Science of the Total Environment 540 (2016) 79–89

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Participatory operations model for cost-efficient monitoring and modeling of river basins — A systematic approach

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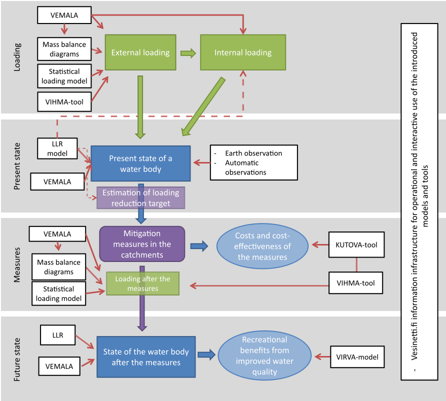
HIGHLIGHTS

- Ecological and economic efficiency of river basin management measures need to be evaluated
- Operational model need to be more effectively automated and integrated
- The web-based map services are useful for the participatory management
- Consultancy services for end users ought to be tailored and provided.
- More emphasis should be placed on the estimation of the economic benefits

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 20 March 2015
Received in revised form 25 June 2015
Accepted 25 June 2015
Available online 14 July 2015

Keywords:
Water Framework Directive
WFD
Operation model
Web-based map service
River basin management
Integrated model
Ecological status
Economic impacts
Costs and benefits

ABSTRACT

The worldwide economic downturn and the climate change in the beginning of 21st century have stressed the need for cost efficient and systematic operations model for the monitoring and management of surface waters. However, these processes are still all too fragmented and incapable to respond these challenges. For example in Finland, the estimation of the costs and benefits of planned management measures is insufficient. On this account, we present a new operations model to streamline these processes and to ensure the lucid decision making and the coherent implementation which facilitate the participation of public and all the involved stakeholders. The model was demonstrated in the real world management of a lake. The benefits, pitfalls and development needs were identified. After the demonstration, the operations model was put into operation and has been actively used in several other management projects throughout Finland.

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http://dx.doi.org/10.1016/j.scitotenv.2015.06.105

1. Introduction

Despite increasing efforts to reduce nutrient loads from river basins, eutrophication problems and algal blooms have continued. The economic downturn and climate change have exacerbated the problem and increased the need for a cost efficient operations model for the monitoring and modeling of surface water bodies (Hering et al., 2010). Apart from modeling and monitoring with enough frequency and spatial coverage (e.g. Carvalho et al., 2006, 2007; Hering et al., 2010) are costly and time-consuming, there is a pressing need for more efficient operations models and tools (Borowski and Hare, 2007; Malve, 2007; Hering et al., 2010).

For example, results of Water Framework Directive (WFD) monitoring programmes revealed that 66% of 527 assessed lakes had high (H) or good (G) ecological status and that 28% had moderate (M), 6% poor (P) and 1% bad (B) status. Percentage classification of Finnish coastal waters was 15% (H + G), 57% (M), 25% (P) and 3% (B) respectively (Mäenpää and Tolonen, 2011). The milder winters and resulting increase in nutrient load to aquatic systems (Puustinen et al., 2010; Andersen et al., 2006; Ulén and Weyhenmeyer., 2007; Mullana et al., 2012) is worsening algal blooms in Finnish surface waters.

Despite well-structured and costed WFD Programs of Measures (PoMs) in Finland, the status of many water bodies remains unknown due to a lack of chemical and biological data. There are also uncertainties in the analysis of pressures and impacts when evaluating the status of water bodies and planning nutrient loading mitigation measures. The mandatory WFD costs benefits analysis (WATECO, 2003) has not been done systematically due to the lack of efficient operations model.

What is more, the planned management measures cannot be implemented without public and stakeholder involvement and participation. For example management measures in Finland are not binding on stakeholders, many actions are voluntary and public involvement is mandatory (European Commission, 2000, article 14). Thus, all the information and knowledge gained should be disseminated in an accessible and lucid format to ensure public involvement and participation (Borowski and Hare, 2007).

Fortunately, there is a set of integrated decision support systems like AQUATOOL (Andreu et al., 1996) and BASINFORM (Klauer et al., 2012) for the planning and operational management of complex river basins. They comprise the identification of the problems, modeling and evaluation of management measures for the selection of cost-efficient combinations of measures. In addition, Gottardo et al. (2009) introduced a decision support system called MODELKEY for the assessment and evaluation of impacts on aquatic ecosystems and to manage and integrate different types of data, parameters and models. A critical source area framework for the development of supplementary diffuse phosphorus load mitigation measures in Irish catchments was presented by Doody et al. (2012). It integrates a wide range of spatial data, P risk assessment tools, P export models and decision support tools. In the Netherlands, a hydrological water quality model (SWAT) was coupled with an economic optimization model (Environmental Costing Model, ECM) (Cools et al., 2011) and in Denmark Petersen et al. (2009) demonstrated a straightforward and systematic implementation of the WFD in the Odense estuary and its upstream catchment. They presented how reference conditions and an ecological status classification have been conducted with historical data and modeling tools. The pressures and impacts of nitrogen loading in the estuary were modeled, the required load reduction was estimated and an integrated cost-effectiveness analysis was conducted to select the most suitable mitigation measures.

