delft cluster into a ring structure. A closer look reveals that 'across the left' the VU University Amsterdam has a main connecting function to the hydrological-engineering cluster through relations with the TNO institute connection to the Utrecht University. The TNO institute performs applied geoscientific research and checking the affiliations of the authors reveals that it mainly concerns researchers from the Geological Survey Netherlands. The VU University Amsterdam researchers are connected to the Department of Palaeoclimatology & Geomorphology and the Spatial Analysis and Decision Support group of the Institute of Environmental Studies. This thus suggests a disciplinary geosciences tie to the RU/UU and Delft Cluster.

At the lower right side of the figure there is a clustering of authors affiliated with Wageningen University and Alterra, institutes that have a research tradition in land development and agricultural engineering. The VU University Amsterdam again has a connecting function, now between the RU/UU cluster and a heterogeneous cluster of organizations in which the Wageningen research organizations are dominant. A check of the affiliations showed that researchers of ecotoxicology and environmental science departments are making up this latter cluster. This suggests an environmental science tie across the right.

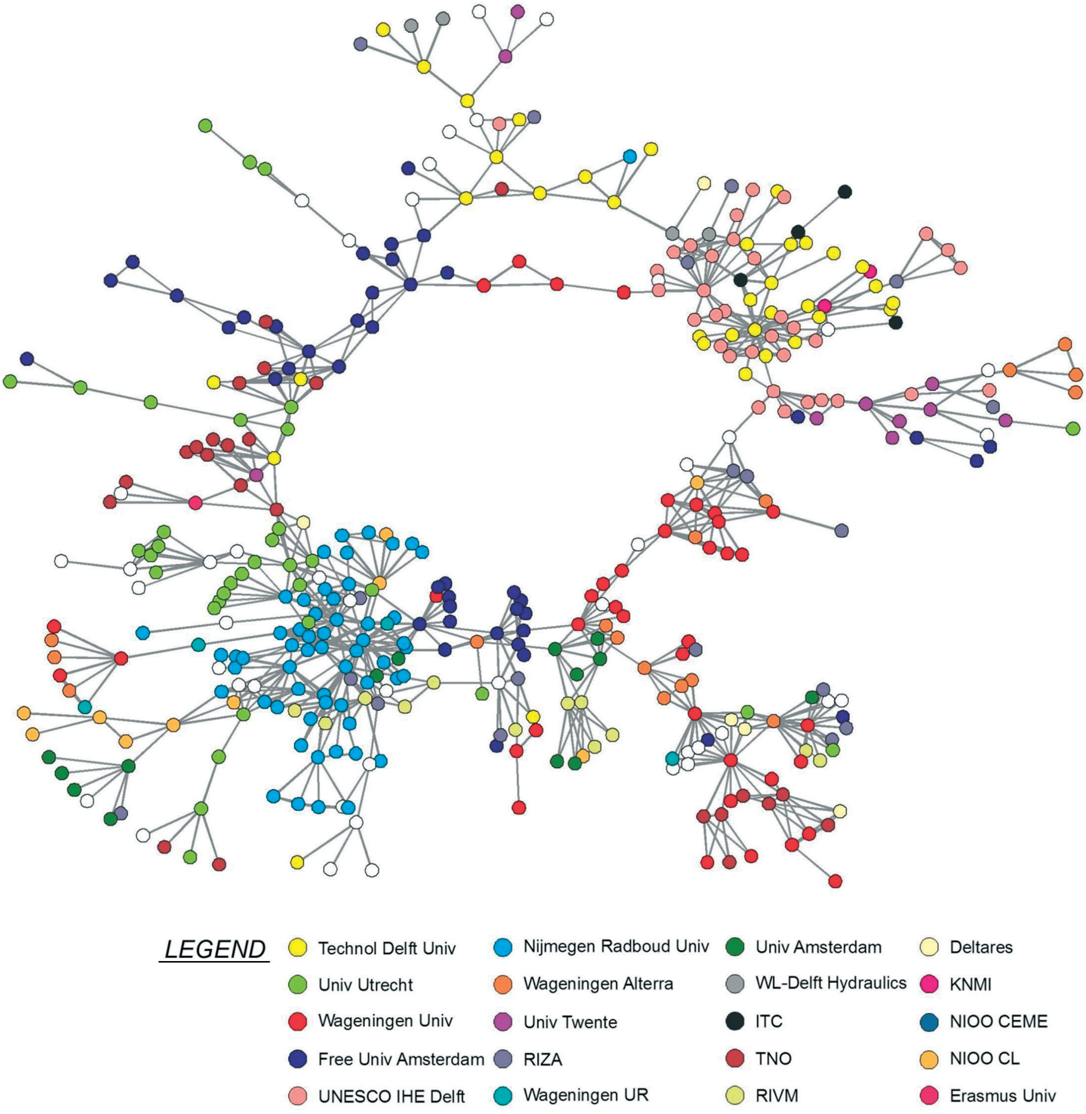


Figure 1. The main component of the co-authors network

A low threshold was set (at least two co-written papers) to define a stable, i.e. non-incidental collaboration.

It is obvious that individual researchers differ in the extent to which and how they are connected to other researchers. Each researcher, i.e. node, can be characterized by its betweenness, which measures the number of times a researcher is an intermediary in the path between two researchers. A node with high betweenness may identify a researcher as a broker that is able to initiate or hinder communication flow through the river scientific network. In our network a researcher plays a brokerage role when s/he forms a link between two of his/her co-authors who do not directly work and publish together. The type of these brokering links can differ, i.e. a researcher may link co-authors of the same institute or of different institutes, thus acting as a 'knowledge broker' in different ways. Here we distinguish between 4 different brokerage roles (Figure 2) (Gould & Fernandez 1989):

- *Coordinator role:* each brokerage situation in which a person publishes with two people from his/her own institute who do not directly publish together; strengthening collaboration within one's own organization;
- Representative role: each brokerage situation in which a person publishes with someone from his/her own institute and with someone from another institution who do not directly publish together; strengthening collaboration between one's own organization and other organizations;
- Liaison role: each brokerage situation in which a person publishes along with two other people both from different outside institutes who do not directly publish together; linking outside organizations;
- Itinerant broker role: each brokerage situation in which a person publishes with two people from the same institute who do not directly publish together; linking researchers within an outside organization.

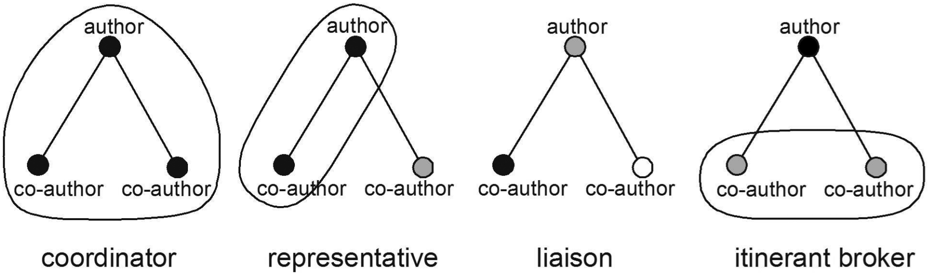


Figure 2. Four brokerage roles

Different node shades represent different organizations.

Table 5 presents descriptive data for aggregate brokerage of researchers at the organizational level. The major research organizations (Table 1) perform the highest degree of brokerage, whereby especially the Radboud University is strong in absolute terms. Brokering between researchers within the organization, i.e. the coordinator and representative roles, can be expected to be more frequent in the larger research institutes with multiple departments and a higher concentration of researchers. Indeed the universities portray strong coordinator roles, whereas organizations involved in applied geoscience like TNO, KNMI and ITC perform strong representative roles.

In contrast institutes involved in applied hydrological and water resource quality research such as Deltares, RIZA and RIVM fulfill strong liaison roles.

Working with people from multiple institutions is assumed indicative of multidisciplinary work. In general it may be that applied researchers – in contrast to academics - are less inclined to, or have less time to invest in a publishing process in formal media like scientific journals and seek collaboration with (university) scholars to do so. The other way around may also be true, i.e. that academic scientists seek collaboration because of the technological innovation it may bring to their research practice.

The difference between universities and applied research institutions is exemplified by Wageningen UR, in which Wageningen University has a strong coordinator role against the strong liason role for Alterra, where the nature of research is much more applied. Finally it is notable that in comparison to the other high ranking universities Wageningen University and Utrecht University perform strong liaison roles. Apparently these universities are more involved in linking organizations through inter-organizational collaboration than the other universities.

Theoretically a collaboration within the same institute is the most easy to establish for reasons of physical closeness and shared research strategies within the institute. The fact that the coordinator role is the strongest overall as well as the fact that the itinerant role is the least occurring indicates this mechanism amongst researchers. Apparently it is uncommon for a researcher to publish with two people from the same institute who have not also published together, an exception being Erasmus University Rotterdam. The tendency for researchers to work with others within their own institute is also supported by the largest predictive co-authoring effects found at the lowest affiliation levels.

Table 5. Organizational brokerage across four different roles (%)

Organizations are sorted along their strongest role (in bold) and secondly by the absolute number of brokerage roles they fulfill (brokerage count).

	Organization	*Brokerage count*	*Authors*	*Avg brokerage per author*	*Coordinator*	*Representative*	*Liason*	*Itinerant broker*
		(#)	(#)	(#)	(%)	(%)	(%)	(%)
1	Radboud University Nijmegen	4696	81	58.0	**53**	32	13	2
2	VU University Amsterdam	2593	123	21.1	**55**	33	10	2
3	Delft University of Technology	2562	96	26.7	**36**	32	24	8
4	UNESCO-IHE	668	68	9.8	**41**	34	22	3
5	University of Twente	458	45	10.2	**46**	34	17	4
6	NIOO-KNAW CEME	88	17	4.6	**73**	25	2	0
7	TNO	706	42	16.8	28	**40**	21	11
8	University of Amsterdam	325	45	7.2	23	**40**	34	3
9	KNMI	195	17	11.5	18	**39**	**39**	3
10	ITC	38	24	1.6	26	**53**	5	16
11	Wageningen University	1872	160	11.7	32	31	**34**	3
12	Utrecht University	1729	123	14.1	29	31	**34**	5
13	RIZA	623	38	16.4	1	16	**71**	12
14	Alterra	386	46	8.4	4	13	**70**	13
15	RIVM	263	29	9.1	9	22	**60**	9
16	Deltares	258	12	21.5	0	5	**82**	12
17	NIOO-KNAW CL	211	11	19.2	10	35	**40**	15
18	Wageningen UR	156	34	4.6	3	23	**67**	8
19	WL-Delft Hydraulics	77	21	3.7	0	19	**52**	29
20	Erasmus University Rotterdam	6	4	1.5	0	0	33	**67**
	Totals (#)	17910			6876	5552	4594	888

Model 2 (Table 4) estimates knowledge sharing, operationalized as citing, between Dutch authors as the dependent variable. This model predicts the number of times two Dutch researchers cite each other. Citing indicates that researchers know and use each other's work. We see that in comparison to the other predictors organizational co-affiliations have modest effects. The two lowest organizational levels have substantial positive effects, indicating that members of the same local branch or centre are more likely to cite each other's work. Furthermore, the negligible effects

of the multi-site and supra-organizations suggest that these larger organizational structures are inconsequential to knowledge exchange. The NCR has a very small positive effect. These effects, however, are dwarfed by the effect of shared references of external literature (*b** = .290). Sharing knowledge within the Dutch context is thus mainly an exponent of sharing international knowledge bases, which is not surprising if one takes into account that science is an international system. Local and national organizational structure apparently only plays a subordinate role.

In comparison to the prediction of co-authorship (*b** = .047), productivity plays a more substantial role (*b** = .106) in the prediction of references among researchers in the Dutch situation. More productive researchers tend to cite one another more frequently if we control for organizational embedding, shared knowledge bases, and topical specialization. This may indicate a national reputation effect although we cannot rule out that the effect arises from the fact that authors with more papers are more probable to cite and to be cited.

Figure 3 shows the citing relations between Dutch researchers in the main component. The centre dominant vertex (light green) in the middle represents a researcher from Utrecht University whose work is cited throughout the network. Radboud University Nijmegen (light blue) clusters in the bottom-middle whereas the VU University Amsterdam (dark blue) and TNO (maroon) cluster at the right.

The figure makes clear that geoscientific research at Utrecht University is cited most frequently and substantially across the main research institutes, especially by geo-institutes like TNO, Deltares, and ITC. This suggests that the research work of Utrecht apparently functions as a common knowledge base to researchers from other fields. Next to Utrecht University also work from Radboud University researches is cited more frequently.

