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Adaptation of a method for involving environmental aspects in spatial planning of river basin management – a case study of the Narva River basin

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Abstract. A method for environmental planning (MEP) was adapted for use in water management in large drainage basins. Using a semi-dynamic method, Fuzzy Cognitive Mapping, an expert system divided the studied Narva River basin into three distinct environmental zones. Consequences were calculated based on environmental effects on and significances of waterbodies. In the DPSIR (referring to driving forces, pressures, state, impacts, and responses) framework, the expert system quantified the effects of large-scale spatial plans into impacts and consequences. Also, several existing concepts were integrated to define environmental sensitivity, which comprises two components: (1) strength of links between components in the DPSIR framework and (2) significance of the feature of interest. The results revealed environmentally cost-effective principles for localizing various driving forces such as wastewater treatment, oil shale mining, and agricultural activities.

Key words: river basin management, environmental sensitivity, Fuzzy Cognitive Mapping, expert system, knowledge base.

INTRODUCTION

A central target of the EU Water Framework Directive (WFD) is to achieve a good status of all European waterbodies (European Community, 2000). As most water pollution emanates from diffuse sources, the WFD challenges many existing land-use practices, especially those determined by agricultural production and urban development (overview in Moss, 2004). Consequently, the directive discourages intensive agriculture on land close to lakes and rivers and encourages minimization of urban run-off and retaining water in wetlands or polders. In those catchments where WFD objectives require strict protective measures, the use of land for agricultural production and urban settlements may fall under conflicts of interests (Moss, 2004). This paper seeks methodological ways to overcome such conflicts with more eco-efficient land-use planning.

An example of an area with such conflicting interests is the Narva River basin, which hosts two large lakes – Peipsi and Võrtsjärv – of moderate ecological status. These lakes are eutrophied due to the load of phosphorus (Nõges & Nõges, 2006). The most significant contributing driving force has been found to be agricultural diffuse load, followed by household and industrial wastewaters (Ministry of

Environment, 2010a). Considering also other waterbodies and groundwater in that drainage basin, other most significant drivers are oil shale based power engineering, drainage, dams, and peat mining (Ministry of Environment, 2010a). Such various land-demanding economic activities in the Narva basin provide an opportunity to test how advancements in land-use planning methodologies might generate more sustainable river basin management solutions.

STUDY AREA

"Water Scenarios for Europe and for Neighbouring States (SCENES)", a project under the EU 6th Research Framework Programme, selected the Narva River drainage basin as one of the pilot study areas for developing and analysing a set of comprehensive scenarios of Europe's freshwater futures up to 2050. These scenarios will provide a reference point for long-term strategic planning of European water resource development. In the SCENES project, the Narva basin represents the Eastern Baltic region.

The Narva basin (56 200 km^2) is located in Estonia and the Russian Federation (Fig. 1). The area is situated in the central part of the southeastern coast of the

Fig. 1. Narva River drainage basin.

Baltic Sea and has a population of approximately 1.1 million. Forests and semi-natural areas dominate in the flat drainage basin, which has its highest point at 338 m above sea level and an average elevation of 163 m. The area includes the large Lake Peipsi/Chudskoe, which consists of three unequal parts: the largest in the north known as Lake Peipsi *s.s.* (2603 km^2) is connected through the narrow strait-like Lake Lämmijärv/Teploe (240 km^2) to the southern part called Lake Pihkva/Pskovskoe (710 km^2). The water of Peipsi (25 km^3) has a residence time of two years. The Narva River is 77 km long and has its source in the northeastern part of Lake Peipsi. The Baltic Sea receives an average of about 400 $m^3\ s^{-1}$ of water from the Narva River.

METHODOLOGY

To comply with practical guidance of WFD Common Implementation Strategy, an analysis of pressures and impacts of river basins should follow the Drivers–Pressures–State–Impacts–Responses (DPSIR) approach of the European Environmental Agency (Smeets & Weterings, 1999; IMPRESS, 2002). In this framework, 'Driving Forces' mean economic factors and human activities while 'Pressures' serve as the ways how drivers affect the environment. 'State' refers to the quality of the environment, which is affected by the pressures. State, in turn, affects human health, ecosystems, and natural resources, which together form 'Impacts'. Finally, impacts lead to 'Responses' in society such as environmental regulations. Among these regulations, this paper focuses on large-scale spatial development plans.

