Practical measures for improving the ecological state of lake Marken using in depth system knowledge

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Abstract

For Lake Marken in the Netherlands, high suspended sediment concentrations result in reduced ecological values and prevent goals and standards from being met (Water Framework Directive, Natura 2000). A practical measure to improve the ecology that is currently studied is the construction of sheltered areas in the North West part of Lake Marken. For implementation of this measure, a strategy is being followed that combines in depth system knowledge with stakeholder aspects. In the present paper we will show which knowledge of the underlying physical and ecological processes was needed and how it was applied in the strategy. We used a coupled silt model for Lake Marken to study effects of the structures on hydrodynamics, waves, and sediment. Results of the silt model simulations were interpreted with in depth ecological expert knowledge to assess the ecological impact of the structures. Effects of the considered sheltered areas on transparency and wave- and siltdynamics are limited compared to the scale of the lake. However, these changes give local opportunities for ecology. Its effectiveness may be enhanced by local un-deepening.

Key words

shallow lake, Water Framework Directive, suspended sediment, ecology, stakeholders

Introduction

Lake Marken is a large shallow lake in The Netherlands. For this lake, high suspended sediment concentrations result in reduced ecological values and prevent goals and standards from being met (Water Framework Directive, Natura 2000). Mainly due to wind driven waves (fine) sediment particles on the bed are resuspended and transported by hydrodynamic flow. High concentrations of suspended sediment particles generally result in low transparency values. Because the lake is largely artificial and shallows and transition zones are underrepresented, this aspect dominates the ecology of the lake and diversity is low. Local improvement of and more

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variation in transparency may help to provide opportunities for a more diverse and productive ecosystem. For this, a practical measure to improve the ecology that is currently studied is the construction of sheltered areas in the North West part of Lake Marken. For the study of the required size, shape, and location of the structures in depth knowledge was needed. In the present paper we will show how this knowledge of the underlying physical (via a coupled silt model for Lake Marken) and ecological processes (by expert judgement) was used.

Study area

Lake Marken is a shallow lake in The Netherlands. It has an average depth of 3.6 meter and a surface of 680 square kilometer. The lake used to be the southwestern part of a brackish inland sea that was closed by a dike in 1932 and turned fresh soon after. As this part was sheltered from the current between the main inlet, the River IJssel, to the Wadden Sea, fine sediments were deposited here. Lake Marken in its current shape originated from the construction of more dikes, separating it from the southeastern part (which was reclaimed) and from Lake IJssel in the north (1975). Aim of this process was to improve flood protection and reclamation of land (see left image in Figure 1). As a result of the location of the dikes, the sediment of Lake Marken is now predominantly clay and loam, while in Lake Ijssel sandy sediments dominate.