Finally Model 3 (Table 4) predicts the number of shared references to researchers outside the Dutch context. This model offers a picture that is similar to the one presented for Model 2. That is, organizational co-affiliations have weaker predictive effects than a shared knowledge base, in this case, internal references (*b** = .170) and shared topics (*b** = .081). In contrast to the prediction of references within the Dutch context, productivity plays a much smaller role (*b** = .052) while co-authorship is more important (*b** = .179). Furthermore, internal referencing and external referencing are mutually dependent.

With respect to the effects of organizational levels it is noted that the NCR has an effect that is comparable in size to the effects of the Centre and Establishment levels (b* =.038).). Members of the NCR tend to cite the same external researchers even when we control for co-affiliations on lower organizational levels, co-authoring, Dutch references, specialization, and productivity. This result implies that even members of the same Centre or Establishment tend to have a more similar knowledge base if they are also both members of the NCR. In this respect, the NCR seems to enhance the sharing of knowledge among its members.

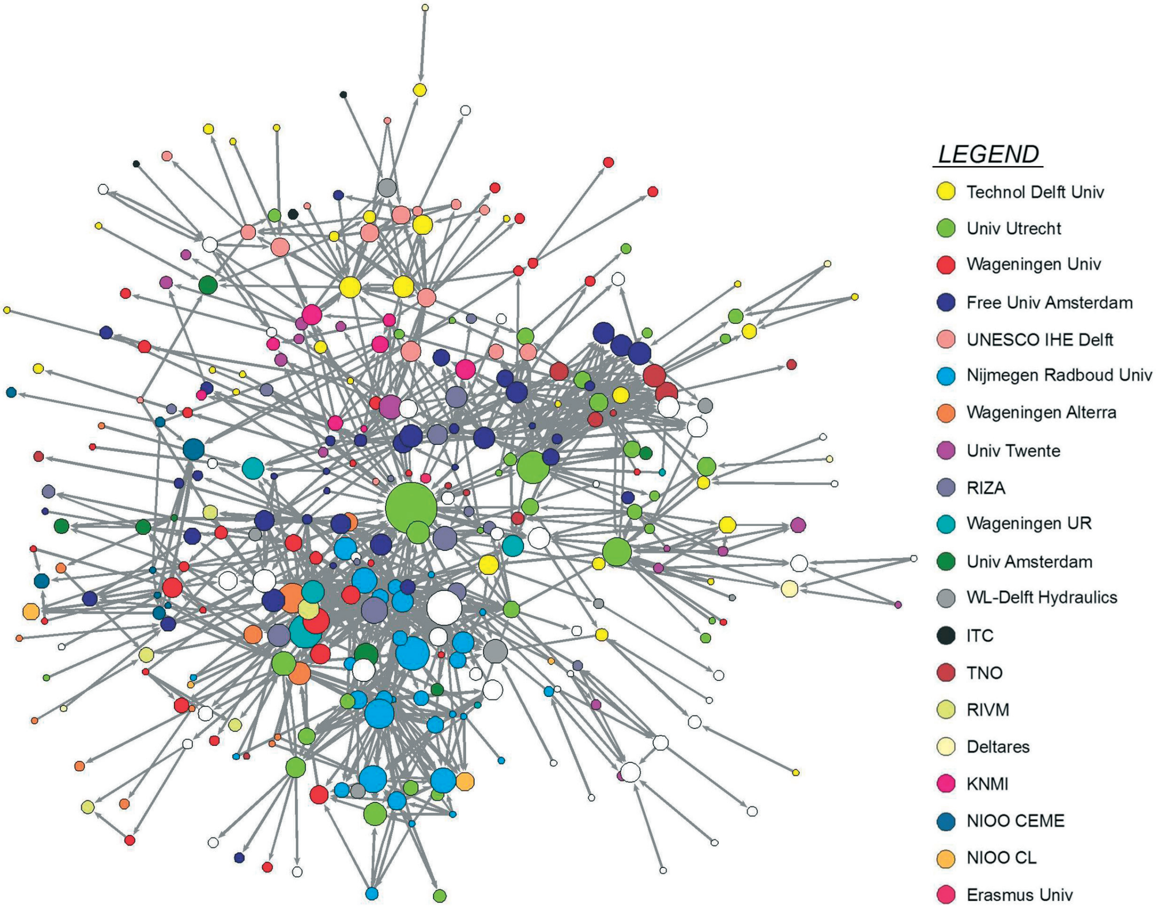


Figure 3. Core network of internal references

Incidental (one-time) citations are omitted with vertex size representing the number of citations received.

4 Discussion & Conclusions

In this study we considered scientific collaboration in river science prompted by observations that difficulties in progressing integrated water management through cross-disciplinary exchange may be linked to the social structure of its supporting science. Specifically we set out to determine whether and which institutional arrangements foster or hinder collaboration and the exchange of knowledge in Dutch river science. While earlier reports (De Wilt et al. 2000; NRLO AWT & RMNO 2000) and studies (Van Hemert 2008; Van Hemert and Van der Meulen 2011) provided qualitative approaches to assessing the development of river science and its cognitive structure, this study focused on the *de facto* and quantifiable performance of river science as expressed through formal communication patterns. We thereby expected that organizational affiliation levels affect collaboration patterns between researchers, and subsequently the cognitive structure of river science as collaboration through co-publishing is expected to be a driver for (cross-disciplinary) knowledge exchange.

Particularly co-affiliations at lower organizational levels were hypothesized to affect collaboration and knowledge exchange more because there is more direct contact and a stronger shared (disciplinary) identity amongst direct colleagues. This is confirmed by the positive predictive effects of the lower organizational levels that we have found. These imply that collaboration across organizational boundaries is less likely to occur. Physical proximity is more important to collaboration than being affiliated through large organizational structures like supra- and multi-site organizations. Hannah et al. (2004) assessed the authorship of research papers in ecohydrology and found that collaborating university researchers very rarely came from more than one academic department. In addition Evans et al (2011) found that although researchers collaborate with international partners, within their own countries and disciplinary borders they prefer to interact with colleagues from their own institutions.

In our study affiliation with the NCR, which has been founded to streamline and bring together riverine research in the Netherlands, did not show an effect on collaboration. Based on our analysis the NCR does not appear to have an apparent role in the exchange of knowledge between Dutch researchers except that NCR members tend more to cite the same external literature. This result suggests that in this case the foundation of supra-organizations has not yet proved an effective instrument for promoting interdisciplinary collaboration, at least not in terms of co-authoring papers.

When the network structure is visualized different organizational clusters of collaborating researchers are recognizable. The universities represent the most prominent research institutes and are central as research 'hubs'. A recognizable cluster of hydrology/engineering research is affiliated with Delft-based institutes. Another cluster is made up by researchers from Radboud University and the Utrecht University. The network structure reveals that direct mutual collaborations between these clusters are limited, which designates barriers for direct cross-disciplinary exchange. This is in line with findings by Van Hemert & Van der Meulen (2011) who assessed the cognitive structure of river science in the Netherlands in a descriptive qualitative way. They observed substantial knowledge exchange between ecology and the geosciences but no indication for cross-disciplinary exchange between ecology, geosciences and water engineering. Similar observations were made based on a bibliometric mapping of international river science (Vugteveen et al. submitted).

An explanation may lie in the different epistemological characteristics of geomorphology, hydrology and ecology. Benda et al. (2002) indeed noted that ecology and geomorphology in a way are scientifically more 'compatible'. Hydrology and engineering have a more applied and solution-oriented research tradition while ecology and geomorphology are more problem-oriented, more fundamental disciplines.

Furthermore Van Hemert & Van der Meulen (2011) noted that ecology functions as a basic discipline for geoscientific specializations in river research. Interestingly in the Dutch river scientific community, geomorphological work by researchers, especially from the Utrecht University, is cited most frequently across other institutes suggesting that the research work of Utrecht functions as a common knowledge base to researchers from other fields. Utrecht University seemingly has an important role in brokering information and in acting as a central conduit for information, which is also supported by the strong liason role that Utrecht University fulfills opposed to the strong coordinator role exemplified by other major universities.

In the network structure it is visible that especially geoscientific researchers act as intermediaries in linking the ecology- oriented RU cluster and the hydrological engineering-oriented Delft cluster. From an epistemological perspective this makes sense as the geophysical environment provides the physical basis for both hydrological engineering and ecological processes, whereby the river basin functions as the shared unit of analysis for integrating lotic ecology and fluvial geomorphological and hydrological research (Van Hemert & Van der Meulen 2011).

Based on the combining findings on institutional collaborations and research output it can be derived that Dutch river science is rather disciplinary organized, thereby exhibiting a disciplinary base that is rooted in hydrology, geomorphology, ecology, environmental science and management. In this sense Dutch river science does not depart from the disciplinary scope of international river science (Thorp et al. 2007), in which research on the bio-physical system is also dominant and the research domain is strongly disciplinary structured (Van Hemert & Van der Meulen 2011; Vugteveen et al. submitted). Given the societal and complex context of riverine management issues calls for river science to include social research in addition to natural science have been made (Lenders 2003; NRLO AWT & RMNO 2000). Merkx & Van den Besselaar (2008) found that in Dutch coastal research broader societal, managerial and policy aspects were being addressed, although substantial contributions from social research did not seem to be involved. Similarly, we found the research output to include river basin management policies, but no evidence for an established social scientific research programme.

Assuming the dependency of social patterns on cognitive structures we investigated if collaborations between researchers of similar disciplinary backgrounds are more easily established. We indeed found that collaboration hinges on shared knowledge. Shared external references have clearly the largest predictive power. Dutch researchers who have more similar citing patterns with respect to external researchers are much more likely to co-author papers.

Alternatively there is also dependency of cognitive structure on the social structure. Affiliation at lower organizational levels not only showed a positive relation to collaboration but also substantial positive effects on citing each other's work. In a study of an interdisciplinary research organization White et al. (2004) used QAP and compared results from both bibliometric and social network measures. They found that citation was motivated more by a researcher's disciplinary perspective than by their interpersonal associations like friendship. In line with this observation we found that researchers sharing international literature - a reflection of a shared disciplinary perspective - tend to cite each other more often.

Finally there are some limitations that need to be addressed to assess the significance of our findings. A well-known limitation of using bibliographic data is the lack of normalization of the institutional field, which we also encountered. The effects of missing data are unknown since we are unable to compare the observed network data with a data set that includes all affiliations.

Similar to White et al. (2004) the predictive power of the QAP regression models in our study proved to be modest. The exact number of co-authored papers, internal references, or shared external references may be difficult to predict while the simpler question whether or not two researchers collaborate or have a shared knowledge base, may be more predictable. At present however no QAP variant exists that handles dichotomous dependent variables, i.e. logistic regression models. Also we realize that there are several important predictors omitted from the model such as formal relations among researchers including supervisor-PhD student relations. In addition there are types of collaboration that do not result in journal publications such as writing research proposals together, shared editorship of publications or organization of scientific conferences as well as e.g. contract research, and so on (Mali et al. 2012). In the Dutch river science context this is for instance the case for NCR. Also consideration of other social aspects like funding structures and existing traditions in the disciplinary organization of universities (Hicks et al. 2010) is required to provide more insight in the social network structure of river science. Indeed there may be programmatic and financial reasons for disciplinary barriers in the knowledge infrastructure. An earlier qualitative evaluation concluded that water-related knowledge development should be more integrated as it was assessed to be programmatically and financially compartmentalized along policy sectors and different interests (De Wilt et al. 2000; NRLO AWT & RMNO 2000).

Finally we did not consider the dynamics of structures, i.e., how and why network structures change and the effects on research performance, as well as the social effects of structure on the distribution of power and influence (Bodin et al. 2006). A more elaborative approach to identifying the role of the most prominent researchers could be to consider the strategies or methods employed by them and then asking which strategies appear more or less efficient given a researcher’s specific position (Bodin & Crona 2009). In their study (van Rijnsoever & Hessels 2011) already addressed some of these issues for Dutch research though for a single university case only.

Social network analysis has only recently been introduced into the study of natural resource management (Bodin et al. 2006; Bodin & Crona 2009), including a few water-related studies (Berardo 2009; Muñoz-Erickson et al. 2010). So far these applications have focused on understanding the characteristics of social networks that increase the likelihood of collective action and successful governance (Prell et al. 2009). Social network analysis proved valuable for gaining systematic insights into the relations and structural characteristics of the social complexity relating river research performance and cross-disciplinarity. The type of analysis performed in this study can serve as a tool to give insight in scientific performance in support for better environmental and political literacy, and can potentially foster adaptive capacity in river management strategies.

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Appendix

Table A1. Keywords used in ISI topic search for river papers

Topic search (in title, abstract and keywords) over all indexes (ISI: SCI-EXP, SSCI, A&HCI); searches were performed with general (1) and more specific river-related keywords (2), as well as an additional search (3) in the social & humanities index (SSCI and A&HCI).