Analytical model

Streefkerk (2005) developed 'A method for incorporating environmental aspects into spatial planning' (MEP) in 1990–1992. Its overall goal is to contribute to and protect the environment without blocking or frustrating spatial or urban developments unnecessarily. MEP works as a semi-quantitative reasoning tool to evaluate negative environmental impacts of various spatial activities such as construction, infrastructure, and industry. Often assisted with GIS, MEP combines sensitivity and impact maps to provide maps of existing and future environmental situations. Both input and output maps apply numerical ratings, which can be acquired for example through an expert system. This technique mainly considers air and noise pollution and associated risk issues, and it takes into account differences in sensitivity to various environmental risks and impacts. MEP can be employed as a planning tool of environmental managers to ensure that potentially harmful projects will be implemented in less sensitive locations.

Streefkerk (2005) defined the concept of environmental impact controversially. He listed the following impact examples, also referred to as 'influences': pollution, noise, land removal, loss of nature, changing of groundwater table, hazards. However, in the DPSIR framework, such examples rather fall under the category of 'Pressures'. 'Impact' in DPSIR, in turn, approximately corresponds to 'situation' in Streefkerk (2005).

In Streefkerk (2005), impacts and the resulting situations are numerically related via ‘sensitivity’, which is defined as the degree of naturalness of an area, assuming that whatever the type of impact, more natural areas are more sensitive, leading to a worse environmental situation. However, in an example, Streefkerk (2005) controversially proposed housing area as being more sensitive than grassland. Hence, sensitivity requires a better definition.

The present study broadens the concept of environmental sensitivity to adapt MEP for large geographical areas and a wide range of environmental issues. We propose that sensitivity consists of two components, the first component being the significance of a feature (e.g., a waterbody). In the DPSIR framework, significance can be related to areas of protection such as human health, natural resources, and the health and biodiversity of ecosystems. Thus, the overall environmental significance of a waterbody emanates from several different function-related significances. The second component quantifies the strength of any causal link between driving forces, pressures, state criteria, and impacts in the DPSIR framework. State can be sensitive to pressures, whereas impacts can be sensitive to state. For example, the state of a waterbody depends on both the strength of pressures and the overall sensitivity of the state to these pressures.

Data collection

To acquire environmental knowledge from the study area, we applied a cognitive mapping technique, defined as a procedure to get human internal representations from spatial information (e.g. Golledge, 1999). An individual’s perception and understanding of a problem can be captured in a cognitive map that consists of interconnected sets of elements representing implicit views of one’s own interests, concerns, and tasks. According to Zhang et al. (1989), a cognitive map represents relationships that are perceived to exist among the attributes and/or concepts of a given environment. According to Kosko (1986), fuzzy cognitive maps represent the degree of causality in causal reasoning. Synthesis of indivual cognitive maps reveals collective cognitive maps that may work as decision support tools (overview in Kwahk & Kim, 1999). This technique structures, analyses, and makes sense of accounts of problems. According to Kwahk & Kim (1999), a cognitive map consists of ‘nodes’, called *causal concepts*, ‘links’, representing *causal connections* among causal concepts, and ‘strengths’, specifying *causal values* of causal connections. According to their classification, depending on the representation of the causal value, different cognitive maps fall under three categories whereas a weighted map has a value in the interval from -1 to $+1$. Such a weighted map resulted also from this study.

We used a fuzzy expert system such as that described by Van der Werf & Zimmer (1998) and Roussel et al. (2000). Cognitive mapping of the expert system using four water quality experts was applied to acquire data for using MEP (Streefkerk, 2005; Fig. 2). In a six-hour workshop, the experts achieved a consensus in designing both the conceptual model and the weighted map. The expert system grouped all surface waters and groundwaters in the drainage basin

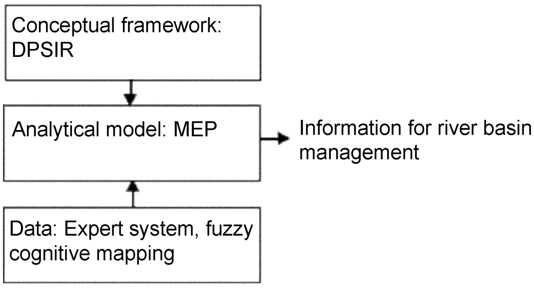

Fig. 2. Methodological approach to acquire information for river basin management.

into entities according to type, geographical location, and function. Each entity in the expert system query received both existing significances and impact rates in four environmental impact categories: damage to humans, damage to wildlife, loss of fish catch, and loss of water (Table 1). For example, as Lake Peipsi *s.s.* is known to provide more fish than Lake Pskovskoe does, the experts rated fish-related significance of Peipsi *s.s.* higher. However, due to overfishing and eutrophication in Lake Pskovskoe, loss of fish catch in that lake (considered as a

Table 1. Parameters used in the environmental mapping of water entities in the Narva River drainage basin. The system considered the following four environmental functions: human health, ecosystem health, fish stocks, and water reserves. Each function is related to the corresponding area of protection

