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Sustainability aspects of water regulation and flood risk reduction in Lake Vänern

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A modern feature of flood risk management is to integrate ecological, economic and social aspects in risk prevention and mitigation. Risk-reducing measures can be in conflict with ecosystem functions and complicate upstream/downstream relations. Flood risks are also influenced by processes in the catchment, such as changes in climate and land-use, or increases of vulnerable urban areas. Lake Vänern in Sweden has high ecological and social values but is also flood-prone, which in this article has been analyzed from a perspective of sustainable development. Lake Vänern and the Göta älv River are used for drinking water supply, shipping, hydropower production, fishing, tourism, as a recipient for industries and wastewater plants, etc. The flood risks are connected to landslide and industrial risks. One interest at stake is the drinking water supply for 800,000 persons in the Gothenburg region. According to climate scenarios, flood risks will increase in the 21st century due to increased precipitation. Recent studies in the region were used to identify relevant interests and values connected to Lake Vänern. The study reveals differing interests in relation to water level regimes. From a flood protection perspective (risks around the lake and downstream to Gothenburg) a low and stable water level is beneficial. For shipping and hydropower, a stable medium-high water level is wanted, whereas from an ecosystem and landscape development perspective larger water level amplitudes are optimal. One out of a few reasons for this is the need to prevent a massive increase in vegetation in coastal areas. There are good reasons to have a broad decision-support, representing different values and interests, when the permanent water regulation scheme will be decided. This study also addresses the potential to reconcile the concept of flood risk management with that of a sustainable development.

Keywords: values, ecosystem, integration, sustainable development

Introduction

Floods pose a threat to many areas in the world and in some regions, such as Northern Europe, the problems are expected to worsen in the future (IPCC, 2012). The risk concept is often used in flood prevention efforts. A common definition of a risk is that it is a function of the probability and

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consequence of future events, but a risk can also be expressed as a function of hazards and vulnerabilities (ISDR, 2009). A risk can be perceived and managed in different ways and the concept of flood risk management has evolved in the last 10 years (Schanze et al., 2006). Earlier strategies for taking care of floods have been more reactive, e.g. concepts of flood fighting or flood resistance, or static, e.g. flood protection. When the risk concept was introduced, it came with an acceptance that certain objects or values can never be completely protected. Another feature of modern flood risk management is the integration of ecological, economic and social aspects in risk prevention and mitigation. The objects or values that should be protected can be of ecological, economic, or social kind. These values can be damaged directly by hazards but also by unwanted consequences of measures taken to reduce flood risks. For example, if something economically valuable is protected by some measure, it might lead to larger social or economic vulnerability (Birkmann et al., 2006). A risk management process consists typically of four steps: (1) risk inventory, (2) risk analysis, (3) risk evaluation and (4) risk-reducing measures (Figure 1). There is a feedback loop from the measures to the risk situation, where measures normally reduce the risk, but can also cause new types of risks (normally related to increased vulnerabilities).

The multitude of vulnerabilities that can be identified in nature and society can be expressed in different ways. In the European Floods Directive (Directive 2007/60/EC; EU, 2007), the categories of vulnerabilities are *"human health and life, the environment, cultural heritage, economic activity and infrastructure."* These vulnerabilities can also be expressed as values to be protected. The interests of certain actors are related to these different values. The Floods Directive is also said to be implemented in coordination with the Water Framework Directive, which aims for good ecological and chemical status of all waters in Europe (Evers and Nyberg, 2013).

One type of risk-reducing measure is directed at water flow regimes in rivers and lakes. If peak-flows can be reduced, a substantial part of the flood risk is reduced. Water regulation, normally managed through systems of reservoirs, is a way to alter the natural flow regime. There are examples of reservoirs where the main purpose is to reduce flood hazards, but in a Northern-European perspective, reservoirs are normally established for hydropower purposes. Most reservoirs have a smoothing effect on hydrographs in most flow situations, which give lower flood risks. There can, however, be unanticipated events in connection with very high flows when reservoirs no longer have a damping effect.

