

Governance of Water Resources in the Phase of Change: A Case Study of the Implementation of the EU Water Framework Directive in Sweden

Monica Hammer, Berit Balfors, Ulla Mörtberg,
Mona Petersson, Andrew Quin

Abstract In this article, focusing on the ongoing implementation of the EU Water Framework Directive, we analyze some of the opportunities and challenges for a sustainable governance of water resources from an ecosystem management perspective. In the face of uncertainty and change, the ecosystem approach as a holistic and integrated management framework is increasingly recognized. The ongoing implementation of the Water Framework Directive (WFD) could be viewed as a reorganization phase in the process of change in institutional arrangements and ecosystems. In this case study from the Northern Baltic Sea River Basin District, Sweden, we focus in particular on data and information management from a multi-level governance perspective from the local stakeholder to the River Basin level. We apply a document analysis, hydrological mapping, and GIS models to analyze some of the institutional framework created for the implementation of the WFD. The study underlines the importance of institutional arrangements that can handle variability of local situations and trade-offs between solutions and priorities on different hierarchical levels.

Keywords Ecosystem management · GIS · Hydrological mapping · Information management · Stakeholder participation

INTRODUCTION

Managing water sustainably and effectively is fundamental for human societies. The water cycle, with its feedback loops to plant cover, soil, and atmosphere provides a range of vital ecosystem services for society (Daily 1997; Falkenmark and Folke 2000; Millennium Ecosystem Assessment 2005). However, until recently, there has been much partial handling of water resources in management and planning, taking

single component approaches, and seeking technical–economic motivation; e.g. wetland technology for nutrient trapping, or tree planting to reduce water logging. Also, over time the ecological system, use patterns as well as the composition of user groups are likely to change in a more or less predictable way. For example, in the lake Mälaren catchment, Sweden, increased seawater levels as a possible result of climate change could lower the buffer capacity to changed river input, and problematic flooding would occur more often. Increasing insights of the complex interactions between water and ecosystems providing services and the need for attention to both terrestrial and aquatic ecosystems has led to a paradigm shift toward a true systems approach in water governance frameworks.

The ecosystem approach as such a holistic and integrated systems management framework of land and water resources is increasingly recognized in, for example, the UN Convention on Biodiversity (CBD), the EU Water Framework Directive (WFD), and the HELCOM Baltic Sea Action Plan, and (CBD 1998; European Parliament, Council 2000; HELCOM (Helsinki commission) 2008). Ecosystem management focuses on sustaining functioning ecosystems and their capacity to deliver ecosystem services for human well-being, as well as the capacity of society to cope with, adapt to, and shape change at different spatial and temporal scales (Holling 1973; Berkes et al. 2003; Christensen et al. 2003, Dale et al. 2000; Folke 2006). For example, the ecosystem approach attempts to overcome problems of spatial fit between the social and ecological system by defining administrative areas according to ecological borders (Folke et al. 1998; Young 2002). The EU Water Framework Directive, (WFD) adopted in 2000, has a clear ecosystem approach in this sense, redrawing the administrative map of water institutions in Europe to larger national and international River Basin Districts (RBD).

In this case study from the Northern Baltic Sea River Drainage Basin, Sweden, we analyze some of the institutional framework created for the implementation of the WFD—from an ecosystem management perspective. We use document analysis, hydrological mapping, and GIS and focus in particular on data and information management from a multi-level governance perspective, from the local stakeholder to the River Basin District level. Key questions that will be addressed are: How can the needs and priorities of local and higher levels be reconciled? How can data and information from the local level be made useful in a larger scale perspective?

THE WFD FROM AN ECOSYSTEM MANAGEMENT PERSPECTIVE

The common water policy framework formulated in the WFD has two main aims; to protect European waters and achieve a good ecological status of all waters by the year 2015 and to get citizens and stakeholder organizations actively involved in the water management process (European Commission 2003). The intentions of the WFD is to identify and cover all lakes $>0.5 \text{ km}^2$ and water areas with a catchment $>10 \text{ km}^2$. This implies an extensive demand for detailed water-related data and information. Thus, the ongoing process of implementing the EU Water Framework Directive could be viewed as a reorganization phase following change in terms of new demands on institutional arrangements of the EU Water Framework Directive, as well as of changing ecosystems due to, for example, climate change. This implies an increased need for adaptive capacity and transformability that can address risk and uncertainties and enable ecosystem management (Gunderson and Holling 2002).

Furthermore, water systems represent nested institutional and ecological systems, where the spatial dimensions of water management create needs for coordinating institutions (Jöborn et al. 2005; Ostrom 2005; Meinzen-Dick 2007). Water-related ecosystem services, though often meeting needs expressed over large spatial scales such as the Baltic Sea region, are actually generally delivered at the local scale. For example, Stockholm archipelago constitutes some 25% of the total shore length of Swedish Baltic Sea coast. This mosaic land- and seascape is an important life-support system in the Baltic Sea and provides a vast array of ecosystem services such as biological filtration, provision of spawning and nursery areas for fish and bird species, and nutrient recycling critical for sustaining human societies (Holmlund and Hammer 1999; Hammer et al. 2003). A local decline in the water quality could have large impact on the archipelago region.

Hence, understanding water flows and functions in the ecosystem is a key to understanding bundles of ecosystem services and the links between landscape, water bodies, and the sea. Also, water-related issues and priorities are intimately dependent on human actions in the form of land use and water-regulating measures on multiple levels. For example, there are differences within the Northern Baltic Sea River Basin District where the problem of eutrophication in lakes in downstream agricultural areas and coastal areas gets most attention in the WFD program of measures, though other problems upstream occur at local scales such as storm water, metal leakage, and increased fresh-water demand due to urbanization.

To clarify linkages between water processes and ecosystem services is crucial also for empowering stakeholders to manage environmental assets in an informed way which in turn necessitates the development of tools which both can communicate such linkages to stakeholders and involve them in management. A major challenge for a successful governance of water resources is thus to build knowledge, incentives, and learning capabilities into institutions and organizations for governance that allow adaptive management of local and regional systems. This requires an active role of individuals or organizations to build and manage information. A particular problem is how we can sustain not only the functions of direct value to humans but also the ability of the system to cope with future disturbances.