There are pressing and highly relevant questions concerning the use of these tools; how do they cope in a large administrative, geographical context with limited monitoring and modeling resources? How well do they facilitate public participation and can it resolve the mutual misunderstandings of water managers and the research community around the role and importance of model-based tools in implementing water management (Borowski and Hare, 2007)? Therefore it is necessary to (1) improve researchers' understanding of water management processes and the role their tools play within such a process, (2) identify the importance of these tools in social learning-oriented management processes for both communities, (3) improve the role of software consultancies as carriers of research results and (4) consider new methods of model transferability between target basins.

This paper demonstrates a new, cost-efficient and participatory operations model for the monitoring, modeling and management of lakes and river basins in order to commit stakeholders to implementation of PoMs. The criteria for the evaluation were 1) improvement in the understanding of factors affecting the ecological status of waters, 2) easy access to monitoring data and model-based planning and decision-making tools, 3) portability of operations model and related tools for the uniform and transferable assessment of ecological and socio-economic impacts, 4) transparency of uncertainties and risks and 5) activity of stakeholder involvement and participation. As a result, we provide future development needs for the implementation and development.

2. Material and methods

Our operations model and the related tools included the estimation of nutrient loading as well as its ecological impacts and cost-efficiency of management measures (Fig. 1). The monitoring and modeling results were gathered into the www.vesinetti.fi tool, which provides an information infrastructure for the operational and interactive use and exchange of resulting data and models between research community, authorities, stakeholders and public.

Monitoring and modeling results were housed in the www.vesinetti.fi tool, which provides an information infrastructure for operational and interactive use and exchange of data and models between research community, authorities, stakeholders and the public. The www.vesinetti.fi comprises a GIS data base system and model interface; it includes basic information on water bodies (e.g. area and mean depth, satellite images and in situ observations of coastal areas and lakes). Models can be run and files and comments can be uploaded or downloaded in separate dialogue windows for each water body. The system meets INSPIRE standards and is publicly available in Finnish (www.vesinetti.fi).

Another participatory data gathering system Lakewiki (http://www.jarviwiki.fi/wiki/Main_page?setlang=en) is a web service which is built and maintained in cooperation with the authorities and the public. The public can participate in Lakewiki by adding detailed information on their local lake, entering their own observations e.g. on cyanobacteria, ice-out, water temperature, and uploading photos or videos. Lakewiki was created with the aim of sharing information on Finland's lakes, to raise awareness and promote the protection of our waters. The connection to Vesinetti was established to show content such as basic lake information and a comments section within the Vesinetti map service.

2.1. Description of tools

The tested tools included monitoring, modeling and planning methods, which are outlined briefly in the following sections. Each tool is presented in terms of input, output and main usage in Appendix 1. A short description of each tool connected to the operations model (Fig. 1) is given below.

2.1.1. Nutrient loading estimation tools

VEMALA is an operational, national-scale, nutrient (phosphorus and nitrogen) loading model for Finnish watersheds. It simulates runoff processes, nutrient processes, leaching and transport on land, in rivers and in lakes (Huttunen et al., accepted for publication). The model provides an estimate of the external loading, outflow loading, retention and concentration of nutrients and chlorophyll a in all Finnish lakes (of which there are about 58,000), as well as nutrient loading source