Lake Vänern is the largest reservoir in Sweden, and also the largest lake in the European Union. The lake experienced the largest flood in modern time from autumn 2000 until spring 2001. After several rainy autumn months, the peak level occurred on 11 January, ca. 1.3 m above the long-term average. Due to the slow dynamics of the lake, the unusually high water levels lasted until the following summer. The consequences of this flood event have been described by Blumenthal (2010). She found that most of the cities around the lake had to establish temporary barriers and pumping capacities to mitigate damages. Despite those efforts damages were caused on sewage treatment plants, sewage and stormwater grids, roads, harbours, recreational and tourist sites. Sectors such as fishery and agriculture also suffered damages and disturbances. The direct costs for this event were estimated at more than 140 million SEK (ca. 16 million euro). The costs were reduced substantially as a consequence of the temporary protection measures that were taken. The indirect costs of this event, including business interruption

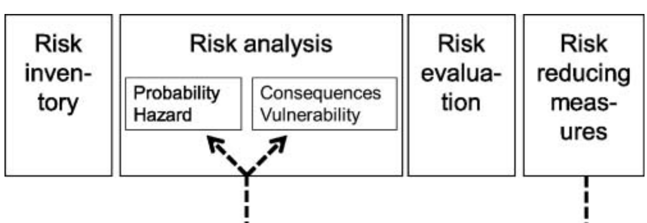

Figure 1. The risk management process, including a feedback loop from measures to hazards and vulnerabilities.

because of disturbed transportation or energy systems, for example, have not been estimated.

A 200-year-long time series of water level data for Lake Vänern shows that amplitudes have decreased gradually for the last 75 years (online data available at www.smhi.se). This decrease of water level amplitudes is not a result of a clear regulation policy (Bergström and Eklund, 2013) but is a gradual adaptation of the regulation to the needs of certain sectors, such as shipping and agriculture (SOU, 2006). Since 2008, the mean water level has been lowered by 15 cm, as a risk-reducing measure. The lower and more stable water level (lower amplitudes) has positive implications for the flood risk situation, but has most likely negative effects on the ecosystem status and landscape development, as well as on the social use of the lake (Koffman et al., 2013).

The flood in Lake Vänern was one of the triggers for the comprehensive governmental Commission on Climate and Vulnerability during 2005–2007 (SOU, 2006, 2007). The commission presented climate change scenarios for Sweden and the possible consequences of human health, biodiversity and society. Because of increased amounts of precipitation, scenarios for Lake Vänern show increased flood risks. The flood problems in the great lakes in Sweden, including Lake Vänern, were investigated in a special report and the potential flood damages were assessed. The commission also investigated possible risk-reducing measures, e.g. increasing lake discharge either by stabilizing the river valley downstream or establishing a 30-km long outlet canal or tunnel directly to the west coast. Andersson et al. (2013) have later calculated the potential direct costs of a 100-year flood event to be 100–360 million SEK (ca. 12–40 million Euros). The direct costs of a low-probability flood event (return period of more than 10,000 years) were calculated to be 10 billion SEK (ca. 1.2 billion Euros). The indirect costs of these water levels have not been estimated but qualitative assessments point at very large and partly unforeseeable consequences.

One of the measures proposed by the governmental commission was to lower the lake water level to gain more storage capacity during wet periods (rain and/or snowmelt). In 2008 an agreement was made between the hydropower company Vattenfall and the County Administrative Board of Västra Götaland, which resulted in a lowered water level by 15 cm from autumn 2008 and onwards, during a 5-year test period. This agreement has been prolonged to 2014. The measure resulted in an improved risk situation, but has been criticized for several reasons. One reason is the increased vegetation growth along shores and in the archipelago (Finsberg and Paltto, 2010), which can be related to lower and more stable water levels, including the lack of mechanical cleaning forces from an ice-cover during high-water-level situations. There are also other factors likely to contribute to an increased vegetation growth, e.g. reduced grazing along shores and a general eutrophication due to the historical and present nitrogen deposition.