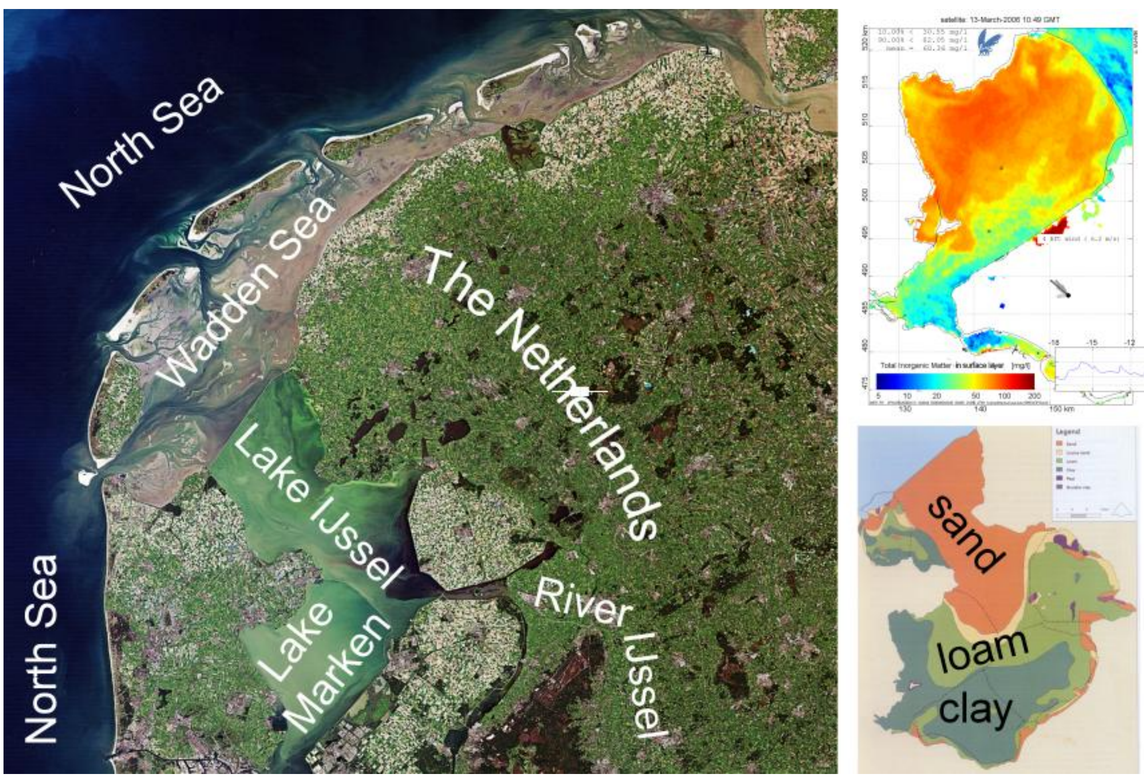

Figure 1. Geographical location of Lake Marken and surrounding area (left, photo: ESA), processed satellite image of total inorganic matter [mg/l] near water surface of Lake Marken at 10h49 GMT March 13th 2006 (right top, Eleveld [2012]), and composition of the bed for Lake IJssel and Lake Marken (right bottom, Winkels [1997]).

The composition of the bed for Lake IJssel and Lake Marken is shown in the right bottom image of Figure 1 (Winkels [1997]). The clay and loam sediments of Lake Marken were eroded by burrowing benthic invertebrates, resulting in a top layer of soft, fluffy material, which is easily disturbed by wind and wave action and the central part is generally turbid as a result of high concentrations of suspended silt (De Lucas Pardo [2014]). See for instance the processed satellite image of total inorganic matter [mg/l] near the water surface of Lake Marken at 10h49 GMT on March 13th 2006 in the right top image of Figure 1 (Eleveld [2012]). In Lake Marken flow of water and waves are mainly wind driven. The resulting sediment dynamics have a three dimensional character (Vijverberg et al. [2011]).

Context

Last 25 years the ecological state of Lake Marken decreased so much that goals and standards are not met (Water Framework Directive, Natura 2000). Typical mussel, fish, and waterbird species showed a decrease in densities between 1981 and 2000. This seems to be related to a combination of a decrease in nutrients, climatic conditions and increased predation pressure (fishery), reinforced by resulting changes in phytoplankton species composition and changes in the nature of interaction between algae and suspended silt particles. The latter rendering part of phytoplankton inaccessible as food to the foodweb (Noordhuis et al. [2009], De Lucas Pardo [2014]).

One of the contributing water quality parameters is transparency. High suspended sediment concentrations result in reduced transparency values. Mainly due to wind driven waves (fine) sediment particles on the bed are resuspended and transported by hydrodynamic flow. High concentrations of suspended sediment particles generally result in low transparency values. Because the lake is largely artificial and shallows and transition zones are underrepresented, this aspect dominates the ecology of the lake and diversity is low. Light on the bottom is important for waterplants to grow, gradients between clear and turbid water are important for fish-eating waterbirds to get food. Waterplants reduce resuspension and provide habitat for young fish and many species of invertebrates, which in turn can feed birds. Local improvement of and more variation in transparency may help to establish a more stable state for the decreasing species. In addition, reduced resuspension of silt particles may prevent the enclosure of algae in mixed flocs, leaving more of the algae available to filterfeeders like Zebra Mussels and Daphnia, enriching the foodweb of the system.