The requirements and guidelines of the WFD raise questions concerning the management of information by various actors within river basins. Nilsson (2006), in a study of information management in transboundary river basins in Europe, concluded that: information needs were generally defined by experts without the involvement of other stakeholders, information was only communicated to various stakeholders through passive channels; and, most data collected concerned the state of water bodies and environmental impacts, while data on drivers and pressures were generally neglected. There is a need for further research into the exchange of information among all relevant actors in river basins, how uncertainty is addressed, and, also, whether data may be a source of conflict or cooperation among actors.

THE WFD IN THE BALTIC SEA DRAINAGE BASIN

The Baltic Sea region is framed by the ecological boundaries of its drainage basin covering 1739000 km^2 and inhabited by some 110 million people (Hedin et al. 2007; Fig. 1). The drainage basin is four times larger than the actual sea itself. The Baltic Sea is a semi-enclosed low diversity brackish water body. It is a non-tidal sea consisting of a series of basins receiving fresh-water inputs

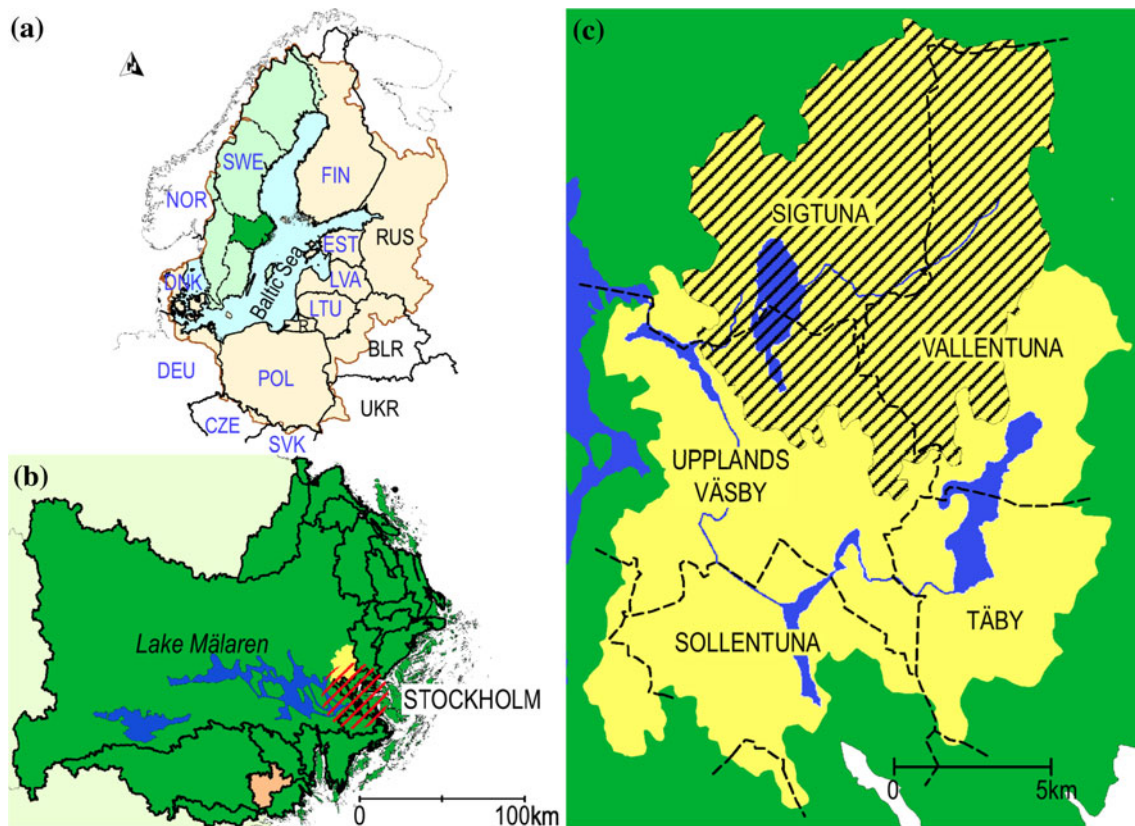


Fig. 1 (a) The Baltic Sea drainage area (yellow), with the five river basin districts of Sweden (green), and countries within the drainage area, where the European Union countries are typed in blue (country code ISO 3166-1). (b) The Northern Baltic Sea River Basin District with catchments entering the Baltic Sea. The catchment of Norrström, including the Lake Mälaren, is the largest catchment in the district and also where the sub-catchment of Oxunda is situated (yellow). The catchment of River Svärtaån (light red) represents one of the smaller

from the around 200 rivers in the catchment area. The influxes of saline oxygenated water through the Danish straits determine salinity, temperature stratification of the water column, and affect bottom oxygen conditions in the deep waters. The Baltic Sea is surrounded by highly industrialized countries, and is close to major sources of air pollution in Northern and Eastern Europe. The increased human activities in the Baltic Sea Drainage Basin in combination with its special topographic and biological characteristics have altered the Baltic Sea ecosystem substantially.

Main environmental concerns in the Baltic Sea include eutrophication, pollution of chemical substances, overfishing, and deterioration of biological diversity by, for example, degradation of habitats. A main cause for eutrophication in the Baltic Sea is discharges from land-based activities such as agriculture within and even outside the drainage basin. Ca. 75% of the nitrogen load and at least 95% of the phosphorus is discharged from land via, for example, rivers (HELCOM (Helsinki commission) 2008).

catchments discharging directly into the Baltic Sea. (c) The Oxunda River Basin, including municipalities (dashed line), and the case study area, the northern Oxunda catchment, shaded (///). The Oxunda river mouth is in the north western part situated at the municipality border of Sigtuna and Upplands-Väsby. ArcView GIS data from Baltic Drainage Basin Project (BDBP), UNEP/GRID-Arendal 2001. Swedish Map data of lakes and catchments from SVAR, and WISS. © SMHI, © Lantmäteriet Gävle 2010. Permission I 2010/0056

The Baltic Sea Drainage basin is also a large heterogeneous socio-economic region shared by 14 countries whereof nine are coastal states (Fig. 1). During the last decades, the region has undergone profound socio-economic changes since the fall of the Soviet Union and the transformation of the eastern region into independent democratic states, e.g. Estonia, Latvia, and Lithuania. Earlier, national environmental policies dominated in the Baltic region, but is now transforming into a dominance of cross-border cooperation and transnational networking reinforced by the recent enlargement of the EU where ten states in the Baltic Sea Region now belong to the EU (Kern and Löffelsend 2004; Fig. 1).