1)	river*			
2)	alluvi* SAME deposi*	drainage basin(s)	meander*	stream gradient*
	alluvial AND river*	floodplain*	Meuse	stream order*
	alluvial plain*	flow power	morphodynamics	stream reach*
	anadromous	fluvial AND river*	oxbow*	streambank*
	backwater*	fluvial dynamics	pool* SAME riffle*	streambed*
	braided channel*	headwater*	Rhine	streamflow
	braided stream*	hydroconnectivity	running water*	tributar*
	catadromous	hydropower	side channel	water management
	catchment(s)	instream*	stream bank*	water resource(s)
	dam(s)	inundation	stream bed*	watershed(s)
	dike(s), dyke(s)	levee(s)	stream channel*	weir(s)
	drainage area*	lotic	stream discharge*	
3)	water	flood(s)	flooding	

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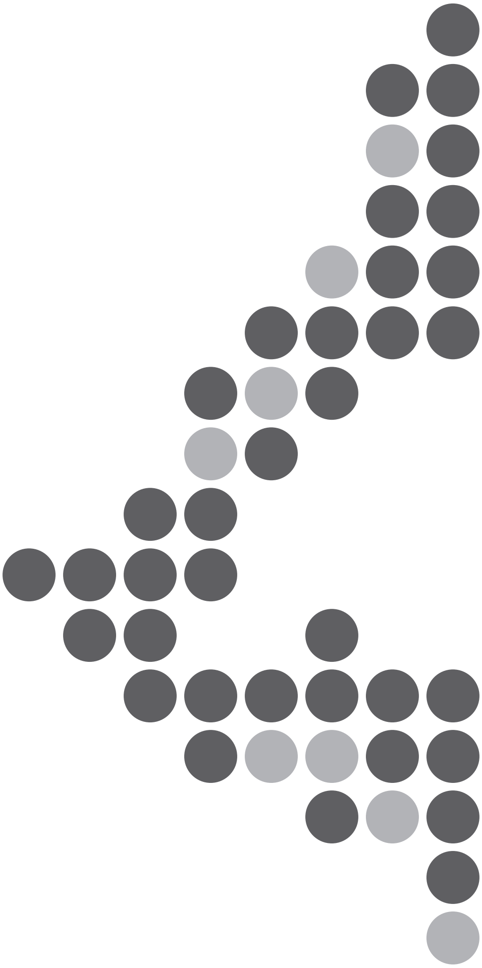
CHAPTER 7

Synthesis



1 Articulating Integrated Water Management

This thesis set out to critically analyze the meaning and scope of the integrated approach and its wider meaning for integrated water management (IWM) strategies. Point of departure was the observation by several authors that IWM has different meanings to different scholars as well as IWM stakeholders, which is associated with the fact that conceptual premises and the elements under integration between different management approaches vary widely (Biswas 2008; Downs et al. 1991; Scrase & Sheate 2002).

The main issue being addressed was an analysis of the integrative discourse regarding current water management with specific attention to its scientific framing. Specifically, the consideration of IWM scientific framing included a focus on how the challenge of cross-disciplinarity has shaped the relationships and interactions within IWM related research. This concluding chapter will synthesize the overall findings in relation to the research questions posed in the introduction. Based on these findings an overarching conceptual framework is presented that links the analytical and conceptual dimensions of IWM as forwarded by this thesis.

Understanding River Ecosystem Health (Chapter 2)

The theoretical underpinning of integrated management strategies requires understanding of the combined social-ecological functioning of a river system and the human-natural relationships involved (Surridge & Harris 2007). Chapter 2 reviewed developments in the elaboration of the River Ecosystem Health (REH) approach to answer in what way this model of systemic framing allows combining scientific facts and societal values for supporting and assessing IWM strategies. In literature the general concept of health is linked with different underlying theoretical and philosophical perspectives (Hofmann 2001) but it was applied as an evaluative concept of system performance.

An analysis of available literature showed there is still no consistent meaning of the central concept Ecosystem Health, resulting in an elaboration of theoretical models that have unclear and insufficient conceptual grounds. Furthermore, a diverse terminology is used for describing REH, resulting in confusion with other concepts such as biological integrity. However, if the concept is to have merit and longevity in the field of river research and management and is to be purposeful for examining the performance of ecosystems, a coherent and clear definition of the conceptual meaning and its operational domain is required (Hearnshaw et al. 2005; Rapport et al. 1999). Therefore a redefinition of REH has been proposed based on identified characteristics of health and derived from considering semantic and conceptual definitions. Herein REH is defined as a river's ability to sustain its ecological functioning (vigour and resilience) in accordance with its organization while allowing social and economic needs to be met.

Ecosystem health thus focuses on ecosystems as its unit of measurement and concentrates on ecological functioning in the context of human utility. It seeks to ensure the sustainability of the ecosystem while acknowledging that humans are an integral part of (most) river ecosystems. Consequently at the root of ecosystem health are the ideals of co-evolutionary development: the conditions necessary to sustain the capacity of an ecosystem are very much dependent on society, while society in turn is dependent on these very ecosystems for its own health and development (Hearnshaw et al. 2005). Consequently REH derives its meaning within the broader context of River System Health (RSH) that considers societal functioning next to ecological functioning (see Figure 2.2). Ecosystem health standards therefore need to be derived with reference to the ecosystems role in the whole social-ecological system.

Next to holding rational claims, REH as a management concept is undeniably value-laden as it involves how we as a society view our relation with nature and (should) deal with the natural resource of water. Obviously any environmental quality appropriation in terms of “good”, “better” or “worse” inherently involves a value judgment. The health of an ecosystem therefore presents not a technical but a normative concept since ultimately society, including science, determines what is “good” or “healthy” environmental performance.

The scope of REH guided management and definitions of optimum performance are thus bound by a specific socio-cultural value context. This implies that assessments of health state require definition of the (optimum) capacities of an ecosystem for the effective performance of the roles and tasks (i.e. benefits from ecosystem services) for which it has been locally ‘socialized’. Thereby the ecological criteria and benchmarks for demarcating health and the degree to which societal values and preferences can be met should be determined by boundary conditions of viability, i.e. the system's ability to survive, develop, and maintain its resilience (Bossel 1999, 2001; Sullivan & Meigh 2007). In the context of defining sustainability goals for IWM this subsequently means that one should account for long-term viability and maintaining ecosystem services while acknowledging that ecosystems are dynamic and ever changing entities. The REH concept is compatible with a management process of accounting for change in the sense that it communicates that effective management of a changing system may best be focused on the maintenance of (rationally deliberated) *values*, i.e. qualities, and not on maintaining the (same) *state* of the system (Hearnshaw et al. 2005; Kabat et al. 2012).

The practical assessment of health requires the integration of measures of multiple and complementary attributes. The assessment framework presented in Chapter 2 (see Figure 2.3) highlights a selection of suitable indicators that together enable REH assessment (Tables 2.2 & 2.3). This means using descriptive 'top-down' indicators of system performance (i.e. condition indicators) that are able to evaluate the effects of human interactions on ecological functions, as well as diagnostic 'bottom-up' indicators that are indicative of the causative stress factors (i.e. stressor indicators). The challenge then for assessing REH is to select a comprehensive and meaningful indicator set that combines the sense of holism with the clarity of reductionism.

Next to seeing relationships at the level of values the ecosystem health concept owes its popularity to its intuitive appeal. The health metaphor provides a powerful discursive tool as it enables an easy comprehension by fundamentally drawing on the expressions developed in human health and integrating these notions with ecological theory. The health metaphor therefore has added value in facilitating cooperation and stakeholder involvement in river management, as it is able to mobilize social and natural scientists and performs a communicative function for the general public (Keulartz 2007).

Understanding the science-policy interface (Chapter 3)

Water management strategies act at the science-policy interface as they are being scientifically informed and politically value laden. Although IWM schemes have been widely adopted since the eighties dissimilarities in the processes of science and policy have been argued to underlie the difficulties and ambiguities in their policy implementation (Cullen 1990; Jeffrey & Gearey 2006). Chapter 3 therefore examined the various meanings of IWM within the domains of science and policy. Moreover, the question was asked to what degree the science-based rationales of IWM have triggered strategy development in water management policies.

It was shown that in science (see Table 3.1), IWM presents a collection of theories and approaches that are based on distinct research traditions with different underpinnings relating human-nature relationships. The reviewed management concepts represent a spectrum ranging from 'management for humans' to 'management for nature'. These governance paradigms capture different eco-centric and holo-centric motives and include positivist and constructivist epistemological premises (Röling 2000; Stephens & Hess 1999).

From the analysis it showed that most concepts do not strictly adhere to either one perspective. In the current scientific arena, there is general consensus that best management practices cannot be solely based on optimizing consumptive uses (Cortner & Moote 1994). Integration efforts in scientific developments of IWM tend to be more and more aimed at including 'soft' relations from a holo-centric perspective (Röling 2000), defining management in the context of social governance networks and the images and interpretations by human members of its system (Checkland 2000). Concepts such as social learning for example build on the theory of soft systems and articulate that IWM practice needs learning and participation by different interest groups (Mostert et al. 2008; Pahl-Wostl et al. 2007).

Using the case of Dutch water policy Chapter 3 furthermore showed that IWM is functional for framing diverse objectives and is able to accommodate the political agenda over time instead of being a fixed procedural framework with set principles. IWM plays a role in adapting different orientations towards integration over time to various shifts in political focus and urgency.

Apparently IWM means something different in both science and policy. In science IWM is seen as a comprehensive systemic understanding for linking research, while at the policy level it is understood as a political and ideological construct in deliberating and unifying management objectives. This difference corresponds with observed cultural differences between science and policy; whereas in science the rational–analytical model is dominant, policy is driven by a mode of bargaining and the containment of conflicts (Cullen et al. 1999; Hoppe 2005). Being able to prevent these conflicts requires responsive and reflexive management strategies in which understandings of diverse societal values are taken into account.

Understanding value orientations (Chapter 4)

Understanding of the societal context in which stakeholders are embedded is considered essential to guide scientific efforts for IWM support and move beyond mere technical perspectives (Endter-Wada et al. 1998; Ludwig 2001; Pahl-Wostl 2002). However, to date knowledge about this societal context is hardly used in most social-ecological management models (Glaeser et al. 2009). Chapter 4 therefore focused on the societal value orientations that underpin IWM and how these differ among stakeholders in the context of Dutch water management. Developing understanding of the different views that exist on water systems and their management can stimulate reflection about the scientific support needed for underpinning IWM strategies.

In the study a set of statements was used that described the current valuation discourse on water management in nine basic value dimensions covering ethical, affective, and cognitive value priorities (see Figure 4.1). The ethical perspective refers to moral justifications for choices in water management; the affective view concerns aesthetic motives; and the cognitive view denotes rational motives. Furthermore, statements were categorized according the form in which values may be expressed, namely, at the individual or social level, or assigned to objects in the experienced world of humans (Lockwood 1999; Swart et al. 2001).

Using Q-methodology five different orientations were identified that represent characteristically different ways of valuing water systems and their management by stakeholders (see Table 4.4). The expert-dominated group of *Holists* adhered to the social-ecological aspects of water systems by valuing their complex dynamics and associated landscape. In contrast, the group of *Technocrats* complied to a more traditional utilitarian resource management view with a focus on user functions and technical control of the water system. The *Producers* group was comprised of stakeholders from different economic sectors who especially emphasized the economic use values of nature. Conversely *Accountable Managers*, including governmental managing bodies, put more emphasis on the socio-political aspects of water systems and management by highly valuing a fair division of responsibilities and stewardship. Finally, the *Environmentalists* showed a clear orientation emphasizing a personal relation with nature and expressing an ethical protective standpoint to dealing with nature, based on an intrinsic value of nature.

Understandings of how value orientations shape the perceptual framing of issues and problems amongst these stakeholder groups is relevant for the technical development of IWM approaches; bringing facts and values together helps the advancement of IWM by producing socially robust problem solutions (Gibbons 1999). Decision makers can benefit from these understandings of value orientations to resolve conflicts, develop planning scenarios, and build consensus. Bringing understandings about value orientations into development schemes for IWM however poses challenges for the organization and practice of science (Bradshaw & Bekoff 2001). Besides technical- and natural sciences the scientific support of IWM needs to synthesize and integrate social scientific concepts and methodologies (Balstad Miller 1998; Donaldson et al. 2010; Lowe et al. 2009; McCulloch 2007).

In order to better understand the combined social-ecological complexities in water management issues the necessity for cross-disciplinary bridging of expertise, methodologies and epistemological perspectives has been widely acknowledged (Ewel 2001; Klein 2004). In contrast, the difficulties of overcoming disciplinary barriers and attaining cross-disciplinary collaboration have been recognized as well. Obstacles have been attributed to several well-known reasons, including differences in scientific language, theory types, research strategies and organization (Benda et al. 2002; Boulton et al. 2008; Cullen 1990; Donaldson et al. 2010; Petts et al. 2006).