These are the main underlying physical and ecological processes and interconnections. With this knowledge, a practical measure that was studied is the construction of sheltered areas in the North West part of Lake Marken. Construction of dams, islands, and shallow areas will influence the physical processes to improve water quality and ecological state. The study of the required size, shape, and location of the structures was carried out in a broader context. Besides the in depth knowledge related to ecological impact this also included other aspects like implementation costs, engineering, recreation, and safety. For this, an approach was followed in which, for different stakeholders, four working sessions were hold during the study (Maronier et al. [2014]).

The study had to follow formal rules for design and realization of infrastructural projects by the Dutch public works about the objectives and how these objectives were quantified. Therefore, at the start of the study, some effort was needed to specify the outcome of the study, how this was going to be measured, and how these results were going to be translated and evaluated such that policy makers can use them.

Methods

The following methods were used:

- a coupled silt model for Lake Marken to study effects of the structures on hydrodynamics, waves, and sediment,
- ecological expert judgements by interpreting results of silt model simulations with in depth ecological expert knowledge to assess the ecological impact of the structures.

The coupled silt model for Lake Marken to study hydrodynamics, waves, and sediment in Lake Marken has been under development by Deltares since 2007 (Kessel et al. [2009]). It takes into account wind-driven currents and waves to compute the amount of resuspension and sedimentation for a typical year - see also Figure 2 for a schematic representation of the processes modelled. In the model that we used for the present study a fetch length approach was used for wave effects (Genseberger et al. [2011]); the same approach is used in studies for other shallow lakes in the Netherlands (Penning et al. [2012]). For computing currents the silt model uses the shallow water solver Delft3D-FLOW (Delft3D [2015]). After this, resuspension, transport of sediment by currents, sedimentation, and light penetration are computed with the advection diffusion reaction solver Delft3D-WAQ (Delft3D [2015]). For resuspension, bed shear stress due to waves and currents are combined in Delft3D-WAQ.

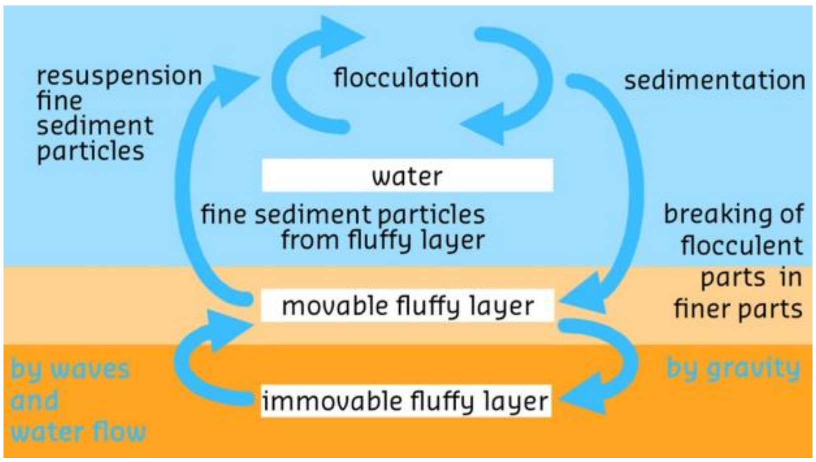

Figure 2. Schematic representation of processes that are taken into account in the silt model for Lake Marken.