Parameter	Symbol	Explanation/Query question	Information source
Function-related significance	s	How significant is the entity in relation to one of four areas of protection?	Expert system query
Overall environmental significance	S	How significant is the entity?	$S = \sum s$
Function-related impact rate	i	How much is the entity affected by one of four categories of environmental impact?	Expert system query
Overall environmental impact rate	I	How much is the entity environmentally impacted?	$I = \sum i$
Function-related consequence rate	is	How serious is the consequence for the given area of protection?	$is = i \times s$
Overall environmental consequence rate	IS	How serious is the total environmental consequence of all impacts?	$IS = \sum is$; $IS = I \times S$

function-related impact) received a higher rate. The products of significances and impacts revealed consequences. For example, when the overall environmental impact on the Narva River rated 45% and the overall environmental significance of the entity rated 20%, the overall environmental consequence of the Narva River was 45% × 20% = 9%.

Out of several available causal frameworks for environmental assessment, the expert system chose a modified DPSIR, which, in contrast to previous applications, started with responses and ended with areas of protection. The list of responses that were analysed comprised only the most relevant estimated large-scale development plans (DPs). Furthermore, as suggested by Kok (2009), the experts considered only factors that are ‘easy to manipulate’ and also operate on a relatively short and similar temporal scale. Also, to simplify the analysis, the expert system excluded marginal causes and links with less than 10% estimated relevance. The resulting framework comprised 39 components with 52 causal links between them. An example of components and links for bodies of surface water is shown in Fig. 3. The experts rated all the 52 links between 0 and 1 (100%) depending on the strength of the link (as suggested in Benetto et al., 2008), which resulted in the relative effect of each pressure, driving force, and DP. A hypothetical maximum (100%) effect would mean that the given pressure, driving force, or DP would generate a maximal environmental consequence for the given entity. For example, if the overall consequence for Lake Pskovskoe is 26%, and 67% of that proportion originates from the load of nitrogen and phosphorus, then the effect of those nutrients on Lake Pskovskoe will be 26% × 67% = 17.4%.

The modelling of the effects of responses described above quantified the links between water-related environmental impacts and various DPs. To these DPs, environmental zoning added principles for advancement of the water protection aspects that proposed localization of harmful activities to zones with weaker and fewer impacts and significances. For example, animal farming generates a large nitrogen and phosphorus load and should thus be conducted in zones where such pressure has a more limited effect on waterbodies.

In conclusion, we demonstrate here that practical information for river basin management can successfully emerge from the application of MEP as we have advanced this analytical tool from two aspects. First, in the conceptual aspect, in previous studies MEP failed to adequately evaluate and compare different environmental impacts of various human activities. Here, DPSIR framework gives clear, sufficient, and widely approved assessment criteria. Second, as comparison of these human activities requires a universal, commensurable rating system, we adopted here the data collection technique of Fuzzy Cognitive Mapping of expert system (Fig. 2).

RESULTS

All waters of the drainage basin were grouped into the following five entities: Lake Peipsi *s.s.*, Lake Pskovskoe, the Narva River, groundwater, and ‘other waterbodies’.