The Baltic Sea drainage basin could thus be described as an integrated social–ecological system in transition (Berkes et al. 2003). The Baltic Sea is a common good at stake where policy approaches as well as impacts vary considerably between countries and constitutes a challenge for different types of cooperative policies that needs to be developed and applied systematically. The EU Water

Framework Directive is probably one of the more important and challenging legislations in this respect. The scope of the WFD aims at more integrated water management and encompasses different water resources, such as surface waters, groundwater, estuaries, and adjacent coastal waters out to 1 nautical mile from the coast. Hence, the possibilities of reaching the environmental objectives for the Baltic Sea, such as no eutrophication, are largely dependent on altered activities on land within the framework of the WFD.

In EU, each country is responsible for implementing the WFD and setting up competent authorities according to river basin districts (European Parliament, Council 2000; Hedin et al. 2007). The design of these authorities varies between countries. The WFD is implemented in the 6-year water planning cycles (in Sweden referred to as “water cycles”) and member states were committed to produce the first river basin management plans by the year 2009. The water planning cycle consists of five steps starting with a baseline in which the existing conditions are mapped and analyzed. In the next step, environmental targets and norms for river basins are defined along the goals of the WFD that provides the basis for the development of Program of Measures, (PoM) in step three. The PoM includes concrete measures and actions for achieving the targets to reach good ecological status. According to Article 4 in the Directive, the member states are also to ensure that no further deterioration occurs in the status of the affected water body. In addition, a monitoring program is developed in cooperation with authorities, organizations, and other stakeholders. The deadline for the first water planning cycle is in 2015 when environmental objectives should be reached, unless use has been made of the possibility to extend deadlines according to WFD. The monitoring programs aim to provide an overview of quality and quantity issues of water resources in each RBD as well as follow-up of the implemented measures. As part of the third step, an Environmental Assessment (EIA) according to the EU Strategic Environmental Assessment Directive, adopted in 2001, should be made in which environmental impacts of the proposed measures are analyzed. Step four is the implementation phase of the PoM and the monitoring program. The water planning cycle is concluded with a report to the EU in which the results of the previous steps are evaluated.

The WFD emphasizes an integrated, iterative process with co-governance between different stakeholders and the responsible water management authority within the different river basin districts. In Article 14 in the WFD, active involvement of all interested parties in the implementation of the directive is encouraged (European Parliament, Council 2000). Three general forms of public participation can be identified in the WFD; supplying information to the public and stakeholders, consulting public/stakeholders to gain information and active involvement (EU 2000).

The Implementation of WFD in Sweden

In Sweden, the administration of water before the WFD was spread over a number of administrations at different levels. The Swedish planning system has historically been characterized by a strong central state level and a traditional emphasis on water and land use planning as a municipal task, while the regional level has had little power (Böhme 2002; Andersson et al. unpubl.). Sweden is divided into 290 municipalities and the local level is the only level with a clear strategic spatial approach and planning responsibility. At the regional level, the state maintains a presence through the 21 County Administrative Boards.

The implementation of the WFD in Sweden has caused significant legislative changes in the Environmental Code regarding the new regional division of water planning, environmental quality norms, and a program of measures and a management plan for water (Hedin et al. 2007). To implement the WFD, Sweden, with its long coastline and 119 main river basins, formed five river basin districts based on the connection to major sea basins (Fig. 1). In each RBD, one of the counties is assigned as the water authority and is responsible for co-ordinating water management with the other counties in the basin. Each county has a planning secretariat responsible for operative work, which should take place in coordination with the water authority above them, and with municipalities, local water councils, and other local actors below them.

However, the water authorities imply larger areas than would always be relevant from a local management perspective (Lundqvist 2004). Also, the management forms on the local catchment levels are not as clear as on the regional level. Various types of water management associations, municipalities, industry, and other actors are responsible for managing water resources within catchments, and are thus responsible for management of water-related information (Andersson et al. unpubl.). Local water councils have been suggested to be established on catchment level, yet they will not be responsible nor have any legitimacy in decision-making.

The 6-year planning cycles with mitigation plans and EIAs required to implement the WFD add further to the need for appropriate information management. Implementation of the WFD by member states entails routine data collection covering various information needs relevant for the governance of water resources. The information needs include collection of comprehensive data covering the characteristics and state of water bodies, as well as a record of the various pressures on water bodies caused by human activities and the resulting impacts. Implementation of the WFD further entails member states providing data to the EU on numerous aspects that cover the governance of water resources, including records of mitigation measures,

public participation activities, and the designation of protected areas. The WFD also emphasizes the need for “the active involvement of all interested parties in this Directive”, specifically with regard to river basin management plans. At a minimum, the WFD obliges member states to make certain information outlined in the river basin management plans to be made available to the public, and to organize public consultation, while active involvement should be encouraged (European Commission 2003). In Sweden, a consultation process was undertaken by the Water authorities during the period March 1–September 1, 2009 on the suggested Program of Measures, the Management Plans, and the Environmental Assessment.

MATERIALS AND METHODS

Case Study Area

The Northern Baltic Sea River Basin District

The Northern Baltic Sea River Basin District (Fig. 1) discharging into the Lake Mälaren and the Baltic Proper is the smallest of the Swedish RBDs encompassing 36 700 km² and 7000 km² coastal waters. The RBD consists of 76 municipalities in 7 counties and is also the most populated with 3 million inhabitants living in particular in the densely populated urban area of the city of Stockholm.

Even so, built areas constitute only some 5% of the RBD, while about 61% of the area consists of forests, agricultural areas make up ca. 22%, lakes ca. 9.5%, and wetlands, 2.5%. The main water problems defined for the RBD include eutrophication, where ca. 48% of the RBD is affected, and overexploitation of fresh-water resources, resulting in, for example, salt water intrusion in wells in the coastal areas (Länsstyrelsen 2009b). The region is also in a socio-economic transition with increasing connections to the growing urban area of Stockholm affecting land use, water resources, and biodiversity. Further, the regional system needs to respond to the challenges of climate change, where the Lake Mälaren drainage basin, in particular the populated lowland areas is considered to be at risk of flooding due to both seasonal and spatial changes in precipitation patterns (Bergström et al. 2006).

Oxunda Sub-Catchment

In the Northern Baltic Sea river basin district, there are currently ca. 20 local water organizations. One of them is the Oxunda river water council. It was founded in 1998 as a collaboration between the five municipalities covering the Oxunda river basin. The aim is to conserve or improve biodiversity, natural and cultural values, and restore

polluted waters. A Program of Measures, including monitoring has been developed and information and guidance to locals is viewed as an important task for the water council.