Understanding international river science (Chapter 5)

The recognition of the benefits of cross-disciplinary efforts for IWM raised the question to what extent current river science presents a cross-disciplinary endeavor. By considering scholarly output Chapter 5 mapped the scientific landscape of international river science and evaluated the extent to which its present knowledge base gives evidence of cross-disciplinarity.

For the assessment different bibliometric approaches and indicators were used including citation and word-reference analysis (Van den Besselaar & Heimeriks 2001). River science was found embedded in a network of twenty three research fields wherein the core disciplines were shown to be limnology, fisheries & fish research, hydrology & water resources, and geomorphology. Furthermore distinct clusters of fields (meta-fields) were identified, broadly covering biological and ecological sciences, environmental sciences and the geo- and geochemical sciences. Though knowledge exchange within these meta-fields was observed, generally limited knowledge exchange was exhibited between them. In addition the mapping made clear that the knowledge base of river science does not yet clearly reflect the arrival of new cross-disciplinary fields such as ecohydrology, hydroecology or hydromorphology (Bond 2003; Hannah et al. 2004; Vaughan et al. 2009). Together this demonstrates that river science today operates in a scientific structure characterized by distinct disciplinary fields.

Complementary to the field mapping a topics analysis was performed. This showed that although individual fields hardly use knowledge from disciplines outside of their meta-field, various research topics are addressed by multiple fields at the operational research front. Such research topics thus represent a combined contribution of mono-disciplinary research, which implies multi-disciplinary research efforts at the operational research front (Tress et al. 2005). Especially comprehensive topics on human-natural issues such as the effects of climate change in river basins may function as theoretical ‘boundary objects’ for different disciplines as they invite so-called ‘epistemological pluralism’ (Donaldson et al. 2010; Miller et al. 2008).

Given the claimed necessity for integrating research and knowledge from the natural and social sciences for IWM a specific indicator of interest concerns the acceptance of more advanced social scientific concepts and theories in river-related scientific research. In the performed bibliometric mapping a lack of engagement of social science beyond natural sciences was found. Though planning and management issues were found to be part of river science research, there was no evidence in the mapping of established social scientific disciplines such as psychology, sociology, political science, economics and policy studies (Surridge & Harris 2007). Instead river science is still found to be mainly driven by natural science as has been traditionally the case. Also Botey et al. (2012) found that studies related to ecosystem management are dominated by the philosophical, ontological, and epistemological preferences of natural science. Concerning river science the firm establishment of ecological disciplines in the mapping suggests that the ecosystem paradigm itself has settled in the heart of the scientific landscape (Brierley & Fryirs 2008; Wrona & Cash 1996).

Importantly the mapping exercise of river science made clear that there is only a modest exchange of knowledge between fields. It was seen that fields hardly inform themselves with knowledge from fields outside their direct scientific domain, which means that mono-disciplinary instead of cross-disciplinary theory development is stimulated. These findings are in line with observations by Porter & Rafols (2009) who examined the degree of interdisciplinarity in mathematics, physics, biology, engineering, medicine and neurosciences. They suggest science is becoming more interdisciplinary, but in small steps – drawing mainly from direct neighboring fields and only modestly increasing the connections to distant cognitive areas, like social scientific fields in the case of river science.

When considering the dynamics of river science at the field level, it was found that cross-disciplinary behaviour is restricted to the sharing and mutual adoption of research topics.

The research scope of hydrology & water resources research field for example shares many of the identified topics with other fields, but at the same time remains a strongly mono-disciplinary oriented field. Based on the findings river science as a whole can be qualified as a multi-disciplinary, i.e. consisting of input by multiple mono-disciplines, endeavour. However, inter- or transdisciplinary research efforts do not seem to be apparent in river science yet, as the analysis did not provide evidence of the theoretical merging and integration of knowledge bases from individual disciplines (Tress et al. 2005).

Though co-production and integration of knowledge requires collaborative learning and knowledge sharing (Roux et al. 2006), institutional and individual barriers in scientific activities have been mentioned as an important factor in limiting cross-disciplinary co-production and affecting the bidirectional exchange of knowledge (Boulton et al. 2008; De Wilt et al. 2000; Van Hemert & Van der Meulen 2011). A final study was therefore performed to assess the importance of social and institutional factors.

Understanding Dutch river science (Chapter 6)

Chapter 6 focused on the question whether and which collaborative patterns and institutional arrangements foster or hinder knowledge exchange within the Dutch river science network. Exploratory and statistical techniques from social network analysis were applied to bibliographic data for mapping and evaluating cross-disciplinary collaboration. It was investigated whether collaborations between researchers of similar disciplinary backgrounds are more easily established. The results indeed indicate that collaboration in terms of co-authoring papers is mainly driven by a shared knowledge base. Researchers sharing international literature - a reflection of a shared disciplinary perspective - tend to cite each other more often and collaboration was positively related to close proximity at work, that is, being affiliated to the same centre or department. In contrast, organizational contacts at higher levels, even affiliations to an organization designed to integrate river science, seem to be of less consequence to co-authoring papers or citing each other's work.

Using visualization techniques it was shown that the core community of active river scientists has a ring-shaped network structure in which different organizational clusters of collaborating researchers are recognizable. The universities represent the most prominent research institutes and are central as research 'hubs'. A main cluster of hydrology/engineering research is affiliated with Delft-based institutes while another large cluster is made up by researchers from Radboud University and the Utrecht University. The network structure revealed that direct mutual collaborations between these clusters are limited, which designates barriers for direct cross-disciplinary exchange. Geoscientists, especially in geomorphology seem to act as intermediaries in linking cognitively more distant disciplines like ecology and hydrology.

The limited cross-disciplinary collaboration observed in the river science network may as such negatively influence innovative contributions and solutions for integrated river management. Dutch river science is rather disciplinary organized, thereby exhibiting a disciplinary base that is rooted in hydrology, geomorphology, ecology, environmental science and management. In this sense Dutch river science does not depart from the disciplinary scope of international river science that was mapped in Chapter 5, in which research on the bio-physical system was also found dominant and the research domain strongly disciplinary structured (Thorp et al. 2007; Van Hemert & Van der Meulen 2011).

Similarly to the international river science study in Chapter 5 no evidence was found of an established social scientific research programme in the Dutch river science network. National calls for combined social and natural science support of water management have been made (NRLO AWT & RMNO 2000) but the findings suggests that collaborative learning (Roux et al. 2006) must still be further stimulated in (national) scientific programmes on rivers. The findings support the notion that collaboration is itself a complex system of people. Cross-disciplinary interactions should arguably be intentionally stimulated and managed through specific research programmes. However, the analysis showed that an organizational level specifically designed to integrate river science in the Netherlands was of limited consequence in measured co-authorships. This makes clear that it may be difficult to organize and coordinate effective working environments (Pennington 2008; Perz et al. 2010).

2 An integrative framework for IWM

The concepts, approaches and findings advanced in the previous chapters together form an inductive base from which an investigative and methodical framework for IWM strategies will be derived in this section. This framework is presented in Figure 1 and reflects key systemic dimensions and interconnections that define an integrative perspective on IWM.

The framework acknowledges the interconnections within and across systemic dimensions that are relevant for the development and evaluation of IWM approaches and strategies. These nested and interacting systemic dimensions involve social-ecological, societal-organizational, personal-cultural, and normative-cognitive components and their interrelationships, which will be described below. Based on the foregoing findings this framework aims to communicate some essential attributes of IWM strategies, i.e. that any integrated approach for IWM needs to be *interconnected*, *comprehensive*, *strategic* and *interactive* (Born & Sonzogni 1995). Interconnectedness and comprehensiveness comprise the fundamental characteristics of an integrative system perspective in IWM (Stephens & Hess 1999). *Interconnectedness* addresses the relevant interrelationships and linkages among the included system components while *comprehensiveness* relates to the degree of inclusivity. Interconnectedness concerns the cross-scale linkages and feedbacks within and across different system dimensions covering social, biological, physical and chemical processes, and interrelationships among the many and disparate entities that together make up the socio-economic community and natural environment of interest. Being comprehensive then involves specifying all the relevant elements of concern for defining the scope and scale of IWM activities. These elements may include ecosystem components, resource uses, and the different engaged social communities.

The above attributes are essential to developing and evaluating integrated approaches and underlie the design of the integrative framework presented in Figure 7.1. Combining the findings and theoretical underpinnings of the previous chapters this framework aims to provide a useful mind map that synthesizes the meaning of integration and presents the focal elements to be considered in evolving integrated approaches and IWM strategies.

In this framework the *social-ecological dimension* concerns the definition and understanding of system boundaries, components and functioning (Mika et al. 2008). It designates the objective ‘hard’ reality of social-ecological systemic complexity and performance in terms of functioning and structural attributes. The concepts of River Ecosystem Health and River System Health –which communicates a wider sustainability approach– present suitable conceptual frames to model and evaluate the relevant systemic relations in IWM strategies and objectives. These concepts express that system processes that are conditional for maintaining ecological viability and human well-being need to be recognized.

When evaluating system processes in management it is necessary to be aware of the significance of scalar context (Brierley et al. 2008; Cullum et al. 2008). Natural and social systems express different and typical hierarchies of spatial and temporal scales which determine the underlying circumstances for system dynamics (Cash et al. 2006; Cumming et al. 2006). Spatial and temporal scales to which processes and values relate need to be made explicitly recognized. This particularly concerns those management aspects which are sensitive to a place and time, such as social, historic and cultural values (Lenders & Knippenberg 2005). Disregard of context by following a standardized approach in developing management solutions has been mentioned as an important barrier regarding the effective implementation of IWM (Hooper et al. 1999). For example in current river management the catchment unit has evolved as the primary unit for planning and guiding management objectives. However, socioeconomic processes, administrative units and webs of power that influence the management of water resources often do not coincide and harmonize with geographical limits

(Falkenmark 2004; Gregory et al. 2011; Hillman et al. 2008; Molle 2009). Such scale differences in geographic and socio-economic processes however need to be recognized in management strategies.

Next in Figure 7.1, the *societal-organizational dimension* seats in the social-ecological dimension and relates to the network constellations of management actors and stakeholders, and how they employ activities and interact through dependency relations, habits, and social codes in the total management network. It is the dimension that signifies the integration of communities, organizations, sectors and administration. The network structure of scientific and policy arrangements in reality are complex and intertwined concerning many and diverse stakeholders and institutions. In this thesis the conceptual discussion of IWM has been limited to considering the IWM policy domain versus the scientific domain and its networks. Translated in a simplified representation in Figure 1, policy-makers act in (sub) networks in which planning and implementation activities take place whereas scientists perform research in scientific networks.

A principal element associated with IWM is the need for continuous learning, achieved through the inclusion of multiple sectors of society and their diverse sets of knowledge and values (Newig et al. 2010; Pahl-Wostl et al. 2008). Chapters 5 and 6 specifically considered learning in scientific networks by evaluating the degree of cross-disciplinary knowledge exchange and collaboration. As exemplified by these studies network analysis can serve as a tool to give insight in scientific performance in support for better environmental and political literacy. Having greatly expanded across the academic spectrum in the past five years, network analysis tools are increasingly used for gaining systematic insights into the relational and structural characteristics of social and environmental complexity (McMahon et al. 2001; Watts 2004). Next to identifying social structural perspectives and important relational patterns (Bodin et al. 2006; Bodin & Crona 2009; Crona & Hubacek 2010) IWM strategies may benefit from network analysis by allowing evaluation of both the social relations between different sectors of society - including policy and science -, as well as environmental systemic relations including properties like resilience (Chilvers & Evans 2009; Janssen et al. 2006; Mageau et al. 1998). The movement in environmental research towards acknowledging people as integral ecological subjects instead of mere instrumental independent agents is opening up possibilities for natural scientists to collaborate with social scientists (Lowe et al. 2009). The theoretical concepts and tools of network analysis have the potential for stimulating cross-disciplinary research by joint use in social and natural scientific disciplines. Besides networks also a new concept like community resiliency using common ground in ecological and social-psychological strands of literature may stimulate new IWM approaches by combined natural and social scientific contributions (Berkes & Ross 2013).