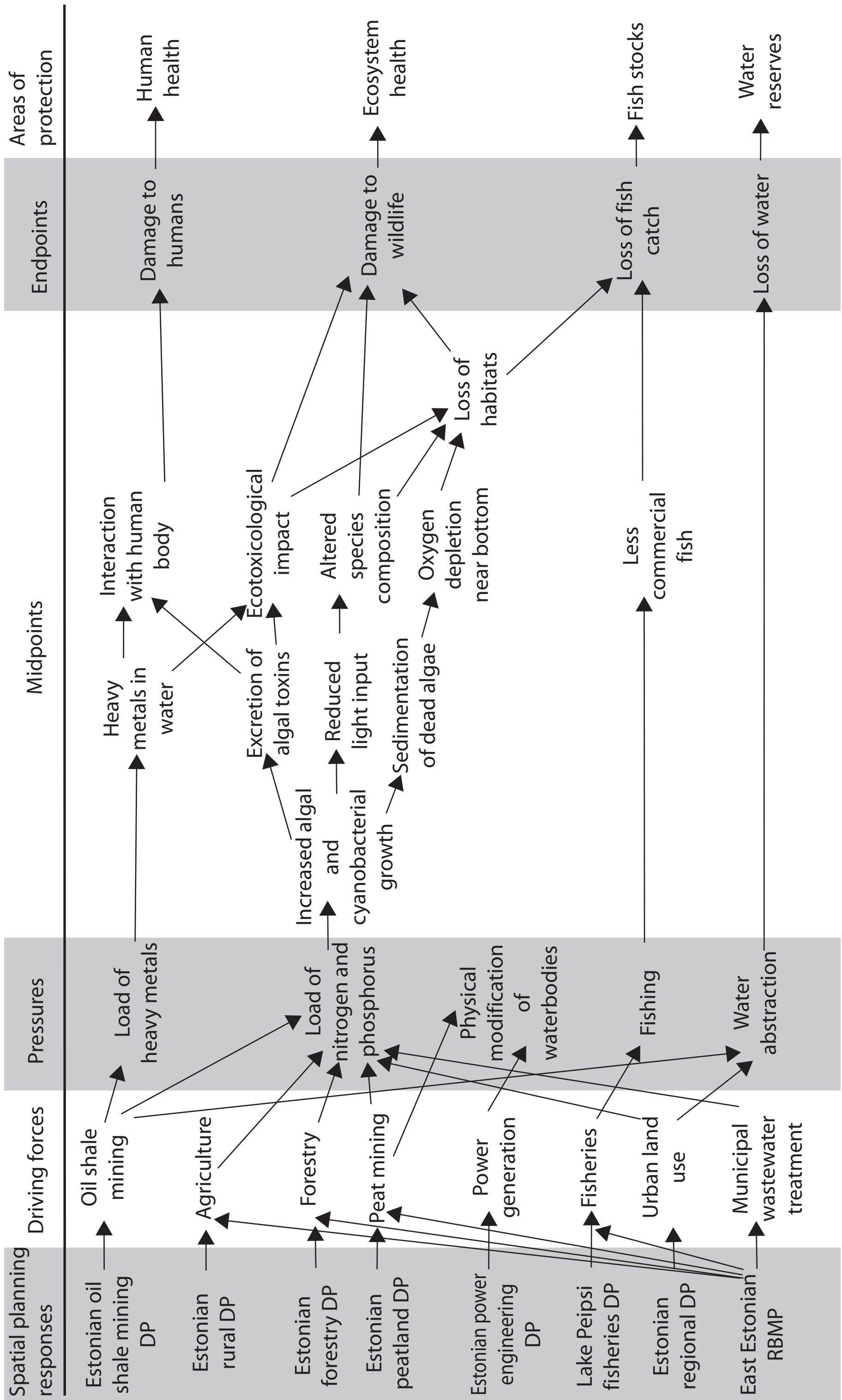

Fig. 3. Components of the DPSIR system in the Narva River drainage basin. DP = development plan; RBMP = river basin management plan.

Rating significances, impacts, and consequences

The expert system assessed each of the five water entities against four areas of protection (functions; Table 2): human health, ecosystem health, fish stocks, and water reserves. The most significant of these functions appeared to be human health

Table 2. Results of cognitive mapping of the expert system in the assessment of environmental significance and consequences and the related effects of pressures, driving forces, and responses in water entities of the Narva River basin, rated between 0 and 10

	Lake Peipsi *s.s.*	Lake Pskovskoe	Narva River	Groundwater	Other waterbodies
Significance	**3.8**	**3.3**	**2.0**	**3.8**	**4.5**
Human health	4	3	1	7	7
Ecosystem health	3	4	1	0	4
Fish stocks	8	6	1	0	1
Water reserves	0	0	5	8	6
Consequences	**2.4**	**2.6**	**0.8**	**1.2**	**1.4**
Damage to humans	1.6	1.8	0.5	1.4	2.8
Damage to wildlife	1.5	3.2	0.4	0.0	2.4
Loss of fish catch	6.4	5.4	0.6	0.0	0.3
Shortage of water	0.0	0.0	1.5	3.2	0.0
Pressures					
Load of heavy metals	0.6	0.4	0.1	0.1	3.4
Load of N and P	4.8	6.9	0.8	0.0	1.8
Groundwater pollution	0.0	0.0	0.0	1.3	0.0
Physical modification	0.9	0.4	0.2	0.0	0.2
Fishing	3.2	2.7	0.3	0.0	0.2
Water abstraction	0.0	0.0	1.5	3.2	0.0
Driving forces					
Urban land use	0.0	0.7	0.2	0.4	0.2
Peat mining	0.5	0.7	0.1	0.1	0.9
Oil shale mining	1.1	0.4	1.6	3.1	2.9
Agriculture	1.9	1.4	0.3	0.8	0.5
Forestry	0.5	0.7	0.1	0.1	0.2
Power generation	0.9	0.4	0.2	0.0	0.2
Fisheries	3.2	2.7	0.3	0.0	0.2
Wastewater treatment	1.4	3.5	0.3	0.0	0.5
Responses					
RBMP	1.3	0.0	0.2	3.3	4.1
Oil shale DP	0.9	0.0	1.3	0.0	0.1
Rural DP	0.6	0.0	0.1	1.3	1.1
Forestry DP	0.1	0.0	0.0	0.1	0.1
Peatland DP	0.0	0.0	0.0	0.0	0.0
DP of power engineering	0.5	0.0	0.1	0.0	0.0
Peipsi fisheries DP	2.2	1.9	0.2	0.0	0.0
Regional DP	0.0	0.0	0.0	0.0	0.1
Other responses	3.9	8.5	1.1	3.3	4.1