The silt model only covers part of the ecosystem that we need to address in the study. Figure 3 shows a schematic representation of the system with underlying physical, chemical, and biological processes and their interconnections. For the ecological expert judgement we interpreted results of the silt model and used in depth ecological expert knowledge of vegetation, fish, benthos, and birds from the recent so-called ANT study. In this ANT study long term trends and intercorrelations were analyzed for different species and their foodweb in the Lakes IJssel and Marken.

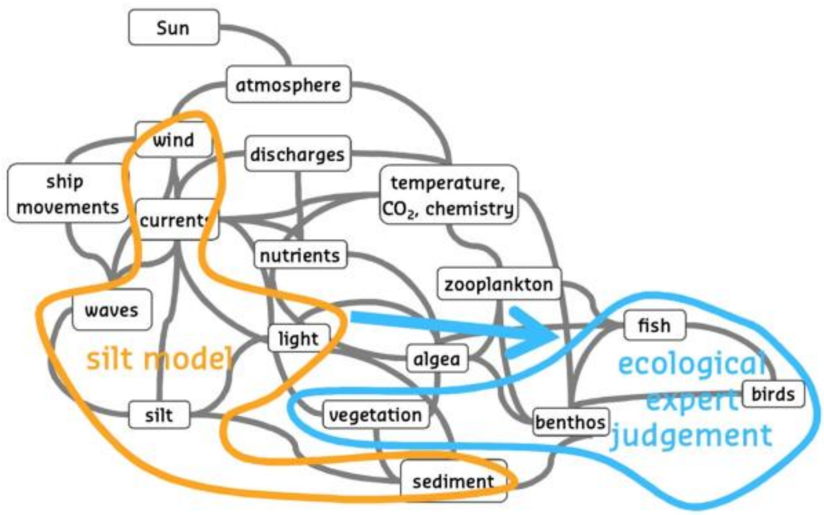

Figure 3. Schematic representation of the system with underlying physical, chemical, and biological processes and their interconnections. The orange enclosure highlights the part that is modeled with the silt model of Lake Marken. The blue enclosure is the part that is assessed by ecological expert judgement (based on results of the silt model and in depth knowledge of relevant processes and their interconnections).

Results

The working sessions with stakeholders resulted in three possible scenarios visualized by landscape architects (Maronier et al. [2014]): “westcoasts dams”, “central island”, and “eastern archipel” (see Figure 4). These scenarios were evaluated with the silt model and by ecological expert judgement.

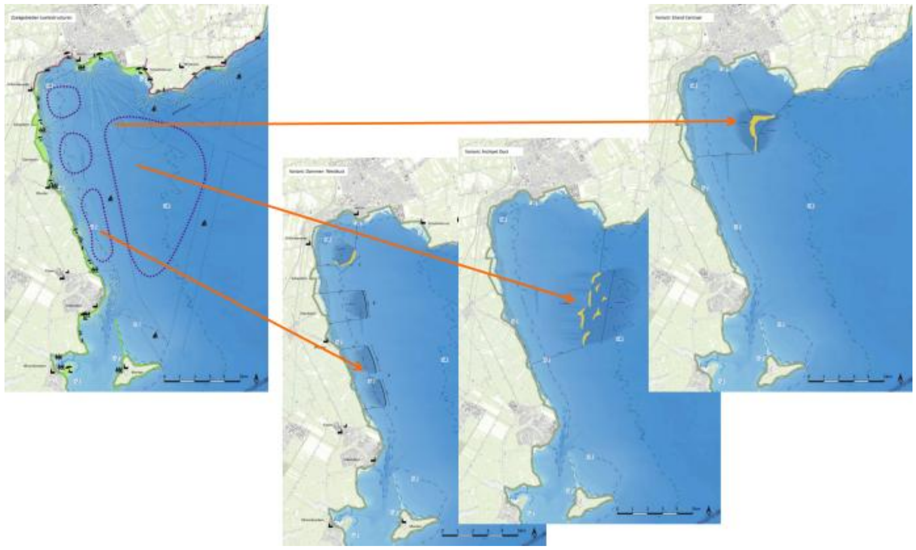

Figure 4. Possible locations for measures (dotted lines in left image), and three scenarios with measures: "westcoasts dams" (second image from the left), "eastern archipel" (third image from the left), and "central island" (right image). Design by landscape architects from Bureau Stroming – http://www.stroming.nl/eng/index.asp (Maronier et al. [2014]).