Next to acknowledging social interactions, IWM strategies need to be socially relevant in terms of coherently taking into account (understandings of) the existing societal value frames. The *personal-cultural dimension* presents a ‘soft’ dimension (Checkland 2000) that acknowledges the plurality of value frames in individual (“I”) and collective spheres (“We”). It represents the (inter-)subjective system level that includes the exchange of normative assumptions and knowledge. In the IWM discourse differences may exist between management actors in how they frame management issues and see options for management actions. Network actors thus base their behaviour to reach IWM goals on their definitions of reality (‘what is’) and on their values and frames of reference (‘what ought to be’). Individual actors embody different associations of understandings and values that drive rational, aesthetic and moral motives for how they think and what they do. Together, these realities and values shape how research issues and management are ultimately understood, and are an important factor in achieving management collaborations (Dewulf et al. 2007). This is referred to as the *normative-cognitive dimension*. Chapter 4 examined the national context of Dutch river management and identified a set of such value orientations. Different sets of orientations exist depending on different historic, geographic and societal settings. For applying adaptive governance approaches understanding of this dimension is essential; in the context of using system health as an evaluative management framework it becomes important to reveal *whose* values and norms are constitutive for its definition (Hofmann 2001).

The chosen Q-methodology approach in Chapter 3 presents a straightforward and practical tool to elucidate these orientations in a meaningful way for developing management strategies and open up active dialogues about (un)shared values for effective collaboration (Eigenbrode et al. 2007).

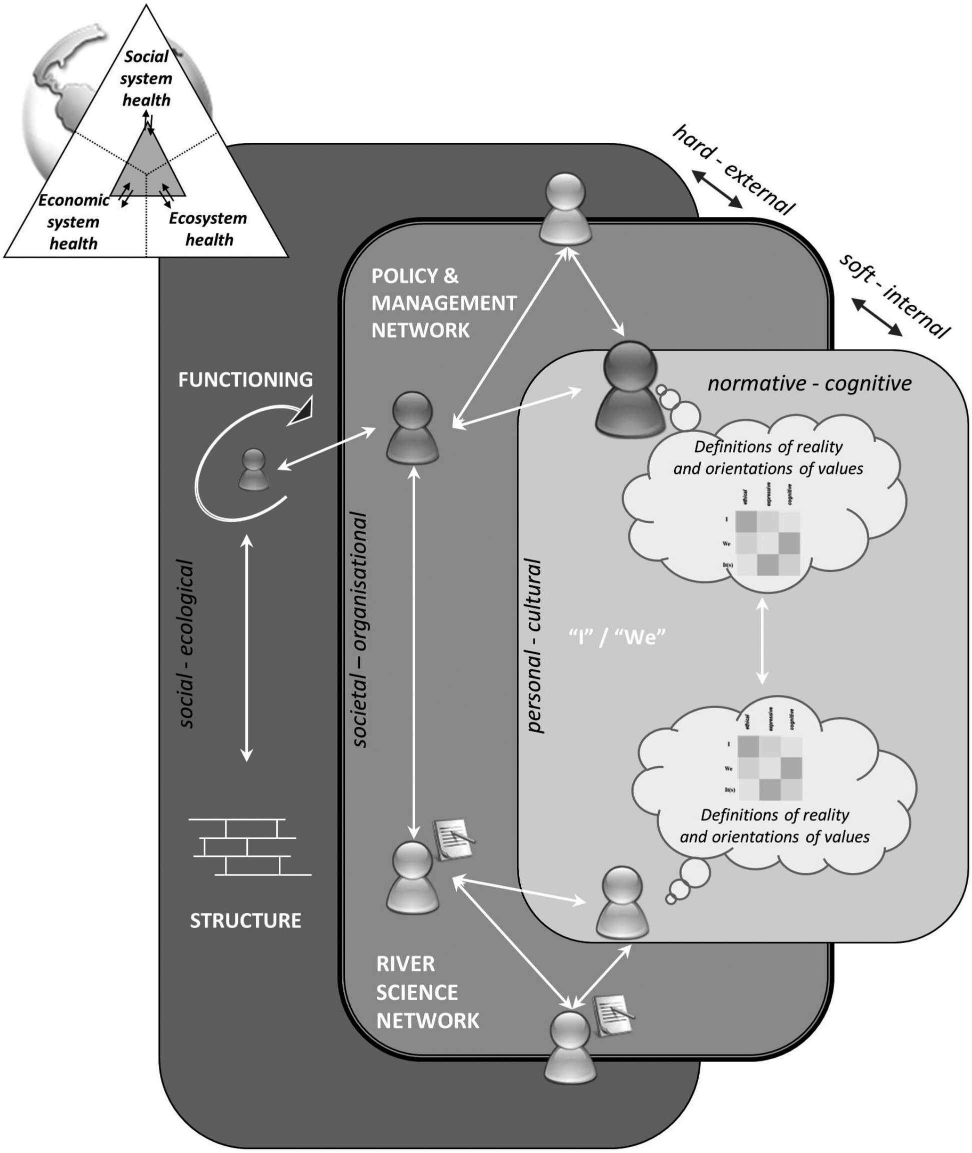


Figure 1. Connecting the dots

An integrative IWM framework defining key systemic dimensions and essential interconnections for analyzing integrated approaches and IWM strategies.

The figure combines graphic elements from figures and findings in previous chapters. The societal-organizational dimension is outlined in bold to indicate the operational action frame for IWM, i.e. where actors interact to develop strategies.

As explained above interconnectedness and comprehensiveness represent principal aspects in theoretically framing an integrative system perspective. In addition two other aspects are specifically relevant for the practicality of IWM development. First there is the very practical notion that an IWM approach requires a strategic process of defining the substantive elements in management, i.e. defining what *can* instead of what *should* be included. Secondly IWM development requires interactive and coordinative procedures since knowledge about substantive elements is dispersed amongst actors and institutions (Born & Sonzogni 1995). These aspects will be subsequently described in more detail.

Developing a comprehensive IWM strategy involves having *all* the relevant factors and dimensions in view. But obviously the demarcation of what counts as ‘all factors’ gives rise to much debate. An early interpretation of the system approach to river basin planning and management has been to regard an integrated approach as synonymous with a comprehensive approach in which attention should be given to all components and linkages in a system (Mitchell 2005). However when such a truly comprehensive approach is taken the likelihood of identifying practical solutions in a reasonable time frame and with feasible financing may become low, leading to the danger of ending up with superficial solutions (Boon 2000; Hooper et al. 1999). Consequently the number of variables and interrelationships subjected to analysis and action in IWM strategies must be reduced to be workable.

The *strategic/reductive* feature is essential when applying the systems approach at the practical level of management. Note that this argument for being strategic makes clear that the holistic perspective of IWM - acknowledging that the whole being managed is greater than the sum of the parts - contains an implicit paradox; i.e. that a process of rational reduction is required to identify elements for management. Such strategic down-sizing acts as a filtering process that bounds the inevitable complexity and uncertainty inherent to IWM. It aims to make IWM adaptive and more attuned to the realities of the political decision arena by trying to prevent unfeasible all-encompassing analyses that are too work-intensive and expensive.

As defined above, rather than seeking to examine all variables and relationships, an integrated approach in practice needs to focus on what are considered to be key or selected variables and relationships, thereby still being critically aware of not oversimplifying ecological complexity (Moss 2008). The rationale is that usually a relatively few variables and relationships cause most of the variability in a system, and therefore those are the ones deserving attention. In addition, it is appreciated that not all variables and relationships can be readily manipulated or managed, and so it is sensible to give attention to those contributing significantly to variation in the system and amenable to intervention by managers. Ecosystem health offers a conceptual foundation to highlight the key factors or “vital signs” that ought to be attended to and focus further research on. For IWM development River System Health presents a useful integrative concept which communicates that maintaining desired environmental and social system functions requires attention to all ‘vital’ *key elements* in the respective ecological, social and economic subsystems that are essential to the continuing productivity and wellbeing of the system as a *whole* (Tulloch 2010).

Reaching strategic choices requires the communication among and the co-ordination of diverse scientists and/or stakeholders to define the system parts and interrelationships of concern. An important procedural attribute of IWM is therefore that it must be *interactive,* since knowledge and information is dispersed amongst individual actors and institutions. IWM thus requires collaborative processes for making necessary tradeoff decisions. Hereby the arena for interaction is defined by the system scale and system relations considered in the process, i.e. the relevant degree of comprehensiveness and interconnectedness.

Over the years the number and types of stakeholders involved in management processes have expanded (Connick & Innes 2003), and collaborative processes now require more structured methods of information exchange and decision-making (Margerum 2008; Tulloch 2010). Network analyses can identify structural relations and communities, providing insights in key actors and stakeholders. Additionally the Q-sort methodology as applied in this thesis provides a suitable tool to identify and understand the different (conflicting) interests and underlying value orientations that are present in the network. These methodologies can be part of wider participatory and adaptive approaches to understand and enhance citizen and stakeholder engagement, building up the social capital and collaborative partnerships that are deemed essential for moving IWM forward as a successful public policy.

Interpreted in the context of the scientific practice being interactive typically involves engaging in cross-disciplinary endeavors. Khagram et al. (2010) suggest that such endeavors are best achieved by working across knowledge-based research programmes, i.e. a combination of different theory types, philosophies of knowledge and research strategies, rather than institutional structures. However, as the analysis of river science in the Netherlands made clear this may require the reorganization of research collaboration and interactions, next to shifts in the conceptualization of research and the incentive structures needed to undertake.

In conclusion, the combined studies in this work have provided an evaluation of what the conceptual meaning and scope of IWM entails. The key dimensions of integration that have been elaborated in the foregoing studies are synthesized in the proposed integrative framework. This mind map may direct future interdisciplinary work on IWM as the framework highlights key factors and interrelationships for research in IWM. Together with the combined methodologies presented in this thesis it may be used to frame and interpret IWM relevant data. Hopefully this work provides a handle for other researchers in successfully tackling the challenges of integrated research in the field of environmental management.

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SUMMARY

Over the last decades perspectives on holism and sustainability in water management have challenged science and policy into developing a host of new management concepts and strategies that are commonly labelled under the general banner of the integrated approach. This approach generally recognizes that water systems are complex systems with ecological, social and economic dimensions and that their properties need to be understood and managed from scientific, political and social points of view instead of its separate components.

Multiple elaborations in many variations have appeared under various but similar labels such as Integrated Water Resource Management and Integrated River Basin Management[1]. Despite widespread recognition of the integrated approach its interpretation and elaboration in management strategies and practice has been qualified as troublesome by scholars for various reasons. These include a lack of consensus on the meaning and the scope of IWM, the value-laden nature of IWM, poor articulation in different competing definitions, and barriers in institutional and collaboration arrangements. Given the large water management challenges society is currently facing and the on-going need for effective water management strategies a critical analysis of the meaning and scope of IWM in water management and its supporting science seems timely and urgent.

The central aim of this thesis is to deliver an analysis of the integrative discourse regarding current water management with specific attention to its scientific framing. Here the ‘integrative discourse’ is understood as the strategic and scientific communications in policy and academia that are aimed at acknowledging and understanding the interconnections in water systems in their broadest sense. More particular the research aims to address how underlying theoretical developments concerning systems thinking and societal policy- and value settings have shaped IWM conceptualizations, and how the challenge of cross-disciplinarity is reflected in current relationships and interactions within research.

The first study addressed system management conceptualizations that are able to address the combined fact and value based nature of IWM. The conceptu-

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[1] Integrated Water Management – IWM – will be used as an umbrella term.

alization and elaboration of an illustrative concept, River Ecosystem Health (REH), was reviewed. Analysis of literature showed that there is still no consistent meaning of the central concept Ecosystem Health. There is a diverse terminology associated with defining REH, resulting in confusion with other concepts and in models (i.e. elaborations) that have unclear and insufficient conceptual grounds. However, if the concept is to have merit and longevity in the field of river research and management, unambiguous definition of the conceptual meaning and operational domain are required. The study therefore proposes a redefinition based on identified characteristics of health derived from considering semantic and conceptual definitions. Herein REH is defined as a river's ability to sustain its ecological functioning (vigour and resilience) in accordance with its organization while allowing social and economic needs to be met. Following this definition REH has merit in a broader context of river system health that considers the societal functioning of the river system next to its ecological functioning. Assessment of health requires the integration of measures of multiple, complementary attributes and their analysis in a synthesized way. An assessment framework was proposed for assessing REH using descriptive 'top-down' indicators of system performance (i.e. condition indicators) as well as diagnostic 'bottom-up' indicators that are indicative of the causative stress factors (i.e. stressor indicators). Condition indicators include measures of system activity, metabolism (vigour), resilience, structure and interactions between system components (organization). The variety of stress effects that the system may endure may be diagnosed by using biotic, chemical as well as physical stressor indicators. The challenge for assessing REH is to select and use a comprehensive and meaningful indicator set that combines the sense of holism with the clarity of reductionism by focusing on the vital key attributes of system functioning.