DP = development plan; RBMP = river basin management plan.

followed by water reserves (32% and 28% of all significances, respectively). 'Other waterbodies' emerged as the most significant water entity (representing 26% of all waters), which was associated with 33% of ecosystem health and 32% of both human health and water reserves. Groundwater (42%) proved to be the most significant water reserve. The most significant fish stocks were located in lakes Peipsi *s.s.* (50%) and Pskovskoe (38%).

The area of protection most extensively affected appeared to be fish stocks, followed by ecosystem health and human health (52%, 46%, and 42%, respectively). All these impacts peaked in Lake Pskovskoe, which therefore qualified as the most extensively influenced entity (58%). Impacts on water reserves remained low in each of the five entities.

The impacts created the worst overall environmental consequences for lakes Pskovskoe (26%) and Peipsi *s.s.* (24%). Also, they were most detrimental to human health in 'other waterbodies' (28%), ecosystem health in Lake Pskovskoe (32%), fish stocks in Peipsi *s.s.* (54%), and water reserves in groundwater (32%).

Environmental zoning

For the sake of simplicity, the experts divided the study area into only three environmental zones (designated A–C; Fig. 4). Of all pressures, it appeared

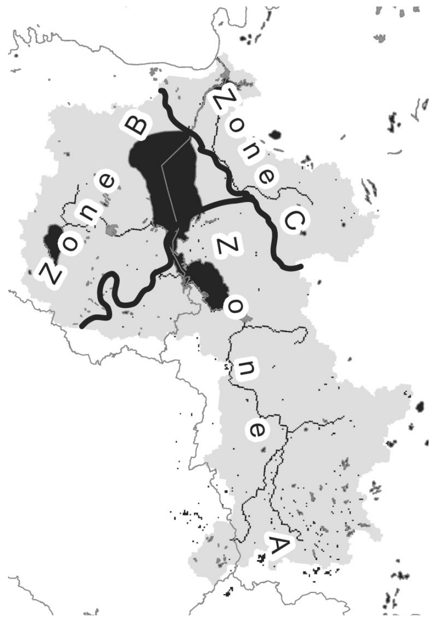

Fig. 4. Environmental zones in the Narva River drainage basin.

that the load of N and P had the greatest influence (contributing 38% to all consequences), and thus it was important to base the environmental zoning on the catchments of each of the five water entities.

Lake Pskovskoe and its catchment had the largest N and P loads and were delineated as Zone A, which was classified as having a poor environmental state and also the most damaged wildlife. The Narva River and its immediate catchment were assigned to Zone C and classified as having a good environmental state with the least severe consequences. The remaining area, comprising Peipsi *s.s.* and its immediate catchment, was called Zone B and was classified as having a moderately affected environmental state with the most severely depleted fish stocks.

Effects of pressures

Load of nutrients (N and P) constituted the strongest pressure, with an overall total effect of 7.2% on the system consequences and corresponding values of 17.4%, 12.0%, and 4.4% for Lake Pskovskoe, Peipsi *s.s.*, and ‘other waterbodies’. The other most important pressures were fishing (3.2%), followed by water abstraction (2.4%) and load of heavy metals (2.3%).

Effects of driving forces

The strongest driving forces emerged as oil shale mining (effect 4.5%) and fisheries (3.2%). The strongest effects were exerted by oil shale mining on groundwater (7.9%), by fisheries on Peipsi *s.s.* (8.0%), and by wastewater treatment on Lake Pskovskoe (8.7%).

Effects of development plans (DPs)

The knowledge system assessed eight large-scale DPs that could be assumed to have a significant effect on the environment of the investigated waterbodies (Table 3). The maximum potential total effect of all these plans was rated as 6.1%, while other responses were found to have an influence of at least 16.5% on the studied waterbodies. The greatest potential effects appeared for the Estonian oil shale exploitation DP (up to 2.3%), followed by the Lake Peipsi fisheries DP (2.2%), the East Estonian river basin management plan (RBMP; 0.8%), and the Estonian rural DP (0.4%).