Oxunda river drainage basin, with a population of ca. 100000 inhabitants, consists of a relatively large part of the northern suburban area of Stockholm. The drainage basin is 270 km² where 39% is forest, 26% is agricultural land, and as much as 17% is built area including roads. The larger lakes are more or less eutrophicated and the entire drainage basin is classified as sensitive for nitrate and sewage water according to the nitrate and Council Directive concerning urban waste-water treatment. In the Program of Measures for the Northern Baltic Sea River Basin District, eutrophication is identified as the dominating water problem also in Oxunda catchment. In the Program of Measures, a reduction of phosphorus with 20% and nitrogen with 50–70% is stipulated (Länsstyrelsen 2009a). Suggested mitigation measures include wetland construction and restoration, protection zones, and dams.

Data Collection and Modeling

This study is partly based on a document analysis of official documents on the Water Framework Directive in Sweden, in particular the Program of Measures (PoM), Management Plans and Environmental Impact Assessment for the Northern Baltic Sea River Basin District (Länsstyrelsen 2009a, b, c). The documents were circulated for comments by the Water Authority in 2009 and we performed a descriptive content analysis (Neuendorf 2002) of the responses most relevant for Oxunda sub-catchment including Oxunda Water Council, each of the five municipalities in Oxunda sub-catchment, Stockholm County Council, and the Federation of Swedish Farmers (LRF) in Mälardalen, Södermanland, and Örebro counties.

A river basin system can be divided into inherently linked physical, biological, chemical, geological, and human subsystems forming complex systems. To further illustrate and analyze challenges and tradeoffs regarding, data and information management and multilevel scale issues in practical implementation of the WFD, we applied hydrological mapping in combination with information on property rights, land use and landscape features based on Geographic Information Systems (GIS) in the northwestern part of Oxunda sub-catchment (Fig. 2).

GIS-based hydrological mapping and modeling can be useful tools to for example, identify key areas where monitoring should be intensified, plan for actions and measures needed to obtain or maintain good ecological status, help the process of negotiation among relevant stakeholders (Saloranta et al. 2003), and also function as a tool for social learning and adaptive management (Toderi et al. 2007).

We focus on one example of a mitigation measure that needs both scientific knowledge and active stakeholder participation, namely the creation of wetlands for nutrient retention, which is one of the measures proposed within the Program of Measures for the Northern Baltic Sea River basin District (Länsstyrelsen 2009a).

GIS-based tools were used for linking landscape features, hydrologic properties, and decision-support, mainly ArcGIS and ArcHydro (ESRI 2008). To study water ecosystem services in a landscape perspective, data from several different sources were used, including a digital elevation databank with 50 m pixel size, a topographic map, and a property map (Lantmäteriet 2010a, b, c), data on crops and land use on agricultural land (Swedish Board of Agriculture 2008, unpubl.), and data on sub-catchments (SMHI 2010). In order to achieve such knowledge over large areas, sites that are prone to water logging were localized using Topographic Wetness Index¹ (TWI; Beven and Kirkby 1979). This is a mathematically simple parameterization of soil moisture status that is calculated on slopes and depends, therefore, on digital terrain data. The use of wetness indices as part of the input information for selection of suitable areas for wetland restoration and creation has been used by, for example, Russell et al. (1997), White and Fennessy (2005), and Polyakov et al. (2005). The results together with information on soils can give a picture of the present situation and possible future situations concerning wetland potential.

RESULTS AND DISCUSSION

Multi-Level Data and Information Management

The results from the content analysis in the case study indicate that there are some challenges in achieving some of the WFD's requirements and recommendations with respect to information and local participation. In summary, these challenges include: problems in classifying the status of water bodies; a need to improve and co-ordinate

monitoring within River Basin Districts; and means of tackling and controlling diffuse sources of pollutants.

The responses from several of the municipalities indicated that there were uncertainties in classifying the status of water bodies and some respondents added that the classification of status could sometimes be established based on loose and insufficient criteria. Respondents expressed that there was a need for further in-depth discussions among municipalities and local water councils on the subject of status classification of water bodies. Since the classification of status is used as a decision-making criterion, helping to determine if action needs to be taken, it is important that this information is based on sound data. Hence, an improved process for classifying the status of water bodies is requested to minimize uncertainties regarding the need for management measures (compare with e.g. Destouni et al. 2010).

A majority of the respondents stated that environmental monitoring within the River Basin District needs to be better coordinated and developed. Coordination will be a particular challenge, considering that priorities may vary from regional to local levels—given the heterogeneity of the landscape, it will not always be the case that local goals will be consistent with regional goals. For example, in the rural dominated Svärtaån river catchment in southeastern part of the Northern Baltic Sea River Basin District (see Fig. 1), the local water association was concerned about the lack of data and difficulties to penetrate the information on nutrient leakage scattered in several documents and that the reduction requirements would jeopardize local agriculture. Thus, it is important that there is clear communication from actors at the regional level to actors at local level and vice versa, indicating what actions will be necessary locally in order to achieve regional goals.

Respondents at the municipal level in the Oxunda case study described that there was a lack of clear guidelines for, and means of controlling, diffuse sources of pollution. Considering the many different actors operating within a water basin, municipalities were also concerned about how decisions should be made regarding the level of effort that should be required from various actors. One respondent suggested that there was a risk that specific actors could be singled out and required to undertake stringent mitigation actions, since Environmental Quality Standards typically cover only specific water courses and not the water basin as a whole. As a specific example, nutrient leakage from, predominantly, agricultural land is a widespread issue and the dominant problem identified in the North Baltic Sea River Basin District (Länsstyrelsen 2009a). If it is accepted among local actors that nutrient leakage is an issue to be dealt with, one possible form of mitigation measure is to create wetlands as is also suggested in the WFD Program of Measures. Wetland

¹ Topographic Wetness Index (TWI) can be calculated as $\ln(\alpha/\tan\beta)$ where α is the cumulative upslope area draining through a point and $\tan\beta$ is the slope angle at that point. The index describes the tendency of water to accumulate at any point in a catchment, in terms of α , and the tendency for gravitational forces to move that water downslope, expressed in terms of $\tan\beta$ as an approximate hydraulic gradient (Quinn et al. 1995). Thus, wet areas can arise either from large contributing drainage areas or from very flat slopes, whereas areas with low index values are drier, resulting from either steep slopes or small contributing drainage areas. The relatively coarse DEM (50 m) was interpolated to 5 m using kriging, before calculating TWI. In order to create a smooth surface for enhances visibility, neighborhood statistics was then calculated on the TWI results with a 50 m radius.