Another negative consequence of the lowered water level is the potential disturbance of recreational activities, if water levels become too low. A low-level situation that occurred during spring and early summer 2009 caused complaints from boat and property owners, tourist entrepreneurs and fishermen (Persson, 2010).

At the end of the five-year test period the two county administrative boards surrounding Lake Vänern (Västra Götaland in the south and Värmland in the north) initiated two investigations of the consequences of the lowered water level. A hydrological investigation (Bergström and Eklund, 2013) showed that the new regulation regime had resulted in lower water levels, which was in accordance with the agreement from 2008. There was also a tendency of lower water level amplitudes.

The second investigation was about the consequences of the lowered water level for ecosystems, landscape and outdoor recreation in connection to the lower water level (Koffman et al., 2013). They point out that the test period of 5 years was too short to see any significant changes, but conclude that the lower and more stable water level will most likely contribute to a continued vegetation expansion. It could also threaten fish reproduction in shallow bays, and the abundance of certain bird species in the archipelago. Outdoor recreation is affected in many ways by the lower water level and increased vegetation along lake shores. Koffman et al. (2013) proposed changes in the water regulation regime, aiming for a more natural seasonal variation in water level.

A situation like that of Lake Vänern can also be found for Lake Ontario and the St Lawrence River. Even though Lake Ontario is more than 3 times the size of Lake Vänern and the St Lawrence River discharges (from all of the Great Lakes) about 13 times more water than the Göta älv River, the conditions for the water level regulation, the flood risks around the lake, and further problems in the outlet river are similar to that of Lake Vänern. Loucks (2006) has described the efforts around Lake Ontario on the part of the International Joint Commission to reconcile all interests and stakeholders. A special work group with representatives of different parties in Canada and the US has addressed the water regulation issues in a collaborative planning process for the purpose of finding an agreement on water regulation between a wide range of interests.

The objective of this article has been to identify and analyze different ecological, economic or social values and the various interests that are connected with the water regulation and flood risk management measures in Lake Vänern. The analysis has resulted in a synthesis of different interests and ideas, which can be used as a basis for more integrated and sustainable decision-making.

Methods

This study is based on an analysis of documentation from previous floods in Lake Vänern (Blumenthal et al., 2010; Andersson et al., 2013), investigations of water regulation and flood risk management practice (Bergström and Eklund, 2013; SOU, 2006) and reports on the consequences of the changed regulation of the lake (e.g. the review of several studies on biodiversity, landscape development and outdoor recreation by Koffman et al., 2013). A wide range of values and interests has been identified, often as statements from different societal sectors on preferred water regulation. The different interests have been categorised based on preferred regulation regime and their different perspectives have been put in a framework of sustainable development, based on three overlapping sustainability dimensions: economy, ecology and social values.

Site description

Lake Vänern with an area of 5,650 km^2 is the largest lake in Sweden and in the European Union (SOU, 2006) (Figure 2). The Göta älv River is ca. 93 km long and flows from the lake outlet at Vargön (near Vänersborg) to the North Sea at Gothenburg. The total catchment area of 50,100 km^2 is dominated by forest landscape but contains also significant mountain and agricultural areas. About 15% of the catchment is located in Norway. The altitude of the catchment varies from 1,700 m a.s.l. in the Norwegian mountains down to sea level in Gothenburg. Lake Vänern and the Göta älv River are used for hydropower production, shipping, tourism, recreation, fishing, drinking water supply, and as recipients of waste water from municipalities and industries, etc.