Incorporation of water protection aspects into DPs

The Estonian oil shale exploitation DP affected groundwater, the Narva River, and other waterbodies, and the rating of the impacts indicated that oil shale mining should be localized in Zone C rather than Zone B (Table 4). Also, the

Table 3. Development plans (DP) that affect the environment of waterbodies in the Narva River drainage basin

DP	Content	Existing water management and environmental sensitivity concepts	Proposed conceptual advancements	References
East Estonian river basin management plan	The plan determines protection and exploitation of waters in East Estonian river basin, which covers the Estonian part of the study area. Until 2015, most of the water management resources, altogether € 467 million, are to be allocated into point pollution sources	Special measures protect groundwater in nitrate-vulnerable areas	In addition to groundwater, surface waters should be also zoned according to sensitivity/vulnerability	Ministry of Environment, 2010a
Estonian oil shale DP	The DP determines the future of the Estonian oil shale industry, whose significant part is located in the study area	The oil shale reserves fall into distinct categories of environmental sensitivity. Higher sensitivity emanates from an overlap with or vicinity to protected areas. The DP requests applied studies to enable to decide upon new mines considering environmental sensitivity	In addition to protected areas, environmental sensitivity should consider also water protection aspects, including catchment approach	Ministry of Envrionment, 2008; Tallinna Tehnikaülikool, 2003
Estonian rural DP	The DP was prepared to support regionally balanced development of rural areas through the European Union Common Agricultural Policy measures	To protect groundwater, agri-environmental support schemes include a special measure to support environmentally friendly agricultural production in nitrate-vulnerable areas	Agri-environmental schemes should target also vulnerable/sensitive surface waters	Ministry of Agriculture, 2008
Estonian forestry DP	The DP prioritizes the development of Estonian forestry and sets relevant actions	Water issues are neglected in the DP	Management of forests, including restoration of drainage systems, should consider water protection aspects. Forests need respective zoning	Ministry of Environment, 2003

Table 3. *Continued*

DP	Content	Existing water management and environmental sensitivity concepts	Proposed conceptual advancements	References
DP of protection and sustainable exploitation of Estonian peatlands (Estonian Peatland DP)	The DP sets principles and actions for the management of peatlands for the next couple of decades	A drafted conceptual paper overlooks the impacts of peat mines on the quality of downstream water-bodies	The DP should zone peatlands according to expected consequences of various management activities to waterbodies	Republic of Estonia, 2010; Ministry of Environment, 2010b
Estonian power engineering DP	Effective and innovative power engineering should support sustainable and balanced development of Estonia. The DP aims to reduce the share of oil shale in the Estonian energy budget. Most of Estonian electricity is produced in power plants on the bank of the Narva River	The DP targets more environmentally friendly end-of-life management of oil shale ash as well as development of cleaner oil shale mining technologies	Spatial planning of wind farms, hydro plants, oil shale mines and environmental measures should consider variable zones of environmental sensitivity	Anonymous, 2010
Lake Peipsi fisheries DP	Peipsi Sub-Basin Fishers' Association aims to increase income and to improve the life quality of local fishermen while decreasing the number of professional fishermen. The DP recognizes the need to sustain the fish stock	The DP recognizes spatial differences in the existing situation. However, solutions remain mostly spatially undifferentiated	Clear zoning of various goals, priorities, and activities could better bridge gaps between short-term and strategic objectives	Peipsi Alamvesikonna …, 2004
Estonian Regional DP	To reduce regional differences in living standards and economic competitiveness the DP supports various local and regional initiatives	The DP admits that in growth regions, intensified human activity might increase the environmental load	Countermeasures against increasing environmental load should target more sensitive areas	Regional …, 2005

Table 4. Assessment of spatial planning alternatives in the Narva River catchment

	Zone A (L. Pskovskoe and its catchment)	Zone B (L. Peipsi *s.s.* and its immediate catchment)	Zone C (Narva River and its immediate catchment)
Most effective DPs	Lake Peipsi fisheries DP	Lake Peipsi fisheries DP, East Estonian RBMP	Estonian oil shale exploitation DP
Most effective driving forces	Wastewater treatment	Fisheries	Oil shale exploitation
Most effective pressures	Load of N and P	Load of N and P, fishing	Water abstraction
State	Poor	Moderate	Good
Most serious impacts	Loss of fish catch, damage to wildlife	Loss of fish catch	Loss of fish catch
Most significant areas of protection	Fish stocks	Fish stocks	Water reserves
Most serious consequences	Reduced fish stocks, damaged ecosystem health, damaged human health	Reduced fish stocks	Reduced water reserves
Investments to wastewater treatment	Required	Recommended	Not necessary
Relationship with N load	Reduction required	Slight increase can be tolerated	Significant increase can be tolerated
Relationship with P load	Major reduction required	Reduction required	Slight increase can be tolerated
Recommended agricultural direction: crop production vs. livestock and fodder production	Crop production	Livestock production	Livestock production
Recultivation of forested areas, restoration of drainage systems (extensification)	Not suitable	Not suitable	Suitable
Increase in fertilization (intensification)	Suitable if requirements of good agricultural practice are fulfilled	Suitable if requirements of good agricultural practice are fulfilled	Suitable
Forestation of open lands and avoidance of clear-cuts	Required	Recommended	Not necessary
Mining	Should be avoided	Not suitable	Suitable
Regional development along with increase of population	Should be avoided	Not suitable	Suitable

DP = development plan; RBMP = river basin management plan.