For IWM ecosystem health is attractive as it has intuitive appeal and the ability to provide a powerful discursive tool in mobilizing scientists, practitioners and the public. The concept enables an easy comprehension by fundamentally drawing on the expressions developed in human health and integrating these notions with ecological theory. REH places humans at the centre of the river ecosystem, while seeking to ensure the robustness and sustainability of the ecosystem of which they are an integral part. Optimization of the indicator set, development of aggregation and classification methodologies, and implementation of the concept within differing international frames are considered main aims for future research.

IWM strategies function at the science-policy interface as IWM strategies are scientifically fact-informed and politically value-laden. Dissimilarities in the processes of science and policy have been argued to underlie the difficulties and ambiguities in the policy implementation of integrated approaches. A study was performed to compare and critically evaluate the various rationales of IWM approaches within and across the domains of science and policy whereby emphasis was given to describing how science has elaborated IWM in a conceptual way. The reviewed management concepts represent a spectrum of viewpoints ranging from ‘management for humans’ to ‘management for nature’. Most concepts do not strictly adhere to either one perspective and there is general consensus that management practices cannot be solely based on optimizing consumptive uses.

In the science domain IWM presents a collection of theories and approaches covering ecosystem, community and resource management. These approaches are based on distinct research traditions and concern different underpinnings relating human-nature relationships. Using the case of Dutch water policy it was shown that in the policy domain IWM is instrumental for framing diverse objectives and is able to accommodate the political agenda over time instead of being a fixed procedural framework with set principles. Over time IWM has come to encompass different perspectives on integration, i.e. components to be integrated in reaction to various shifts in political focus and urgency.

IWM thus means something different in both environmental science and policy. In science IWM is seen as a comprehensive systemic understanding for linking research, while at the policy level it is understood as a political and ideological construct in deliberating and unifying management objectives. . This different meaning corresponds with observed cultural differences between science and policy; whereas in science the rational–analytical model is dominant, policy is driven by a mode of bargaining and the containment of conflicts. Being able to prevent conflicts requires responsive and reflexive IWM strategies in which understandings of diverse societal values are taken into account.

Further, advancement of IWM depends on clarifying the different roles of science and policy in the framing process as well as considering the practice and nature of science itself.

Although understanding of the societal context of IWM application is considered essential to developing effective strategies, it has been argued that knowledge about this societal context is currently hardly used in most supportive scientific models of IWM. A study was therefore performed to examine the way value orientations differentiate themselves among IWM stakeholders and to assess implications for the scientific support and policy context of integrated approaches. Five orientations were identified that represent characteristically different ways of how stakeholders value water systems and their management in terms of cognitive, ethical, and affective value priorities. These orientations included an expert-dominated group of *Holists* who adhered to the social-ecological system perspective. In contrast, *Technocrats* complied to a more traditional utilitarian resource management view with a focus on the technical control of the water system while a *Producers* group emphasized the economic use values of nature. Conversely *Accountable Managers* put more emphasis on the socio-political aspects of water systems and management by highly valuing a fair division of responsibilities and stewardship. Finally, the *Environmentalists* emphasized a personal relation with nature.

Bringing facts and values together by identifying such stakeholder orientations helps the advancement of IWM by producing socially robust problem solutions. Decision makers can benefit from understandings of value orientations and problem framing to resolve conflicts, develop planning scenarios, and build consensus. This poses challenges for the organization and practice of science; besides input from technical and natural sciences substantiating IWM needs to include social scientific concepts and methodologies. This necessity for cross-disciplinary bridging of expertise, methodologies and epistemological perspectives has been acknowledged in the wider literature of environmental management. In contrast, the difficulties of overcoming disciplinary barriers and attaining cross-disciplinary collaboration have been recognized as well.

The recognition of the benefits of cross-disciplinary efforts for IWM raises the question to what extent the scientific enterprise of IWM research currently demonstrates cross-disciplinarity. A study was performed using different bibliometric approaches and indicators to help understand the knowledge base of current river science and the extent to which it represents a cross-disciplinary endeavour. Based on a mapping of its scientific landscape river science was found embedded in a network of twenty three research fields, including core traditional disciplines like limnology, fisheries & fish research, hydrology & water resources, and geomorphology. Furthermore limited knowledge exchange was found between distinct clusters of fields (meta-fields), broadly covering biological and ecological sciences, environmental sciences and the geo- and geochemical sciences. The analysis demonstrated that current river science operates in a disciplinary scientific structure and that the knowledge base of river science as exhibited through citation patterns does not yet clearly reflect the arrival of new cross-disciplinary fields. In addition the firm establishment of ecological disciplines in the performed mapping suggests that the ecosystem paradigm itself has settled in the heart of the river science landscape. An analysis of the dominant research topics was performed complementary to the field mapping which revealed that although individual fields hardly use knowledge from disciplines outside of their meta-field, many research topics are shared amongst multiple fields at the operational research front. Importantly, in the performed bibliometric mapping a lack of engagement of social science beyond natural sciences was observed since established social scientific disciplines such as sociology, economics and policy studies were found to be absent.

The overall mapping exercise of river science made clear that there is only a modest exchange of knowledge between fields. It was seen that fields hardly inform themselves with knowledge from fields outside their direct scientific domain, which means that mono-disciplinary instead of cross-disciplinary theory development is stimulated. Cross-disciplinary behaviour is restricted to the sharing and mutual adoption of research topics. River science as a whole can thus be qualified as a multi-disciplinary, i.e. consisting of input by multiple mono-disciplines, endeavour. However, inter- or transdisciplinary research efforts do not seem to be apparent in river science yet, as the analysis did not provide evidence of the theoretical merging and integration of knowledge bases from individual disciplines. This is in line with similar studies concerning other fields of science which suggest that science is becoming more interdisciplinary, but in small steps – drawing mainly from direct neighboring fields and only modestly increasing the connections to distant cognitive areas, such as social scientific fields in the case of river science.

Institutional and individual barriers in scientific activities have been mentioned as an important factor in limiting cross-disciplinary co-production and affecting the bidirectional exchange of knowledge. A final study applied exploratory and statistical techniques from social network analysis to bibliographic data for an evaluation of cross-disciplinary collaboration in river science in The Netherlands. Specifically it was determined whether and which collaborative patterns and institutional arrangements foster or hinder collaboration and the exchange of knowledge. The results of this study indicate that collaboration in terms of co-authoring papers is driven mainly by a shared knowledge base and close proximity at work; that is being affiliated to the same centre or department. In contrast, organizational contacts at higher levels, even affiliations to an organizational level designed to integrate river science seem to be of less consequence to co-authoring papers or citing each other's work. It was shown by network visualization that the Dutch community of active river scientists expresses a ring-shaped network structure in which different organizational clusters of collaborating researchers are recognizable. The universities represent the most prominent research institutes and are central as research 'hubs'. A main cluster of hydrology/engineering research is affiliated with Delft-based institutes while another large cluster is made up by researchers from Radboud University and the Utrecht University. The network structure revealed that direct mutual collaborations between these clusters are limited, which designates barriers for direct cross-disciplinary exchange. Geoscientists, especially in geomorphology seem to act as intermediaries in linking cognitively more distant disciplines like ecology and hydrology.

The limited cross-disciplinary collaboration observed in the river science network may negatively influence innovative contributions and solutions for integrated river management. Dutch river science is rather disciplinary organized exhibiting a disciplinary knowledge base that is rooted in hydrology, geomorphology, ecology, environmental science and management. In this sense Dutch river science does not depart from the disciplinary mapping of international river science that was mapped in the preceding study wherein research on the bio-physical system was found dominant and the research domain strongly disciplinary structured.

The findings support the notion that collaboration is itself a complex system of people. Cross-disciplinary interactions should arguably be intentionally stimulated and managed through specific research programmes. However, the analysis showed that an organizational level specifically designed to integrate river science was of limited consequence in measured co-authorships. This makes clear that it may be difficult to organize and coordinate effective co-working environments.

Together the concepts, methodological approaches and findings advanced in the performed studies form an inductive base from which an integrative framework for IWM strategies was derived. The framework communicates key systemic dimensions and interconnections that define an integrative perspective on IWM. It aims to provide a useful mind map that synthesizes the meaning of integration and to present the focal elements to be considered in developing integrated approaches and IWM strategies. Based on work in this thesis and IWM literature there are a few principal characteristics that are essential to an integrated approach. First *interconnectedness* addresses the relevant interrelationships among the included system components while *comprehensiveness* relates to the degree of inclusivity. Furthermore there is the practical notion that an IWM approach requires a *strategic/reductive* process of defining the substantive elements in management, i.e. defining what can instead of what should be included. Finally IWM development requires *interactive* and coordinative procedures since knowledge about substantive elements is commonly dispersed amongst actors and institutions.

The key systemic dimensions to be taken into account in IWM involve social-ecological, societal-organizational, personal-cultural, and normative-cognitive components and relationships. The *social-ecological* dimension concerns the definition and understanding of system boundaries, components and functioning. It involves the objective 'hard' reality of social-ecological systemic complexity and its performance in terms of functioning and structural attributes. The framework acknowledges that temporal-spatial location determines the underlying context for both social and ecological dynamics. The *societal-organizational* dimension is perceived as a network constellation of management actors and stakeholders, and how they employ activities and interact through dependency relations, habits, and social codes in the total management network. Especially application of network analyses is thought promising to further evolve IWM approaches as it has the potential for stimulating cross-disciplinary research by joint use in social and natural scientific disciplines. The *personal-cultural* dimension acknowledges the plurality of individual and collective value frames and represents the (inter-)subjective system level that includes the exchange of normative assumptions and knowledge. Individual actors embody different associations of understandings and values that drive rational, aesthetic and moral motives for how they think and what they do. Together, these realities and values shape how research issues and management are ultimately understood, and are an important factor in achieving management collaborations. This is referred to as the *normative-cognitive dimension*.

In conclusion, the combined studies in this work have provided an evaluation of what the conceptual meaning and scope of IWM entails. The key dimensions of integration that have been elaborated in the foregoing studies are synthesized in the proposed integrative framework. This mind map may direct future interdisciplinary work on IWM as the framework highlights key factors and interrelationships for research in IWM. Together with the combined methodologies presented in this thesis it may be used to frame and interpret IWM relevant data. Hopefully this work provides a handle for other researchers in successfully tackling the challenges of integrated research in the field of water management.

SAMENVATTING

Door diverse socio-economische ontwikkelingen hebben rivier-ecosystemen de afgelopen decennia zwaar onder druk gestaan. Dat heeft onder andere geleid tot een sterke achteruitgang van de kwaliteit van natuur en landschap. De vele maatschappelijke functies die rivieren in grote delen van de wereld, onder andere Nederland, dienen te vervullen maken de problemen waar het huidige waterbeheer voor staat bijzonder complex en veelomvattend.

Gebaseerd op recente perspectieven van holisme en duurzaamheid worden door wetenschap en beleid nieuwe beheerconcepten en strategieën ontwikkeld om tot oplossingen voor deze problemen te komen. Vaak worden deze onder de noemer van de *geïntegreerde benadering* gepresenteerd, met namen als *Integrated Water Resource Management* en *Integrated River Basin Management.*[1] In dergelijke uitwerkingen worden watersystemen gezien als complexe systemen met ecologische, sociale en economische dimensies, waarvan het beheer een gecoördineerde aanpak vereist, gericht op het in samenhang begrijpen van alle relevante onderdelen van het systeem.

Ondanks het feit dat de geïntegreerde benadering alom is geaccepteerd, wijzen wetenschappers en beleidsmakers ook op moeilijkheden in interpretatie en uitwerking van dergelijke geïntegreerde concepten. Deze moeilijkheden betreffen een gebrek aan consensus over de betekenis en reikwijdte van IWM, gerelateerd aan de verschillende en concurrerende definities van de benadering, en het normatieve karakter ervan. Dit laatste verwijst naar de afwegingen in maatschappelijke waarden die een rol spelen in zowel de definiëring als de toepassing van het concept. Ook wijst men op bestaande belemmeringen in organisatie en in samenwerkingsstructuren die nodig zijn om IWM vorm te geven en praktisch uit te voeren.

Gelet op de grote uitdagingen waar het waterbeheer voor staat is er een dringende noodzaak voor effectieve beheerstrategieën. De vraag is echter in hoeverre het IWM concept, gegeven bovengenoemde problematische aspecten, hier een

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[1] Integrated Water Management – IWM – wordt hier gebruikt als generieke term voor verschillende uitwerkingen met een geïntegreerde benadering.

bijdrage aan kan leveren. Een kritische analyse van de werkelijke betekenis en de reikwijdte van IWM in het waterbeheer en de wetenschap is daarom gewenst.

Het hoofddoel van dit proefschrift is daarom om een analyse uit te voeren naar de manier van denken, het zogenaamd discours, van de geïntegreerde benadering in het huidige waterbeheer. De focus in de analyse ligt daarbij op de strategische en wetenschappelijke communicatie die erop gericht is om de samenhang van relaties in watersystemen beter te begrijpen.