The mean discharge to the sea is 565 m^{3}s^{-1} (Bergström and Eklund, 2013). Because of the water regulation (which considers landslide risks downstream), the maximum discharge from the lake is set to 1030 m^{3}s^{-1}. Before the lake was regulated in 1937, the highest observed discharge was ca. 840 m^{3}s^{-1}. There is a 200-year-long data record of water levels for the lake, of which the data of 160 years are shown in Figure 3. The water level amplitude was ca. 2.5 m for the unregulated period, but the regulation has caused a more stable level, especially from the 1980s and onwards (Figure 3). There are restrictions on the minimum and maximum levels of the water level regulation. The allowed regulation amplitude varies between 1.3 m and 1.7 m for different periods of the year, but in practice the amplitude has been typically around 0.6–0.7 m for the latest 10 years.

The risk system in this study is complex. The geography of hazards, vulnerabilities and potential mitigating measures is related to the lake and its drainage basin, but also to the downstream area. Flood risks in the lake and in Gothenburg are connected to landslide risks in the river valley. There are also heavy industrial activities, e.g. paper pulp, metal and chemical industries around the lake and in the river valley that will be affected by flood and landslide events. The drinking water supply for the greater Gothenburg region is part of the risk system. There is an upstream/downstream risk distribution between flood risks around the lake and a downstream system of landslide risks, industrial risks and water quality risks in the river and in Gothenburg, where most of the economic and social values are located. The landslide risks along the river valley are closely related to wet periods and erosion due to high discharge from the lake. Therefore a maximum discharge is decided, which, however, increases the flood risks in the lake.

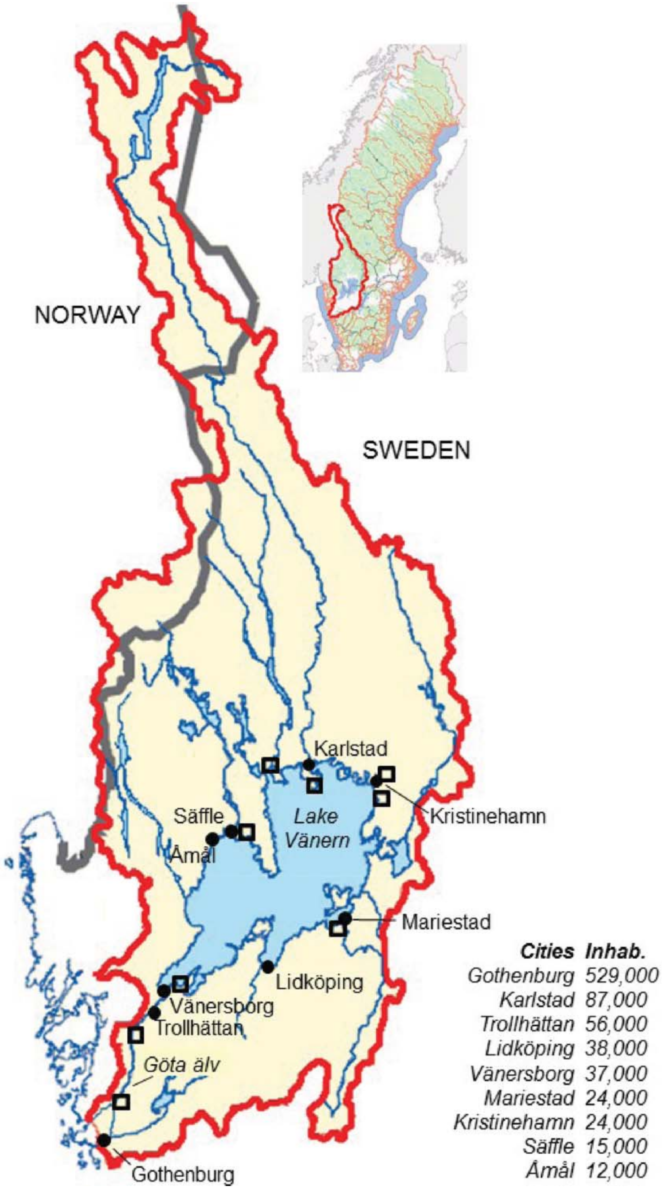

Figure 2. Catchment area for Lake Vänern and the Göta älv River. The locations of larger industries are marked with a square.