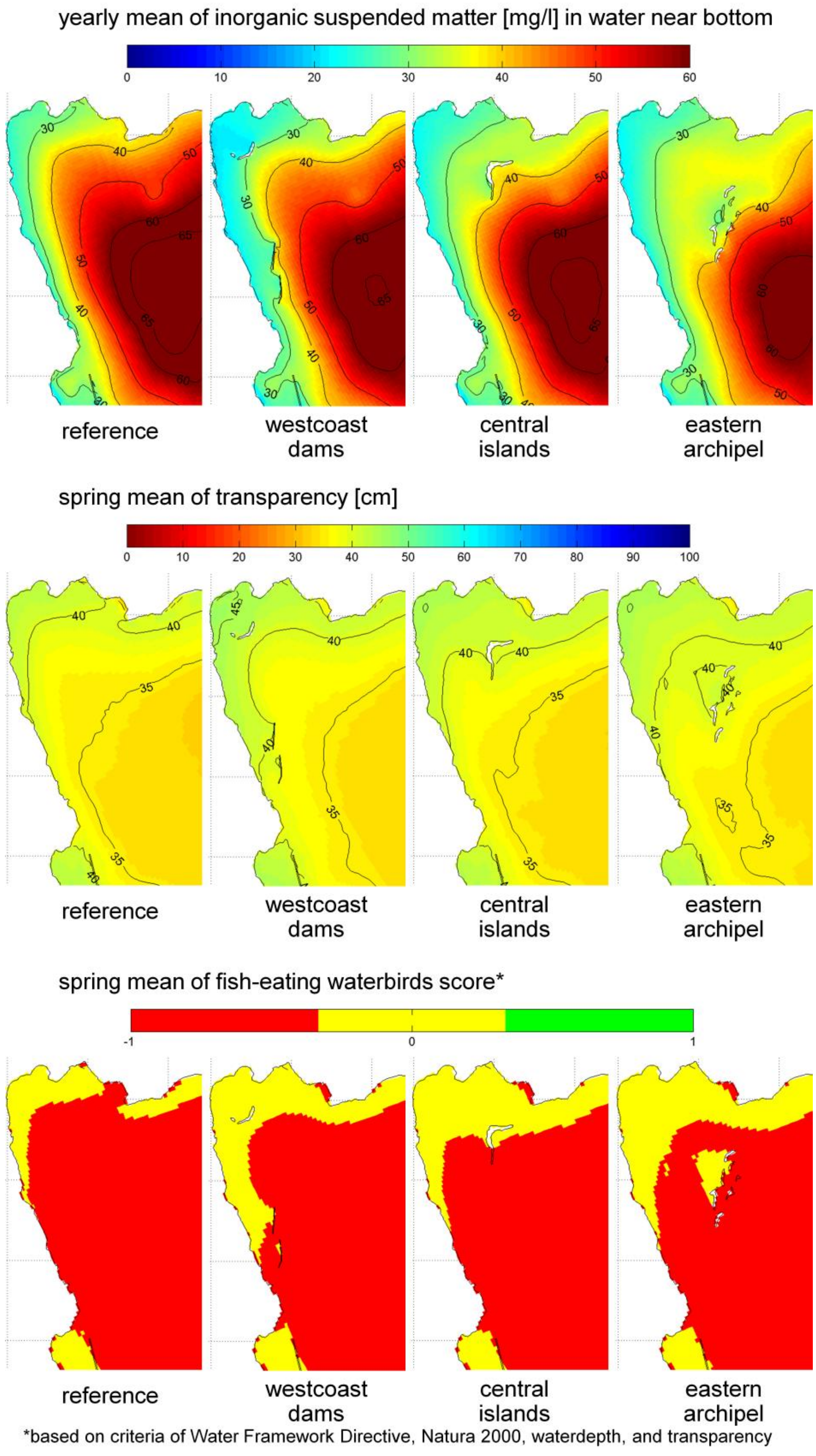

Figure 5. Spatial maps for reference and scenarios of: the yearly mean of inorganic suspended matter [mg/l] in the water near the bottom (top), the spring mean of transparency [cm] (middle), and the spring mean of a fish-eating waterbirds score (bottom).

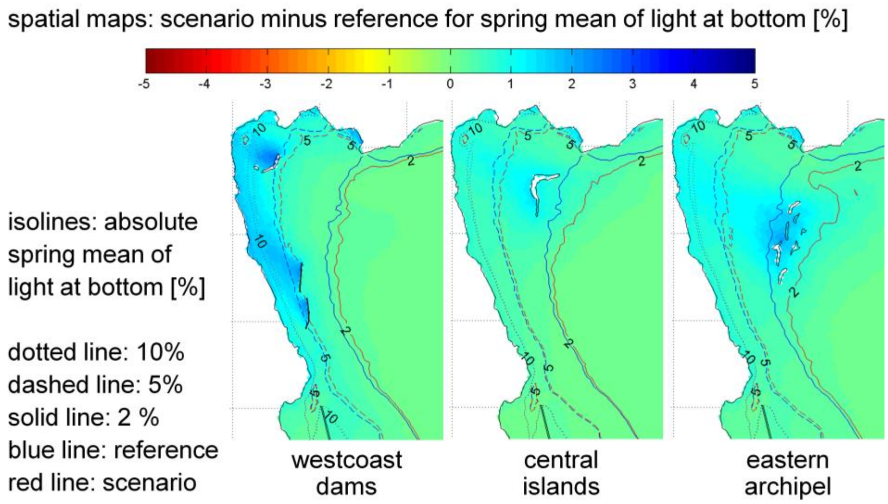

Figure 6. Spring mean of light at the bottom [%]: spatial maps and isolines.

With the silt model spatial maps were made for the scenarios and compared to the present/ reference situation. In Figure 5 we show

- the yearly mean of inorganic suspended matter [mg/l] in the water near the bottom,
- the spring mean of transparency [cm], and
- the spring mean of a fish-eating waterbirds score.

The score is based on criteria of the Water Framework Directive and Natura 2000. For this also waterdepth (birds dive into the water up to a maximum depth) and transparency (for locating fish the birds have to look into the water) are taken into account. Here the color green means good, yellow neutral, and red not good. In Figure 6 we show also the spring mean of light at the bottom. Here the spatial maps show the difference of each scenario with the reference. The isolines show how the thresholds (10% at dotted line, 5% at dashed line, and 2% at solid line) of each scenario (blue line) changed compared to the ones of the reference (red line).