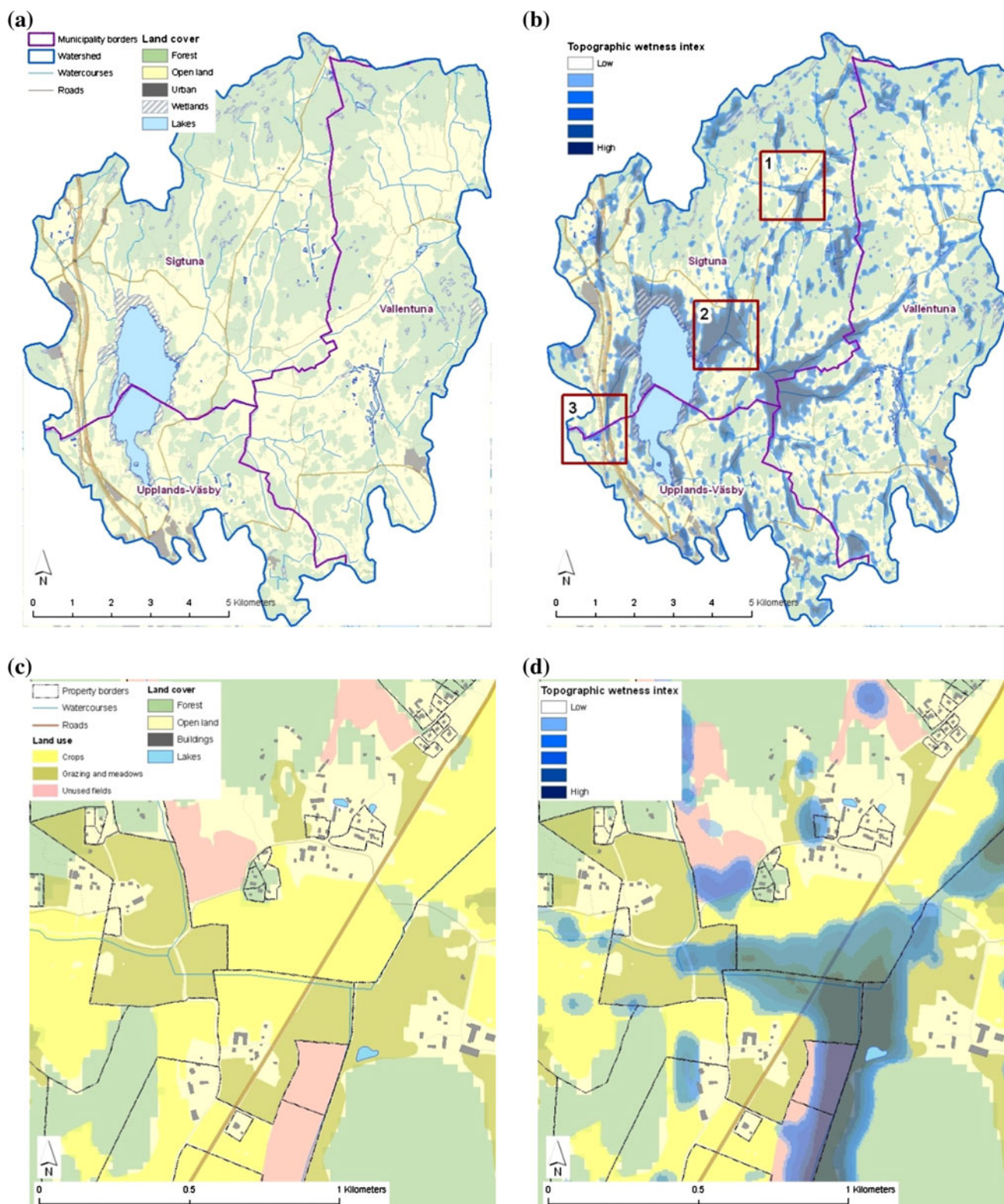


Fig. 2 The northern part of the Oxunda catchment (a–b), with the results of the TWI calculations (b), with locations 1–3 highlighted. In map c–d, zooming in location 1, current land use in and TWI is shown together with property boundaries. The choice of different landowners to provide measures such as creation of new wetlands may not

necessarily coincide with hydrologically suitable areas. Further, this type of measures may not be prioritized by the water organizations in a particular catchment (in this example Oxunda). © Lantmäteriet Gävle 2010. Grant I 2010/0044

creation often includes local landowners and depends on their active participation.

In the GIS model of North-western part of Oxunda sub-catchment (Fig. 2), we give an illustration of information requirements and possibilities for water information systems that can retrieve information from readily available input data. The results of the fairly simple TWI calculation in the Oxunda case study area are depicted in Fig. 2b (overview) and d (detail). This index can be seen as an indicator of where the land has been drained during the last century, and where the potential for creating, restoring, and maintaining wetlands should be high from a topographic point of view.

Still, this information is only a fraction of desirable and reachable data and information needs, and, the used TWI method would need refinement in several ways to calculate a more realistic wetness index (see e.g. Tarboton 1997; Grabs et al. 2009; Tarboton et al. 2009).

Also, the mitigation measure itself requires trade-offs and decisions to be made among multiple actors. For example, trying to find a suitable location for the creation of a wetland might mean loss of land for agricultural production—an issue that can lead to conflict among local actors. More knowledge of different kinds, scientific and non-scientific, is obviously necessary for the task of watershed management, among them prioritizing which measures to take and for localizing potential areas for wetland creation, targeting nutrient retention, and simultaneously supporting biodiversity.

The example in Fig. 2 illustrates some of the information, prioritizing, and decision problems. Within the Northern Oxunda catchment, sites with large contributing areas and gentle slopes have a high TWI which make them more suitable for wetland creation. However, the Sites 1 and 2 in Fig. 2b all contains relatively large areas with high TWI, but still has different potential from other points of view, Sites 1 and 2 are similar peri-urban agricultural landscapes. Still, Site 1 has a more complex use of fields, with a dominance of fodder and pasture over other crops, indicating that the farms may be dominated by peri-urban land use, for example, horse farms. On the watershed scale and from a hydrologic point of view, site 2 would be prioritized due to larger areas with higher TWI, thus having the potential to capture and retain more water than site 1. However, local landowners may have a different view, having large drained fields with wheat crops of high-economic value from a private perspective.