Results

Different values related to Lake Vänern are affected in different ways by floods, and also by the measure taken in 2008 to lower the average water level. One can find values that are positively or negatively affected by floods, and also by the lowered water level. In general it can be stated that nature and the landscape values benefit most from floods and least from the lowered water level. Economic values and potential fatalities are affected most negatively by floods and benefit most by the lowered flood risk. Apart from a pure risk-reduction perspective, where a low water level is beneficial, most societal activities benefit most with a stable medium-high water level. Problems are caused by both too high and too low water tables.

Several values and services are listed in Table 1 together with descriptions of the consequences of

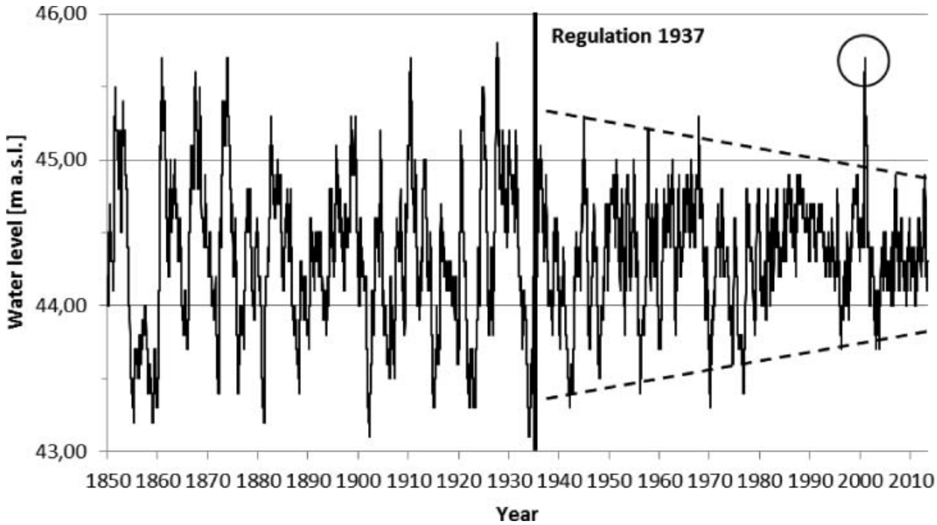

Figure 3. Water level [m a.s.l.] in Lake Vänern between 1850 and 2013. The start of the regulation is marked with a vertical line and the peak level of the flood in 2000–2001 is marked with a circle. Data from the Swedish Meteorological and Hydrological Institute.

floods, and of the lowered water level, which has been a fact in Lake Vänern since 2008. Relevant interests and values connected to Lake Vänern, reported in investigations of climate adaptation, flood events, effects of water regulation, etc., have been included in the table. The categorisation of interests into economic, ecological and social dimensions has been made by the authors, based on the major characteristics of the respective interests. There are some interests that could be said to belong to more than one dimension.

Three major positions can be identified regarding the preferences of water levels and amplitudes:

Interest	*Preferences*
Flood protection	→ Low water level and small amplitudes
Hydropower, shipping	→ Medium water level and small amplitudes
Nature and landscape conservation	→ Larger amplitudes and seasonal variation

Interests such as outdoor recreation and tourism are dependent on both an open landscape, promoted by higher amplitudes, and stable water levels when activities take place. Too high water levels could also damage small-scale infrastructure, such as harbours for leisure boats, camping sites and walking paths (Persson, 2010).

There were no signs of sharp conflicts found among the different interests around Lake Vänern, but there were statements that support a broader decision-support, including more interests and values into the decision on water regulation (Koffman, 2013). It is clear, for example, that representatives of nature conservation recommend a water regulation that, to a larger extent, mimics a natural regime. At the same time, there is no stated support for actions that could cause water-levels that endanger societal values (Persson, 2010).