From Figure 5 and Figure 6 quite direct relations between inorganic suspended matter, transparency, scores, and light can be observed.
To facilitate the ecological expert judgement, for the spatial maps we computed also the areas between the important thresholds. For instance Table 1 shows these areas [km^2] for the spring mean fish-eating waterbirds score and Table 2 for the spring mean of light at the bottom larger than the important thresholds. Note that these areas are computed for Lake Marken as a whole whereas the spatial maps in Figure 5 show only the area where the measures are planned.

score	reference	westcoasts dams	central Island	eastern archipel
-1 (red)	435.2	401.3	401.5	384.1
0 (yellow)	293.3	326.9	326.3	343.7
+1 (green)	3.0	3.0	3.0	3.0

Table 1. Areas [km^2] between the important thresholds for the spring mean fish-eating waterbirds score. Note that these areas are computed for Lake Marken as a whole.

light [%] at bottom larger than	reference	westcoasts dams	central Island	eastern archipel
0	731.5	731.2	730.9	730.8
2	350.3	362.2	365.2	384.2
5	175.9	185.9	184.4	187.1
10	92.4	98.6	96.9	97.8
15	58.1	60.1	59.6	60.2

Table 2. Cummulative area [km^2] per class for spring mean of light at the bottom. Note that these areas are computed for Lake Marken as a whole.