De onderzoeksvraag die hier wordt gesteld is: *hoe is het wetenschappelijke denken over IWM gevormd door enerzijds theoretische ontwikkelingen in systeemdenken en anderzijds verschillende configuraties van maatschappelijke waarden*? Specifieke aandacht is er daarbij voor de vraag in hoeverre en op welke manier *cross*-disciplinariteit[2] tot uiting komt in het onderzoek en wetenschappelijke samenwerkingen rondom IWM.

In Hoofdstuk 2 staat de conceptualisering en uitwerking van *River Ecosystem Health* (REH) centraal. Het centrale begrip *ecosystem health* is toegepast op het waterbeheer en heeft een zowel rationeel als normatief karakter. Echter, illustratief voor IWM, heeft het concept geen consistente betekenis. Dit heeft geleid tot onduidelijke uitwerkingen en verwarring met andere beheerconcepten. Eenduidige definitie van de conceptuele betekenis is echter vereist om het concept REH van waarde te laten zijn in rivieronderzoek en -beheer.

In het hoofdstuk wordt daarom een nieuwe definitie van REH voorgesteld. Deze definitie beschouwt REH als de capaciteit van een riviersysteem om een ecologische werking (kracht en veerkracht) in stand te houden die overeenkomstig is met de organisatie (structuur) van het systeem, waarbij ook aan de diverse sociale en economische behoeften van de maatschappij kan worden voldaan. Het concept richt zich op een duurzaam functioneren van het ecosysteem waarvan mensen een integraal onderdeel vormen. De hernieuwde definitie van REH past binnen een bredere conceptuele definitie van *River Health* waarin niet alleen het ecologisch,

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[2] Cross-disciplinariteit – een gedeeltelijke vertaling van 'cross-disciplinarity'; het begrip verwijst hier naar een onderzoekspraktijk waarin concepten en methoden van verschillende disciplinaire oorsprong worden gecombineerd danwel geïntegreerd. Het omvat hiermee de noties multi-, inter- en inter-disciplinair onderzoek.

maar ook het sociaal en economisch functioneren van het riviersysteem worden beschouwd.

Ook wordt in het hoofdstuk een toetsingskader opgesteld om REH te kunnen meten en beoordelen. De aanpak bestaat uit het toepassen van een combinatie van twee typen indicatoren. De 'top-down' *conditie indicatoren* zijn van belang om het presteren, de conditie, van het systeem vast te kunnen stellen. De indicatoren omvatten metingen van systeemactiviteit, metabolisme (kracht), veerkracht, structuur en van interacties tussen onderdelen van het systeem (organisatie). Daarnaast zijn er 'bottom-up' *stressor indicatoren* nodig om een diagnose te kunnen stellen van de oorzakelijke factoren die de gezondheid van het systeem beïnvloeden. De stressfactoren in het systeem kunnen worden gediagnostiseerd met behulp van biotische, chemische en fysische indicatoren. Een grote uitdaging in het toepassen van REH is de keuze van een omvattende indicator-set die de belangrijkste, 'vitale' kenmerken van systeem-functioneren op een betekenisvolle manier kan meten.

Het gebruik van REH als conceptuele benadering voor IWM is aantrekkelijk vanwege de intuïtieve zeggingskracht voor mensen van het begrip *gezondheid*. Het concept vergemakkelijkt begrip van het systeem door gebruik te maken van vergelijkbare uitdrukkingen als gebruikt voor menselijke gezondheid, geïntegreerd met ecologische theorie. Het REH-concept plaatst de mens centraal in het rivierecosysteem, en probeert een robuust en duurzaam ecosysteem te garanderen waarvan ook de mens een integraal onderdeel vormt. REH kan als zodanig een krachtig communicatief middel zijn om zowel wetenschappers, mensen uit de beheerpraktijk als het algemene publiek bij elkaar te brengen.

De ontwikkeling van IWM strategieën beweegt zich op het grensvlak van wetenschap en beleid. IWM strategieën worden namelijk door wetenschappelijke feiten geïnformeerd maar zijn tegelijkertijd politiek (waarde) geladen. De verschillen tussen wetenschappelijke en beleidsprocessen worden als verklaring genoemd voor de problemen die er bestaan in de toepassing van de geïntegreerde benadering. Hoofdstuk 3 beschrijft een studie waarin de verschillende manieren van denken over IWM zijn vergeleken en geëvalueerd, zowel binnen als tussen de domeinen van wetenschap en beleid. De beschouwde IWM benaderingen laten daarbij een spectrum aan standpunten zien, variërend van 'beheren voor de mens' tot 'beheren voor de natuur'. Bij vergelijking blijkt dat de meeste concepten niet strikt van één van beide perspectieven uitgaan; alle omvatten het idee dat beheer in de praktijk niet alleen maar kan worden gericht op het optimaliseren van consumptief menselijk gebruik. Verder blijkt dat IWM in de wetenschap uit een uiteenlopende verzameling van theoretische benaderingen bestaat over het beheer van ecosystemen, (sociale) gemeenschappen en hulpbronnen. Deze benaderingen zijn gebaseerd op verschillende onderzoekstradities en bevatten verschillende onderbouwingen en argumenten over de aard van mens-natuur relaties.

Toegepast op het Nederlandse waterbeleid maakt de studie duidelijk dat IWM binnen het domein van beleid een instrumentele functie vervuld in het opstellen en onderling verbinden van diverse (uiteenlopende) beleidsdoelstellingen. IWM wordt daarbij gebruikt als flexibel denkkader dat meegroeit met de politieke agenda in plaats van als een vast procedureel kader met vaststaande principes. In de loop van de tijd is IWM, in reactie op verschillende verschuivingen in politieke aandacht en urgentie, meerdere perspectieven op integratie gaan omvatten. IWM betekent duidelijk iets anders in de milieuwetenschap dan in het beleid. In de wetenschap wordt IWM benaderd als een onderzoekskader, gericht op (het genereren van) een omvattend systemisch begrip. Het biedt een kader waarin verschillende onderzoeksthema's op systemisch niveau aan elkaar gekoppeld kunnen worden. Op beleidsniveau echter wordt IWM opgevat als een politiek en ideologisch denkraam om verschillende beheerdoelstellingen bij elkaar te brengen.

Het verschil in betekenis komt mede voort uit de culturele verschillen tussen wetenschap en beleid. Voor de verdere vooruitgang van IWM is het nodig om bewust te zijn van de verschillende rollen die wetenschap en beleid spelen.

Om effectieve strategieën voor IWM te kunnen ontwikkelen is een goed begrip van de onderliggende maatschappelijke waarden en belangen noodzakelijk. Uit de aanwezige literatuur blijkt echter dat empirische kennis over de maatschappelijke context momenteel maar beperkt wordt gebruikt in de meeste wetenschappelijke modellen van IWM. Er is daarom een studie verricht naar de maatschappelijke waardenoriëntaties onder de diverse belanghebbenden in het Nederlandse waterbeheer. Daarbij is specifiek gekeken naar wat deze waardenoriëntaties betekenen voor de wetenschappelijke onderbouwing en het beleid van IWM.

In hoofdstuk 4 zijn vijf waardenoriëntaties geïdentificeerd op basis van gegeven prioriteringen van cognitieve, ethische en affectieve waarden in relatie tot het waterbeheer. Zo kon er een expert-gedomineerde groep van *Holisten* worden onderscheiden die het naar het waterbeheer en het systeem keken vanuit een omvattend sociaal-ecologisch perspectief. Daarentegen hielden *Technocraten* vast aan een traditioneel en utilitair perspectief op beheer, uitgaand van de mogelijkheden om het watersysteem met technische middelen te kunnen controleren. Verder was er een *Producenten* groep die vooral de economische gebruikswaarden van de natuur benadrukten. De *Verantwoordelijke Beheerders* gaven weer meer aandacht aan de sociaal-politieke aspecten van waterbeheer. Zo hechtten zij aan een eerlijke verdeling van de beheerverantwoordelijkheden en een vorm van rentmeesterschap. Ten slotte waardeerden *Milieu-wachters* in mindere mate de collectieve aspecten, maar vooral een goede persoonlijke relatie met de natuur.

Uit hoofdstuk 4 volgt dat de identificatie van waardenoriëntaties kan bijdragen aan de wetenschappelijke ontwikkeling van IWM en het realiseren van robuuste probleemoplossingen in het beleid. Beleidsmakers kunnen profiteren van inzichten in waardenoriëntaties bij het oplossen van conflicten, de ontwikkeling van planscenario's, en om consensus op te bouwen. Dit biedt uitdagingen voor de organisatie en de praktijk van de wetenschap: naast de (traditionele) inbreng van technische en natuurwetenschappen is voor de onderbouwing van IWM ook de bredere en intensievere inzet van sociaalwetenschappelijke concepten en methoden nodig.

Het wordt breed erkend dat het voor verdere IWM ontwikkeling noodzakelijk is om cross-disciplinaire bruggen te slaan tussen verschillende expertises, methoden en epistemologische perspectieven. Dit roept de vraag op in welke mate er momenteel sprake is van cross-disciplinariteit in IWM-gerelateerd onderzoek. Deze vraag staat centraal in hoofdstuk 5 welke zich richt op een analyse van de kennisbasis van de huidige rivierwetenschap met behulp van verschillende bibliometrische methoden en indicatoren.

De analyse laat zien dat de kern van het rivierwetenschappelijke landschap bestaat uit een netwerk van drieëntwintig onderzoeksgebieden die hoofdzakelijk bestaan uit traditionele disciplines, zoals limnologie, visserij- en visonderzoek, hydrologie en waterbeheer, en geomorfologie. De huidige rivierwetenschap opereert daarbij in een disciplinaire wetenschappelijke structuur; in het netwerk blijkt slechts een beperkte kennisuitwisseling te bestaan tussen de verschillende clusters van biologische en ecologische wetenschappen, milieuwetenschappen en de geo- en chemische wetenschappen. De kennisbasis van rivierwetenschap, zoals uitgedrukt in citatiepatronen, wijst daarmee nog niet op de komst van nieuwe cross-disciplinaire velden. Ook volgt uit de analyse dat de ecologische disciplines stevig in het netwerk zijn verankerd. Dit wijst erop dat het ecosysteemparadigma zich permanent heeft gevestigd in het hart van het rivierwetenschappelijke landschap. Ook blijkt uit het netwerk dat er slechts beperkte inbreng is van de sociale wetenschappen. Gevestigde sociaalwetenschappelijke disciplines zoals sociologie, economie en beleidsstudies blijken in het netwerk zo goed als afwezig te zijn.

Naast de netwerkkaart van onderzoeksvelden is er ook een analyse gemaakt van de belangrijke onderzoeksthema's. Hieruit blijkt dat het operationele onderzoeksfront veel onderzoeksthema's met een multidisciplinair karakter omvat waaraan disciplines hun eigen, maar niet onderling geïntegreerde, bijdragen lijken te leveren.

Hoofdstuk 5 heeft duidelijk gemaakt dat er in de huidige rivierwetenschap slechts een bescheiden uitwisseling van kennis is tussen de betrokken onderzoeksvelden en dat velden zichzelf nauwelijks informeren met kennis van gebieden buiten hun directe wetenschappelijke domein. Dit betekent dat vooral mono-disciplinaire in plaats van cross-disciplinaire theorie-ontwikkeling in rivierwetenschap wordt gestimuleerd. Cross-disciplinair gedrag is slechts beperkt tot het delen en wederzijds adopteren van onderzoeksthema's. De bevindingen wijzen niet op de theoretische samenvoeging en integratie van kennis van individuele disciplines. Rivierwetenschap kan daarom worden bestempeld als een multi-disciplinaire inspanning (dwz. bestaande uit meerdere mono-disciplines). Inter-of transdisciplinair onderzoek lijkt nog geen (structureel) onderdeel van rivierwetenschap te zijn.

Bovenstaande bevindingen komen overeen met vergelijkbare studies over andere wetenschapsgebieden waarin wordt geconstateerd dat wetenschap wel meer interdisciplinair wordt, maar dat dit in kleine stappen gebeurt. Kennis wordt vooral onttrokken uit de directe naburige velden en verbindingen met verder gelegen cognitieve gebieden nemen maar in bescheiden mate toe. Dit laatste lijkt in de rivierwetenschap vooral voor sociaal-wetenschappelijke velden te gelden.

Institutionele en individuele barrières in wetenschappelijke activiteiten worden als belangrijke factoren gezien die de cross-disciplinaire co-productie van kennis en de uitwisseling ervan negatief kunnen beïnvloeden. Om deze barrières te onderzoeken zijn in hoofdstuk 6 verkennende en statistische technieken uit de Sociale Netwerk Analyse toegepast om op basis van bibliografische gegevens een evaluatie uit te voeren naar cross-disciplinaire samenwerking in rivierwetenschap in Nederland. Specifiek is daarbij gekeken of, en zo ja welke institutionele arrangementen en patronen zowel de samenwerking tussen wetenschappers als de uitwisseling van kennis bevorderen danwel belemmeren.