Flood protection is an older approach for managing floods. Today the dominant approach is flood risk management, where other interests such as nature protection, land use, etc. should be acknowledged and integrated in the management practice (EU, 2007).

Discussion

The values presented in Table 1 show that there is a broad range of opposing interests connected to the water level regime in Lake Vänern. The lowered water level, which was implemented in autumn 2008, has resulted in an improved risk situation and indirectly given benefits to all those interests that would be harmed by a future flood. This also includes the areas downstream of Lake Vänern.

Table 1. Consequences of floods and of the risk-reducing measure to lower the water level in Lake Vänern, specified for different values and interests. The information is collected from investigations of Lake Vänern (Andersson et al., 2013; Blumenthal et al., 2010; Finsberg and Paltto, 2010; Koffman et al., 2013; Persson, 2010; SOU, 2006).

Values and interests	Flood consequences	Consequences of lowered water level
Ecology and landscape values		
Archipelago landscape: Lake Vänern has a 2000 km long shoreline and 22,000 islands.	Damage could occur to agricultural and forest land due to long periods of flooding but floods keep the landscape open.	Increased vegetation growth along shores due to dryer conditions and less mechanical disturbance by ice-covers.
Unique habitats and species: Land-locked salmon and trout, bird habitats, etc.	Floods are a natural and important component of the ecosystem and landscape.	Ecosystem effects have only been investigated for a few years. Potential consequences for shallow bays and fish spawning areas.
Recipient: Several larger industries use lake water for the industrial processes, and industries and municipalities use the lake as recipient of (purified) waste and sewage water.	Floods could cause release of untreated sewage water and industrial wastewater. Normally the dilution is large during floods.	Lower probability of release of untreated sewage water or industrial wastewater.
Social values		
Life quality: Water adds to life quality in 13 municipalities around the lake.	Flood risks or events cause anxiety or fatalities among citizens.	Lower probability of fatalities and different types of damages to households, etc.
Recreational use: Fishing, boat life, swimming, summer-houses.	Disturbance of recreational activities in the lake area.	Potential negative effects during dry periods.
Drinking water: Ca. 800,000 people around Lake Vänern and in the Gothenburg area use the lake water.	Raw water used for drinking water supply may have lower quality.	Lower probability of negative consequences. Situations with low water levels could cause problems concerning raw water quality.
Economic values		
Hydropower: The largest reservoir in Sweden (a volume of 9 km^3 is regulated).	Increased probability of dam-breaks. Hydropower companies are often blamed for floods.	More controlled discharge situations. Small loss of head.
Fishery: A fleet of professional fishing boats operate in the lake.	Harbours and other facilities may be damaged.	Lower probability of disturbance. May have problems during dry periods. Uncertainties around fish stocks.

(*Continued on next page*)

Table 1. Consequences of floods and of the risk-reducing measure to lower the water level in Lake Vänern, specified for different values and interests. The information is collected from investigations of Lake Vänern (Andersson et al., 2013; Blumenthal et al., 2010; Finsberg and Paltto, 2010; Koffman et al., 2013; Persson, 2010; SOU, 2006). *(Continued)*

Values and interests	Flood consequences	Consequences of lowered water level
Agriculture: Substantial parts of the riparian areas are productive farmland.	High water levels and long duration of floods cause damage to crops, soils, and drainage and dyke systems.	Lower probability of damage to crops, soils, and drainage and dyke systems.
Shipping: Several harbours in the lake and trades via Gothenburg.	Harbour activities may be disturbed. More problems with operations in the outlet river (Göta älv) during high flows.	Lower probability of disturbance in harbours. May have problems during dry periods because of too shallow depth.
Tourism: Increasing tourism based on water-related attractions and activities.	Damages to camping sites, leisure boat harbours, etc. Pollution and debris may affect beaches.	Negative impact if archipelagos and shorelines are more vegetated. Lower probability of disturbance from high water levels. May have problems during dry periods.
Critical infrastructure: Systems for transportation, energy supply, etc. is situated near the lake.	Roads and railroads, energy and sewage systems, etc. are affected during flood events.	Lower probability of disturbance.
Industry: Paper pulp, metal and chemical industries are situated around the lake and in the river valley.	Potential business interruption. Potential leaching of toxic substances.	Lower probability of business interruption and leaching of toxic substances.