As mentioned before, at the start of the study, we defined the objectives of the study and the rules how to quantify the objectives. Effects on ecology were mainly estimated by modeling the changes in the amount of light on the bottom for each scenario (Figure 6 and Table 2 show this for spring). Important are the changes in the area where more than 2% and 10% of surface light reaches the bottom, representing potential habitat for low density vegetation and vegetation with sufficient density and structure to function as habitat for fish and invertebrates (compare for instance the blue with the red isolines for the thresholds in Figure 6). For a more diverse ecosystem, particularly a structured, multispecies and spatially diverse vegetation is useful. Data from local waterplant surveys was compared to model results on the amount of light on the bottom, connecting the 10% threshold to this type of vegetation.

Another aspect of improved ecological diversity was the protection or enlargement of areas of intermediate transparency for the benefit of fish-eating birds. This was studied by modeling the differences between scenario's in the size of areas with an average transparency of 40-70 cm in the relevant seasons for the bird species involved (with results in Figure 5 and Table 1 for spring). Effects of the considered sheltered areas on transparency and wave- and siltdynamics are limited compared to the scale of the lake. However, these changes give local opportunities for ecology. Its effectiveness may be enhanced by local un-deepening.

Based on this, we combined and translated the results of the scenario analysis with the silt model and the ecological expert judgement into an evaluation that is usable for policy makers.

As an example we show one of the tables that summarize this evaluation. Here Table 3 shows the summary of the ecological effects of the three scenarios.

aspect	criterium	westcoast dams	central island	eastern archipel
waterplants and fish population	expected development in sheltered areas	+	0/+	+
protected areas	goals to maintain under Natura 2000	+	0/+	++
	effects on Ecological Main Structure	+	0	0
protected species	protected species	+	0/+	++

Table 3. Summary evaluation ecological effects of measures.

Discussion

Here we show how in depth knowledge physical and ecological processes was used in a study for practical measures in the North West part of Lake Marken. This underlying knowledge was an essential ingredient as the construction of dams, islands, and/or shallow areas will influence the physical processes to improve water quality and ecological state. We used a coupled 3 dimensional silt model to simulate effects of the structures on hydrodynamics, waves, and sediment. Results of these simulations were presented in spatial maps for the ecological expert judgement. They were interpreted with very recent in depth ecological knowledge to assess the ecological impact of the structures. Results and interpretations were translated into an evaluation that is usable for policy makers.
For lakes and reservoirs this type of multidisciplinary and practical study has not been done before on this large scale in the Netherlands. Therefore we think it is a significant case study and is of interest for managing other lakes and reservoirs in other parts of the world as well.

The study of the required size, shape, and location of the structures was carried out in a broader context. Besides the in depth knowledge related to ecological impact this also included other aspects like implementation costs, engineering, recreation, and safety.
Parallel to the assessment of the ecological impact with silt model and in depth knowledge, an approach was followed in which for different stakeholders four working sessions were hold during the study (Maronier et al. [2014]). In the next step, for the first implementation phase, a light version of eastern archipel will be considered to have a balance between implementation costs and ecological impact.

We think the use of in depth system knowledge and the involvement of stakeholders can be combined in an interactive and iterative way. This may lead to a faster process and more optimal solutions. Therefore, for the near future we are working on the further integration of simulation models for the ecological impact assessment of measures in interactive design sessions with a.o. ecologists, landscape architects, stakeholders, and policy makers (Donners et al. [2014a], Donners et al. [2014b]).

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