Uit de studie komt naar voren dat mate van samenwerking, uitgedrukt in co-auteurschappen, voornamelijk wordt bepaald door het hebben van een gemeenschappelijke kennisbasis en een (fysieke) nabijheid op het werk. Daarentegen lijken organisatorische verbanden op hoger niveau minder te leiden tot het aangaan van co-auteurschappen of citatie van elkaars werk. Dit geldt zelfs voor affiliatie met een organisatie die erop is gericht om rivierwetenschap te integreren. Een visualisering van het netwerk laat zien dat de Nederlandse gemeenschap van actieve rivierwetenschappers uit een ringvormige netwerkstructuur bestaat waarin verschillende organisatorische clusters van samenwerkende onderzoekers zijn te herkennen. Hierin zijn de grote Nederlandse universiteiten het meest prominent; ze hebben centrale posities in het netwerk en zijn knooppunten van onderzoek. Een groot cluster van hydrologie en civiele techniek onderzoek wordt gevormd door de Delftse instituten. Een ander groot cluster van ecologisch en geomorfologisch onderzoek vormen de onderzoekers van de Radboud Universiteit en de Universiteit van Utrecht. De netwerkstructuur laat zien dat de directe onderlinge samenwerking tussen deze clusters beperkt is, wat wijst op barrières voor directe cross-disciplinaire uitwisseling. Aardwetenschappers, vooral in de geomorfologie, lijken een intermediaire rol te vervullen in het verbinden van cognitief verder afgelegen disciplines zoals ecologie enerzijds en hydrologie anderzijds.

De Nederlandse rivierwetenschap vertoont een disciplinaire organisatiestructuur met een disciplinaire kennisbasis die is geworteld in hydrologie, geomorfologie, ecologie, milieu-wetenschap en beheer. In die zin wijkt de Nederlandse rivierwetenschap niet af van de internationale rivierwetenschap zoals in kaart gebracht in de voorgaande studie. Hier werd ook een sterk disciplinair gestructureerd onderzoeksdomein gevonden met een sterke nadruk op onderzoek naar het biofysische systeem.

De netwerkanalyse heeft verder duidelijk gemaakt dat wanneer cross-disciplinariteit in onderzoek wordt nagestreefd het noodzakelijk is om cross-disciplinaire interacties gericht te stimuleren en te beheren binnen specifieke onderzoeksprogramma's. Zelfs een organisatorisch niveau, speciaal ontworpen om de rivierwetenschap te integreren, bleek enkel van beperkte invloed op de vorming van co-auteurschappen. Dit duidt erop dat het lastig is om effectieve cross-disciplinaire samenwerking te organiseren.

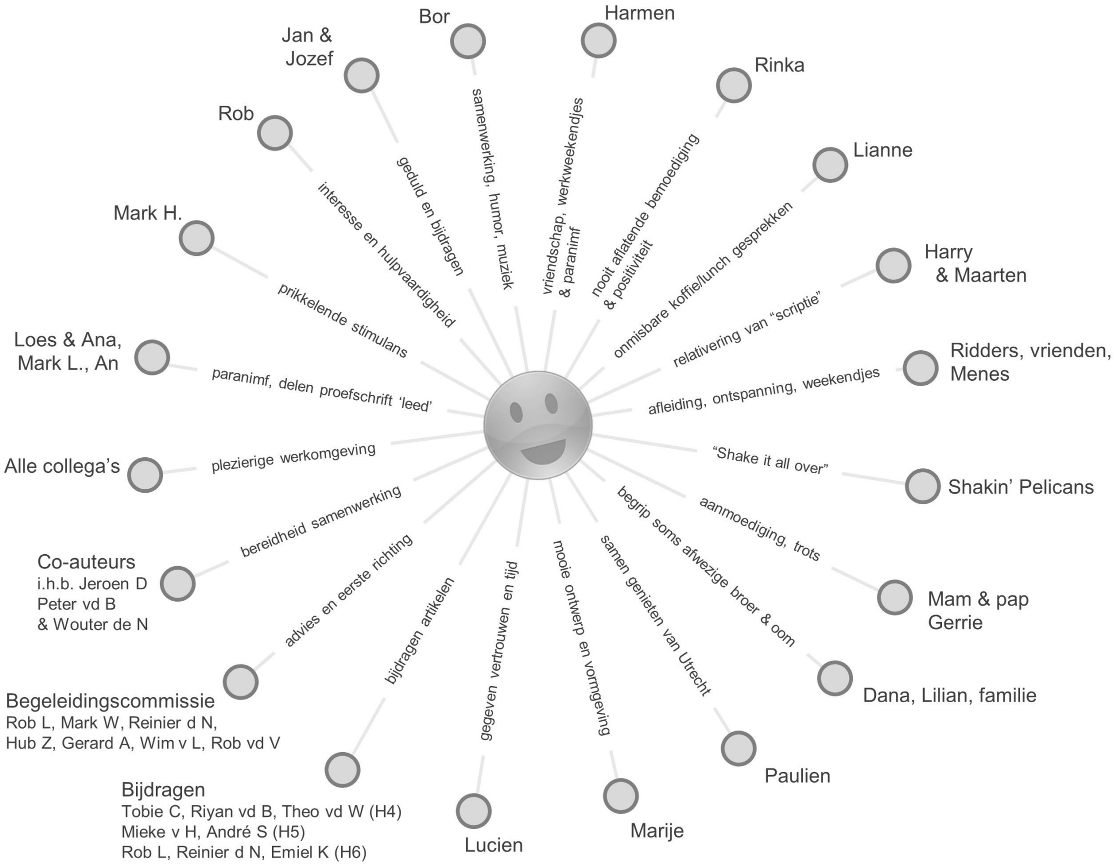
In het laatste hoofdstuk worden tot slot, verwijzend naar de titel van dit proefschrift, ‘de punten verbonden’ door een integratief raamwerk voor IWM-strategieën af te leiden uit de bevindingen van de voorgaande hoofdstukken. Doel van dit IWM-raamwerk is om een bruikbaar denkkader te bieden voor een integratief perspectief op waterbeheer. Het raamwerk synthetiseert de betekenis van integratie en presenteert belangrijke systemische dimensies en relaties die in het denken over geïntegreerde benaderingen en IWM-strategieën beschouwd zouden moeten worden. Uit dit proefschrift en de bestaande literatuur over IWM volgen een paar sleutelkenmerken van een geïntegreerde benadering. Een eerste kenmerk is *verbondenheid* (Eng.: *interconnectedness*), wat erop neerkomt dat in het beheer alle relevante *verbindingen* tussen onderdelen van het systeem dienen te worden beschouwd en onderhouden. Een ander belangrijk kenmerk is *omvattendheid (*Eng.: *comprehensiveness)*, wat verwijst naar hoe inclusief de benadering is in termen van aanwezige systeemonderdelen die worden meegenomen. Idealiter worden ‘alle’ systeemcomponenten meegenomen maar dit is praktisch gezien onmogelijk. Daarom vereist elke omvattende IWM benadering ook een *strategisch/reductief* proces. Dit houdt in dat er definitie nodig is van de inhoudelijke elementen die realistisch gezien meegenomen *kunnen* worden*,* in plaats van *zouden moeten*. Tot slot is voor de ontwikkeling van IWM de inzet van *interactieve* en gecoördineerde werkwijzen nodig; dit omdat inhoudelijke kennis vaak verspreid is onder verschillende actoren en instellingen.

Het gepresenteerde IWM-raamwerk communiceert dat in elke IWM benadering sociaal-ecologische, maatschappelijk-organisatorische, persoonlijk-culturele en normatief-cognitieve systeemdimensies en relaties beschouwd zouden moeten worden. Hierbij gaat beschouwing van de *sociaal-ecologische* dimensie over het begrip van de objectieve ‘harde’ realiteit van het sociaal-ecologische systeem. Het gaat daarbij om de definitie van de systeemgrenzen, de relevante componenten en kennis over het functioneren en de structurele eigenschappen van het systeem. Verder vereist IWM ook een goed begrip van de *maatschappelijke-organisatorische* dimensie. Deze wordt hier opgevat als een netwerkstructuur bestaande uit alle relevante actoren en belanghebbenden in het beheer. Al deze actoren ontplooien verschillende activiteiten en interacteren op basis van verschillende afhankelijkheidsrelaties, gewoonten en sociale codes in het totale netwerk. De *persoonlijke-culturele* dimensie stelt het (inter-) subjectieve systeemniveau voor. Deze dimensie erkent het bestaan van de veelheid aan individuele en collectieve waardenoriëntaties onder actoren, en de *uitwisseling* van rationele en normatieve veronderstellingen die tussen hen plaatsvindt. Individuele actoren belichamen uiteenlopende feiten- en waardenoriëntaties die zijn gebaseerd op allerlei rationele, esthetische en morele motieven. Deze oriëntaties zelf worden met de term *normatieve-cognitieve* dimensie aangeduid. Waardenoriëntaties bepalen de manier waarop men denkt en zich gedraagt in het systeem. Gezamenlijk bepalen deze verschillende percepties en bestaande waarden ten aanzien van de werkelijkheid uiteindelijk hoe beheer van watersystemen wordt begrepen. Het verkrijgen van onderling begrip over deze waardenoriëntaties is een belangrijke factor in het realiseren van succesvolle samenwerkingsverbanden, zowel maatschappelijk als wetenschappelijk.

Als geheel geven de studies in dit proefschrift een veelomvattende evaluatie van de conceptuele betekenis en reikwijdte van IWM. Uit de studies zijn belangrijke dimensies van integratie voor IWM naar voren gekomen welke zijn samengebracht in een integratief raamwerk. Door belangrijke factoren en onderlinge relaties binnen IWM-gerelateerd onderzoek te duiden kan dit werk mogelijk verder richting geven aan toekomstig interdisciplinair werk in integraal waterbeheer. Samen met de gebruikte methoden in dit proefschrift kan het worden gebruikt om het conceptuele kader van IWM verder te ontwikkelen. Dit werk beoogt een bruikbaar handvat te bieden voor andere onderzoekers om de vele uitdagingen van geïntegreerd onderzoek op het gebied van waterbeheer succesvol aan te gaan.

DANKWOORD

De totstandkoming van dit proefschrift zou niet mogelijk zijn geweest zonder de bijdrage, hulp en steun van vele mensen om mij heen. Met een knipoog naar de titel en inhoud van dit proefschrift presenteer ik hier een visualisatie van mijn ONTZETTEND BEDANKT netwerk. Hierin heb ik met een paar termen de kern van mijn persoonlijke dank-relaties proberen te kenschetsen. Echter, onderstaand knutselwerk is per definitie onvolledig en kan slechts een schrale weergave zijn van de echte dankbaarheid die ik voel naar een ieder die er direct of indirect aan heeft bijgedragen dat ik dit proefschrift heb kunnen voltooien.



CURRICULUM VITAE

Pim Vugteveen (1977) was born in Emmen, The Netherlands. He spent part of his childhood in Jakarta, Indonesia and after returning with his family to the Netherlands he attended high school at the Ulenhof College in Doetinchem. After graduating in 1995 he decided to study biology at the University of Groningen, specialising in Animal Ecology. For his study Pim performed research on the prey selection of Knots in the Western Wadden Sea (under supervision of the Royal Netherlands Institute for Sea Research, NIOZ), and on the ranging behaviour of Western Lowland Gorillas in the Central African Republic (under supervision of Wageningen University). He obtained his Master of Science degree in 2000 and after working as a teacher for a year then decided to pursue an additional master's track in Environmental Science at the Radboud University, Nijmegen. He completed this master's programme in 2004 with a thesis on the concept of river ecosystem health. Hereafter Pim was employed by the Department of Environmental Science in temporary projects, first as an educational co-worker and subsequently as a field assistant in a seagrass restoration project situated in the Wadden Sea.

In 2005 Pim started a PhD research on the integrative discourse of integrated water management within the university's Science & Society research programme. This resulted in the work presented in this thesis. In addition to his PhD work Pim was involved in projects on the BIO-SAFE model and participated in the Delta Water Award competition on coastal innovation for which his team received third prize. After the ending of his PhD contract in 2010 he worked at the ARCADIS company in environmental consultancy. Exploring career perspectives in nature conservation he also worked part-time at IUCN NL on a voluntary basis, performing a study on bioenergy and water impacts.

In 2011 he returned to the Radboud University for the WaLTER project on Wadden Sea monitoring and management in which he is currently employed as a post-doctoral researcher.

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