During the 5-year test period of a lowered water table there has been a debate, mainly from nature and landscape protection interests, that the lower and more stable water level contributes to an increased vegetation growth along coastal and island shores. The rapid vegetation growth that has been observed started well before 2008, but the lower water table has been regarded as a step in the wrong direction. Larger amplitudes and high water levels during cold winters could be a factor that would keep some of the vegetation growth away.

This study can serve as a basis for framing a cross-sectoral and participatory consultation and decision process regarding relevant actors, stakeholders, institutions etc. Very different values have to be considered before the authorities decide further on the regulation regime. Potentially lost lives, for example, have to be considered in the same decision as a large change of the landscape around one of the large lakes in Europe.

The initiative by the regional authorities after the 5-year test period to investigate the consequences of ecosystems, landscape development and outdoor recreation indicates an interest in widening the decision-support before a permanent decision is made. This does not mean, however, that a simple solution exists to the regulation regime. Loucks (2006) described an interesting case regarding the water regulation of Lake Ontario and St Lawrence River on the border between Canada and the US. He proposed a method based on a multi-objective, multi-stakeholder approach to planning. The ambition was to *"include both beneficial and damaging impacts from or to navigation, hydropower, recreation, shore erosion, floods, environmental (water quality management) measures, and ecological habitats."* He concluded that the aim of the proposed approach was not to find an optimal water management policy, but to contribute to a necessary discussion among politicians in the search for an optimal policy.

Methods like multi-criteria analysis can be used, where different values are included and given different weights (Meyer et al., 2009). A participatory process with stakeholders and the public could identify priorities and potential thresholds, and a monitoring system with specific sustainability indicators could be established for the future development in the Lake Vänern region.

The risk management model in Figure 1 should not only recognize the feedback loop back to the risk situation (hazards and vulnerabilities), but also include expected or unexpected consequences that are not directly part of the risk system. Modern flood risk management models should include a broad spectrum of aspects, to integrate all sustainability dimensions in the risk analysis and in the decisions of risk-reducing measures. A decision process regarding risk-reducing measures should include analyses of economic, social and ecological consequences of the decision. One could argue that water-regulation decisions should be put in a frame of sustainable development. One opportunity to do so within the EU member states is when the flood risk management plans, according to the Floods Directive, are to be implemented in 2015. The directive requires a consideration of "*...costs and benefits, flood extent and flood conveyance routes and areas which have the potential to retain flood water, such as natural floodplains, the environmental objectives of Article 4 of Directive 2000/60/EC* (The Water Framework Directive)*, soil and water management, spatial planning, land use, nature conservation...*" (FD 2007, Art. 7). Evers and Nyberg (2013) discussed the possibilities and restrictions of combining different EU directives in line with an integrated management of river basins and demonstrated how helpful it would be to identify synergies and conflicts when different strategies and related measures are assessed and decided, such as the water regulation of Lake Vänern.

Conclusions

This study has revealed differing stakeholder interests in relation to the water level regime in a large European lake. The preferences regarding water level and amplitude vary among interests such as risk-reduction, landscape and ecosystem protection, shipping, and municipality development. There are good reasons to have a broad decision-support, representing different values and interests, when water regulation schemes for large flood-prone lakes are decided. The study elucidates the potential to reconcile the concept of flood risk management with that of sustainable development.

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