Hence, monitoring systems will need to be further developed to take into account both local and regional goals. A challenge in the implementation of the WFD as experienced in other externally initiated programs that often involves top-down structures are that they are too rigid in structure and gives local actors such as farmers less

scope to adapt the systems to meet their needs (Meinzen-Dick 2007). A particular concern in the Baltic Sea Region is the large number of international River Basin Districts, covering some 70% of the region. Nilsson and Langaas (2006) assessing cooperation and water quality in 13 international River Basin Districts in the Baltic Sea region found relatively few cases of officially stated plans to produce or coordinate joint river basin management plans at the time of the study.

However, as pointed out by Reid et al. (2006), there are at least two ways in which an ecosystem assessment can be conducted to better consider multiple scales. First, the assessment could include analyses undertaken at other space and time scales, alternatively the assessment could be composed of multiple semi-independent sub-assessments, each with its own user group and scale analysis. Potential information gains include a better problem definition, improved analysis of scale-dependent processes, and also cross-scale effects.

Also, trade-offs between a range of interests in combination with physical and ecological properties on multiple scales is a main challenge requiring tools for decision-support. For example, the same data sets used in the here presented model together with additional data could also be used to map areas of interest, to test the landscape response to different scenarios, and as a platform for discussion, and decision-support to test different scenarios requested by the stakeholders.

Local Participation, Knowledge, and Ecosystem Management

In ecosystem management, a wider range of knowledge sources including local knowledge is important to manage ecosystem functions and respond to feedback signals from the ecosystems in an adaptive way. The WFD emphasizes an integrated, iterative process with co-governance between different stakeholders and the responsible water management authority within different river basin districts. Even so, our case study indicates that there still seems to be many uncertainties regarding appropriate forms and roles for participation, as well as use and transfer of knowledge from the local level.

In Sweden, in general, there are much data already available that are relevant for various aspects of water management. Furthermore, data from various sectors are likely to become highly relevant in decision-making processes for the management of water bodies. However, to reach the aims of the WFD, it is important to ensure that such data can be made readily available in well-devised processes that encourage the active participation of local actors. Furthermore, active involvement may lead local actors to identify themselves information needs that are

relevant for local action, which may be consistent with regional plans. It can also increase opportunities for both adaptive management and accumulating and building local knowledge. Remembering that the WFD recommends encouraging active involvement of local actors, improving the provision of information to local actors represents an opportunity that could help develop water resources management at multiple levels—from the local to the regional. The promotion of active involvement and local action is an obvious role for municipalities and water councils—who currently argue according to the case study—that they lack clear roles, responsibilities, financial resources, and other forms of support. It is thus important to study in greater detail how information is used to improve opportunities for local involvement and action, how such opportunities are currently created in the Swedish context, and to identify how this process might be improved.

The model of Oxunda sub-catchment can serve as an illustration concerning some of the problems in combining WFD intentions, scientific knowledge, and stakeholder participation. For example, the most suitable land for wetland creation from a topographic and hydrologic point of view may not be in line with single landowner intentions or with the priorities of local water organizations.

The model from Oxunda sub-catchment (Fig. 2) also illustrates the problem with scientific knowledge for guiding decisions on measures built on voluntary initiatives and active participation by private landowners, as is often the case with wetland creation. It is also on this level many of the relatively costly measures in practice will have to be undertaken. In Fig. 2c and d, local property boundaries and land use are visible, as well as the TWI. It shows that areas with the highest TWI mainly are located in areas that today are composed of meadows and unused fields, which could be seen as highly suitable areas for wetland creation.

However, wetland creation typically hinges on farmers and other private landowners' willingness to converting parts of their land to wetlands. This willingness is likely to depend on a number of economic and other incentives (Söderqvist 2003; Lindahl and Söderqvist 2004). If at all interested, farmers might have their particular reasons for what land they regard as suitable for a wetland. This might or might not coincide with a location that is preferable from a societal point of view, e.g. a location that fulfills a desirable nutrient abatement capacity and might even be cost-effective in comparison to other locations or measures, and might also provide other ecosystem services to a desirable degree. Factors such as wetland creation costs are highly dependent on location, e.g. to what extent excavation is necessary or not (Söderqvist 2002).

Farmers could provide local ecological knowledge (LEK) of the specific area, which could imply that wetlands become better located. Common rationales for

including local knowledge are that it reflects the thinking of locals and, therefore, is crucial for achieving a management frame and rules that are accepted and implemented by the local users. Also, the local knowledge, while not generalizable beyond the local context, is just as valid in that context as that produced by formal science. In fact, it may be more useful in some ways because it is based on more detailed information and more continuous observation, which is valuable in heterogeneous ecosystems. Combining LEK with science is, however, fraught with ethical, methodological, and conceptual difficulties. Rather than integrating different forms, they should probably be viewed as complements (Gadgil et al. 2003; Chalmers and Fabricius 2007). Further, recent research has highlighted the importance of social learning in the context of water resources management (Blackmore et al. 2007; Steyaert and Jiggins 2007). Participation in the process of wetland localization can imply an increased social acceptance for creating wetlands, and entail social learning among different actors. Thus, a related important issue is how social learning among local actors can be fostered through improved information management in water governance such as the implementation of the WFD.

CONCLUSION

Managing water applying an ecosystem management approach as attempted in the WFD is an information intensive endeavor and requires knowledge of complex interactions in order to monitor, interpret, and respond to ecosystem feedback at multiple scales. Problems in ecosystem management include lack of and quality of data and information as indicated in our case study. The results in our study also pointed to the importance of institutional arrangements that can handle the variability of local situations and trade-offs between different solutions and priorities on different hierarchical levels. Further, the limitations of forecasting and prediction are core problems for ecosystem management, in particular as landscapes simultaneously produce multiple ecosystem services that interrelate in complex, dynamic ways. Without knowledge about the relationships among water-related ecosystem services, there is a risk of incurring unwanted trade-offs, missing opportunities to take advantage of synergies, and possibly experiencing dramatic and unexpected changes in the provision of water resources and related ecosystem services.