Lake Peipsi fisheries DP had almost equal impacts on zones A and B, and hence the knowledge base implied that this transboundary DP should regulate those two zones to equal extents. Although it did influence most of the driving forces, the East Estonian RBMP could reduce their environmental consequences primarily by planning wastewater treatment. Such efforts would be particularly effective in Zone A, whereas wastewater treatment is already sufficient in Zone C. The results regarding the Estonian rural DP indicated significant influence on Zone B, suggesting that areas of intensive agriculture, reforestation, restoration of drainage systems, and increased fertilization should preferably be localized to Zone C instead of Zone A. It also appeared that Zone C would be suitable for animal husbandry but Zone A would be more appropriate for crop production and other driving forces that are less impacting.

DISCUSSION

Conclusions drawn from the case study

Environmental management may get additional opportunities from comparison, arrangement, and integration of various problems. For instance, quantitative assessment of various impacts of different driving forces enables prioritization of responses. The case study revealed that the waterbodies of the Narva River basin suffer from oil shale mining rather than fisheries or insufficient wastewater treatment. Hence, water policy should prioritize measures to reduce impacts from oil shale mining.

A spatially large-scale approach enables zoning of human activities according to environmental sensitivity. Our case study effectively zoned waterbodies in the Narva River basin. For instance, in contrast to the remaining study area, the immediate catchment of the Narva River can desist from further investments to wastewater treatment because the water quality is already good.

The study area is located in both Estonia and the Russian Federation, which essentially manage their resources independently, including their shared transboundary waters. Decisions within transboundary agreements deal only with fishing quotas and a few other issues. On the Estonian side, many strategies (e.g. Regional …, 2005) and DPs (e.g. Ministry of Environment, 2003, 2008; Riigikogu, 2004; Ministry of Agriculture, 2008), which influence driving forces on waterbodies, ignore variations in environmental sensitivity of location alternatives. This case study proposes a general cost-effective approach for incorporating catchment management aspects into a variety of spatial issues (Table 3). Various DPs should take into account that different locations vary with respect to their sensitivity to human activities. For example, the load of N and P affects the environment by 17.4% in Lake Pskovskoe, 12.0% in Peipsi *s.s.*, but only 2.1% in the Narva River. Hence, since the immediate catchment of the river tolerates the load much better, it should be preferable to localize associated human activities to the Narva River catchment.

The results of this case study indicate that the Narva River catchment management in operation today is in need of a subcatchment approach that can effectively control the land-based load of pollutants. However, if the predominating pressures are instead catchment independent in nature (physical modification, fishing, and shipping), it might be better to use environmental zone boundaries that track dams, fish spawning areas, ship trajectories, or other spatial factors.

The experts concluded that practical catchment management requires more detailed zoning. For ‘other waterbodies’ upstream of the town of Pskov, special attention should be paid to the Velikaya River, which provides drinking water for the population of the town. Lakes and rivers need to be further zoned according to their environmental state, considering their significance with respect to recreation and wildlife conservation. Lake Peipsi *s.s.* should be split into a southern part with a moderately impacted environmental state that provides higher wildlife protection significance, and a northern part that is in a good state and gives water to the Narva River, thus functioning as a water reserve and also having a greater recreational significance. Groundwater requires independent zoning that emphasizes the environmental state with regard to quantity as well as strength of the link between agriculture and nutrient loads. Inasmuch as most of the important large-scale DPs are run at national level, more detailed zoning should follow national boundaries.

It should also be mentioned that, due to the transboundary situation in the Narva River catchment, each DP in this case study covered only a fraction of the investigated area. In catchments that are situated entirely within a single nation, any DP might have a greater influence on the waterbodies concerned.

Methodological implications

Several authors have proposed that the cost effectiveness of water management can be improved by allocating harmful activities to less sensitive areas (Cowing et al., 2006; Strauss et al., 2007) and assigning abatement measures to more sensitive sites (Younger & Wolkersdorfer, 2004). However, each of the cited studies addressed only a single driving force and considered only some environmental consequences, and thus a universal context for spatial zoning regarding environmental sensitivity was lacking. Streefkerk (2005) partly bridged that gap by inventing the MEP technique for urban planning, which can locate different kinds of environmentally harmful projects according to their environmental sensitivity. As MEP quantifies problems non-physically, it enables to prioritize various human activities, considering also spatial dynamics. Unfortunately, Streefkerk (2005) defined the concept of environmental sensitivity very narrowly, so that it cannot compare location choices in relation to a wide range of environmental consequences. The present study advanced the sensitivity definition offered by Zacharias & Gregr (2005) by applying a DPSIR framework. That strategy makes sensitivity work as an integrated parameter that comparatively quantifies all environmental consequences of all driving forces and pressures. Consequently, it provides a new context for sustainable management of various economic and social sectors over large geographical areas.

Causal networking enabled us to quantify the potential effects of large-scale DPs in relation to environmental consequences in waterbodies, considering links between pressures, states, impacts, and consequences. Research has provided much information about some of these numerous causal links, for instance source apportionment of nutrient loads (overviews in Azzellino et al., 2008 and Schoumans et al., 2009) and loss of fish catch due to overfishing (overviews in Garcia & de Leiva Moreno, 2003 and Allan et al., 2005). Nevertheless, scientific data are lacking with respect to comparison of these processes, rating of significances, assessment of effects of DPs on driving forces, and several other links. Our results suggest that it would be better to use an alternative quantification approach, particularly when considering a relatively data-poor drainage basin such as that of the Narva River, the largest part of which is situated in the Russian Federation. In support of that conclusion, we were successful in applying Fuzzy Cognitive Mapping of an expert system to quantify the effects of DPs from a knowledge base.

Compared to a single expert, an expert system can obviously comprise more domain-specific knowledge. An expert system also facilitates distribution and addition of new knowledge, making the system versatile and convenient when dealing with dynamic situations. Transparency of reasoning lines enables the user to check the logic behind.

Chen et al. (2008) gave an overview of various artificial intelligence techniques, whereas the modified MEP might fall under their categories ‘rule-based systems’ and ‘fuzzy systems’. Compared to case-based reasoning, artificial neural networks, genetic algorithms, cellular automata, swarm intelligence, and other artificial intelligence techniques, our proposed fuzzy rule-based system very effectively handles vague or imprecise information. In addition, users can easily understand, implement, and apply such systems as knowledge is prescribed in a uniform way, as conditional rules.

However, Chen at al. (2008) indicated also a few weaknesses of such problem-solving method. It fails to automatically add or modify rules. Correct determination of membership functions (strengths of causal relationships) might be difficult. So, such a rule-based system requires availability of comprehensive domain-specific knowledge. This demands much expert workload.

Additionally, we admit that our expert system ignores uncertainty. Hence, it may inadequately provide recommendations instead of just stopping working. As the system actually works mainly on empirical and heuristic knowledge, it lacks truly causal relationships. Consequently, the system cannot learn, scale up interactions or apply them to other areas. Hence, application of the system remains limited to relatively narrow areas.

The causal framework applied here is a modified DPSIR that enables an expert query to create easily understandable and quantifiable links between DPs and environmental impacts. However, the reliability of that type of knowledge base might suffer seriously from the lack of feedback links. To counter that problem, cognitive mapping methods that include such feedback (Kok, 2009) could be used so that consideration can be given to additional processes that in reality change the final effects. In any case, the DPSIR we employed did prove to be sufficient for rough quantification and comparison of the effects of spatial plans on waterbodies.

As experts rely largely on existing literature and common sense, this study could not challenge previous conclusions from water management in the Narva River basin. However, we succeeded in integrating previous results by transforming existing information and using a novel conceptual approach. Such integration enabled us to solve quite complex environmental problems such as prioritization of various measures and geographical areas.

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Keskkonnaaspekti ruumilisse planeerimisse haaramise meetodi kohandamine vesikonna veemajandusega – Narva jõe valgla juhtumiuuring

Kristjan Piirimäe, Karin Pachel ja Alvina Reihan

Meetod keskkonna planeerimiseks (MEP) kohandati veemajanduseks suurtel valglatel. Kasutades hajusat kognitiivse kaardistamise meetodit, jagas ekspertsüsteem uuritud Narva jõe vesikonna kolme keskkonnatsooni. Tagajärgede arvutamisel võeti arvesse veekogudele mõjuvad keskkonnaefektid ja veekogude olulisus. Kasutades DPSIR-i raamistikku, kvantifitseeriti suuremastaapsete ruumiliste planeeringute efektid mõjudeks ja tagajärgedeks. Mitme varasema kontseptsiooni integreerimise tulemusena defineeriti keskkonna tundlikkus koosnevana kahest komponendist: 1) komponentidevaheliste seoste tugevus DPSIR-i raamistikus ja 2) uuritava objekti olulisus. Töötati välja keskkonna mõttes kulutõhusad põhimõtted erinevate survetegurite lokaliseerimiseks, sealhulgas reoveekäitlus, põlevkivi kaevandamine ja põllumajanduslikud tegevused.