Acknowledgments This study was funded by the Foundation for Baltic and East European Studies and the EU BONUS-program. We thank Ingela Andersson, Frida Franzén, Tore Söderqvist, and Dan Warghagen for interesting discussions and comments on earlier versions of the manuscript. We also thank two anonymous reviewers for constructive comments on the manuscript.

REFERENCES

- Bergström, S., S. Hellström, and J. Andréasson. 2006. Water levels and discharges in the water systems of Lake Vänern and Lake Mälaren—Hydrologic white paper to the Commission on Climate and Vulnerability in Sweden. *SMHI Reports Hydrology*, RH No. 20. (in Swedish).
- Berkes, F., J. Colding, and C. Folke. (eds.). 2003. *Navigating Social-Ecological Systems Building Resilience for Complexity and Change*. Cambridge University Press. 393 pp.
- Beven, K., and M. Kirkby. 1979. A physically based variable contributing area model of basin hydrology. *Hydrological Sciences Bulletin* 24: 43–69.
- Blackmore, C., R. Ison, and J. Jiggins. 2007. Editorial: Social learning: an alternative policy instrument for managing in the context of Europe's water. *Environmental Science & Policy* 10: 493–498.
- Böhme, K. 2002. *Nordic Echoes of European Spatial Planning*. Nordregio, Report 2002:8, Stockholm.
- Chalmers, N., and C. Fabricius. 2007. Expert and generalist local knowledge about land-cover change on South Africa's wild coast: Can local ecological knowledge add value to science? *Ecology and Society*. 12:10. <http://www.ecologyandsociety.org/vol12/iss1/art10/>.
- Christensen, N., A. Bartuska, J. Brown, S. Carpenter, R. d'Antoni, J. Francis, J. Franklin, R. MacMahon, et al. 2003. The report of the Ecological Society of America on the scientific basis for ecosystem management. *Ecological Applications* 6: 665–691.
- Convention on Biodiversity (CBD). 1998. Report of the workshop on the Ecosystem Approach. Lilongwe, Malawi. 26–28 January, 1998. UNEP/COP/4/Inf.9.
- Daily, G. (ed.). 1997. *Natures' services. Societal dependence on natural ecosystems*. Washington D.C.: Island Press.
- Dale, V.H., S. Brown, R.A. Haeuber, N.T. Hobbs, N. Huntley, R.J. Naiman, W.E. Ribesame, M.G. Turner, et al. 2000. Ecological principles and guidelines for managing the use of land. *Ecological Applications* 10: 639–670.
- Destouni, G., K. Persson, C. Prieto, and J. Jarsjö. 2010. General quantification of catchment-scale nutrient and pollutant transport through the subsurface and coastal waters. *Environmental Science and Technology* 44: 2048–2055.
- ESRI. 2008. ArcGIS (Version 9.3) GIS Application. Environmental Systems Research Institute, Inc.
- European Parliament, Council. 2000. *Directive 2000/60/EC (Water Framework Directive)*.
- European Commission. 2003. Common Implementation Strategy for the Water Framework Directive (2000/60/EC), Guidance document no. 8, Public Participation in relation to the Water Framework Directive. Office for Official Publications of the European Communities. Luxembourg.
- Falkenmark, M., and C. Folke. 2000. How to bring ecological services into integrated water resources management. *AMBIO* 29: 351–352.
- Folke, C. 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16: 253–267.
- Folke, C., F. Berkes, J. Colding, and U. Svedin. 1998. The problem of fit between ecosystems and institutions. IHDP Working Paper No. 2. International Human Dimensions Program on Global Environmental Change, Bonn, Germany. Available online at: <http://www.ihdp.uni-bonn.de/html/publications/workingpaper/wp02m.htm>.
- Gadgil, M., P. Olsson, F. Berkes, and C. Folke. 2003. Exploring the role of local ecological knowledge in ecosystem management: Three case studies. In *Navigating social-ecological systems: Building resilience for complexity and change*, ed. F. Berkes, J. Colding, and C. Folke, 189–209. Cambridge: Cambridge University Press.
- Grabs, T., J. Seibert, K. Bishop, and H. Laudon. 2009. Modeling spatial patterns of saturated areas: A comparison of the topographic wetness index and a dynamic distributed model. *Journal of Hydrology* 373: 15–23.
- Gunderson, L., and C.S. Holling, (eds.) 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. I Washington D.C.: Island Press.
- Hammer, M., C.M. Holmlund, and M. Åqvist Almlöv. 2003. Social-ecological feedback links for ecosystem management: A case study of the Central Baltic Sea Archipelago. *Ocean and Coastal Management* 46: 527–545.
- Hedin, S., A. Dubois, R. Ikonen, P. Lindblom, S. Nilsson, V.-P. Tynkkynen, M. Viehhauser, Ü. Leisk et al. 2007. The Water Framework Directive in the Baltic Sea Region Countries—vertical implementation, horizontal integration and transnational cooperation. Nordregio. 2007: 2 Stockholm. 176 pp.
- HELCOM (Helsinki commission). 2008. Convention on the protection of the marine environment of the Baltic Sea area. Including the amendments to its Annexes adopted by the Helsinki Commission in 2000, 2001, 2003 and 2007. Helsinki Commission, Baltic Marine Environment Protection Commission. www.helcom.fi.
- Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4: 1–23.
- Holmlund, C.M., and M. Hammer. 1999. Ecosystem Services Generated by Fish Populations. *Ecological Economics* 29: 253–268.
- Jöborn, A., I. Danielsson, B. Arheimer, A. Jonsson, M.H. Larsson, L.J. Lundqvist, M. Löwgren, and K. Tonderski. 2005. Integrated water management for eutrophication control: Public participation, pricing policy, and catchment modeling. *AMBIO* 34: 482–488.
- Kern, K., and T. Löffelsend. 2004. Governance beyond the nation-state: Transnationalization and Europeization of the Baltic Sea region. Discussion Paper SP IV 2004-105. Social Science Research Center. Berlin.
- Lantmäteriet. 2010a. GSD terrain elevation databank. Lantmäteriet, Gävle (retrieved May 10, 2010, grant I 2010/0044, <https://butiken.metria.se/digibib/index.php>).
- Lantmäteriet. 2010b. GSD topographic map. Lantmäteriet, Gävle (retrieved May 10, 2010, grant I 2010/0044, <https://butiken.metria.se/digibib/index.php>).
- Lantmäteriet. 2010c. GSD property Map. Lantmäteriet, Gävle (retrieved May 10, 2010, grant I 2010/0044, <https://butiken.metria.se/digibib/index.php>).
- Lindahl, T., and T. Söderqvist. 2004. Building a catchment-based environmental programme: A stakeholder analysis of wetland creation in Scania, Sweden. *Regional Environmental Change* 4: 132–144.
- Lundqvist, L. 2004. Integrating Swedish water resource management: A multi-level governance trilemma. *Local Environment* 9: 413–424.
- Länsstyrelsen Västmanlands län, Vattenmyndigheten Norra Östersjön. 2009a. Programme of Measures. The Northern Baltic Sea River Basin District 2009–2015 (in Swedish).
- Länsstyrelsen Västmanlands län, Vattenmyndigheten Norra Östersjön. 2009b. Management Plan. The Northern Baltic Sea River Basin District 2009–2015 (in Swedish).
- Länsstyrelsen Västmanlands län, Vattenmyndigheten Norra Östersjön. 2009c. Environmental quality standards. The Northern Baltic Sea River Basin District 2009 (in Swedish).
- Meinzen-Dick, R. 2007. Beyond panaceas in water institutions. *Proceedings of the National Academy of Sciences* 104: 15200–15205.

- Millennium Ecosystem Assessment. (MA). 2005. *Ecosystems and human well-being: Synthesis*. Island Press, Washington D.C., USA.
- Neuendorf, K.A. 2002. *The Content Analysis Guidebook*. Thousand Oaks: Sage Publications.
- Nilsson, S. 2006. Managing water according to river basins. Information management, institutional arrangements and strategic policy support—with focus on the EU Water Framework Directive. TRITA-LWR. PhD Thesis 1030.
- Nilsson, S., and S. Langaas. 2006. International river basin management under the EU Water Framework Directive: An assessment of cooperation and water quality in the Baltic Sea Drainage Basin. *AMBIO* 35: 304–311.
- Ostrom, E. 2005. *Understanding Institutional Diversity*. Princeton: Princeton University Press.
- Polyakov, V., A. Fares, and M.H. Ryder. 2005. Precision riparian buffers for the control of nonpoint source pollutant loading into surface water: A review. *Environmental Reviews* 13: 129–144.
- Quinn, P., K. Beven, and R. Lamb. 1995. The $\ln(a/\tan\beta)$ index: How to calculate it and how to use it within the TOPMODEL framework. *Hydrological Processes* 9: 161–182.
- Reid, W., F. Berkes, T.J. Wilbanks, and D. Capistrano. 2006. *Bridging scales and knowledge systems. Concepts and applications in ecosystem assessment*. Island Press, Covelo. 351 pp.
- Russell, G.D., C.P. Hawkins, and M.P. O'Neill. 1997. The role of GIS in selecting sites for riparian restoration based on hydrology and land use. *Restoration Ecology* 5: 56–68.
- Saloranta, T.M., J. Kämäri, S. Rekolainen, and O. Malve. 2003. Benchmark criteria: A tool for selecting appropriate models in the field of water management. *Environmental Management* 32: 322–333.
- SMHI. 2010. GSD river basin data, Swedish water archive. SVAR 2008. (retrieved Mar 18, 2010, © Lantmäteriet Gävle 2010. Permission I 2010/0056, <http://produkter.smhi.se/svar/svar2008.htm>).
- Söderqvist, T. 2002. Constructed wetlands as nitrogen sinks in Southern Sweden: An empirical analysis of cost determinants. *Ecological Engineering* 19: 161–173.
- Söderqvist, T. 2003. Are farmers prosocial? Determinants of the willingness to participate in a Swedish catchment-based wetland creation programme. *Ecological Economics* 47: 105–120.
- Steyaert, P., and J. Jiggins. 2007. Governance of complex environmental situations through social learning: a synthesis of SLIM's lessons for research, policy and practice. *Environmental Science & Policy* 10: 575–586.
- Tarboton, D. 1997. A new method for the determination of flow directions and upslope areas in grid digital elevation models. *Water Resources Research* 33: 309–319.
- Tarboton, D.G., K.A.T. Schreuders, D.W. Watson, and M.E. Baker. 2009. Generalized terrain-based flow analysis of digital elevation models. 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation, ed. R. S. Anderssen, R. D. Braddock, and L.T.H. Newham. Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation, July 2009: 2000–2006.
- Toderi, M., N. Powell, G. Seddaiu, P.P. Roggero, and D. Gibbon. 2007. Combining social learning with agro-ecological research practice for more effective management of nitrate pollution. *Environmental Science and Policy* 10: 551–563.
- White, D., and S. Fennessy. 2005. Modeling the suitability of wetland restoration potential at the watershed scale. *Ecological Engineering* 24: 359–377.
- Young, O. 2002. *The Institutional Dimensions of Environmental Change: Fit, Interplay, and Scale*. Cambridge, MA: MIT Press.

AUTHOR BIOGRAPHIES

Monica Hammer (✉) is an Associate Professor in Natural Resources Management at Södertörn University, Sweden. Her research interests include ecosystem management approaches of integrated social-ecological systems, identification and assessment of ecosystem services.
Address: School of Life Sciences, Södertörn University, 141 89 Huddinge, Sweden.
 e-mail: monica.hammer@sh.se

Berit Balfors is an Associate Professor at the Department of Land and Water Resources Engineering, KTH. Her research interests include environmental systems analysis with particular focus on environmental assessment and water management.
Address: Department of Land and Water Resources Engineering, KTH, Royal Institute of Technology, 100 44 Stockholm, Sweden.
 e-mail: balfors@kth.se

Ulla Mörtberg is a Lecturer at the Department for Land and Water Resources Engineering, KTH. Her research interests include landscape ecological aspects and modeling of water and biodiversity management and planning.
Address: Department of Land and Water Resources Engineering, KTH, Royal Institute of Technology, 100 44 Stockholm, Sweden.
 e-mail: mortberg@kth.se

Mona Petersson is a Lecturer in Physical Geography at the School of Life Sciences, Södertörn University. Her research interests are landscape processes related to river basins and coastal areas, and the considerations taken within planning and management.
Address: School of Life Sciences, Södertörn University, 141 89 Huddinge, Sweden.
 e-mail: mona.petersson@sh.se

Andrew Quin is a doctoral candidate at KTH working with hydrological modeling and information management using water management.
Address: Department of Land and Water Resources Engineering, KTH, Royal Institute of Technology, 100 44 Stockholm, Sweden.
 e-mail: andrewq@kth.se