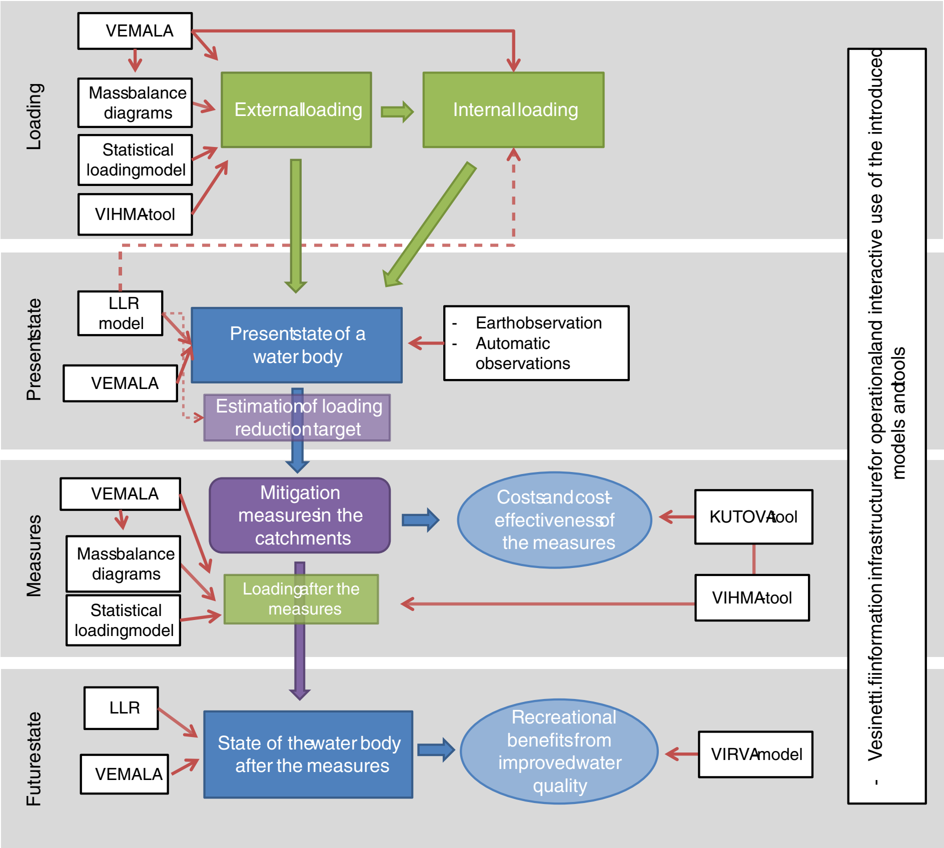

Fig. 1. Operations model for joint use of the models and tools for the river basin management planning includes tools to calculate nutrient loading, present state, required management measures and future state. The models are described in detail in Section 2.1. LLR = Lake Load Response, VEMALA = hydrological water quality model, VIHMA = tool for allocation of measures to control erosion and nutrient loading from agriculture, KUTOVA = tool for selecting cost-effective phosphorus loading mitigation measures, and VIRVA = tool for estimating recreational benefits of improved water quality.

apportionment to its main sources (agriculture, forests and forestry, scattered settlements and point sources).

Mass balance diagrams (MBDs) were developed to provide an easy-to-use Microsoft Excel tool for handling VEMALA simulation results for planners and decision-makers. This tool is based on the average annual mass balances of total phosphorus, total nitrogen and suspended solids obtained from the daily simulations. The loads originating from fields, other land areas, residential areas, point sources or depositions of a specific sub-catchment can be represented and their effect on areas, sub-catchments downstream and lakes can be assessed. The user can simulate either the present situation by using the simulations from 1991 to the present day, or simulate developments until 2050.

The statistical loading model for the calculation of specific loading of TP and TN is based on the water quality and flow data collected during 2000–2011 from 70 monitoring stations in Finland, and the characteristics of their upstream catchments. Forty-one areas, mostly located in the upper reaches of larger river basins, were used for the equation set-up (i.e. model building) for phosphorus (forty two areas were used for nitrogen). The annual mean specific TP and TN loadings calculated for the 41 (P) and 42 (N) areas were explained by linear regression against a number (ca. 25) of catchment characteristics. The list of explanatory variables included e.g. field, lake and forest percentages, the number of scattered settlements, the nutrient loading from point sources, the nutrient content of manure, and the clay content of topsoil. The models are described in detail in Röman et al. (submitted, 2015).

The VIHMA tool (Puustinen et al., 2010) was developed by the Finnish Environment Institute (SYKE) to estimate changes in nutrient loadings from different agricultural measures. VIHMA is a catchment scale model and it gives the nutrient load in three stages estimating: i) the loading from the field, taking into account the pallet of cultivation measures applied there, ii) how the buffer zones would reduce the loading that is coming from fields, and iii) the effect of wetlands on the loading after the cultivation methods and buffer zones. In this study, VIHMA was used to estimate the nutrient loading originating from fields in seven pilot areas and in different scenarios, which were constructed to show the changes in loading with different amounts of measures executed and by targeting them in different ways.

2.1.2. Tools to support ecological status estimation

Lake Load Response (LLR) is an open access internet tool (http://llr.fi/cqi-bin/frontpage.cqi?kieli=ENG) developed to predict the effect of phosphorus and nitrogen loading on the phosphorus, nitrogen and chlorophyll a concentration in a lake (Kotamäki et al., 2015). LLR estimates target nutrient load given the quality standards of good ecological status of a specific lake type. LLR is based on simple empirical models: the nutrient retention model (Vollenweider, 1968 and Chapra, 1975) and the hierarchical linear model for chlorophyll a (Malve and Qian, 2006; Malve, 2007). The LLR's phosphorus loading model has also been re-parameterized by adding an internal load term to the model. As a probability-based model, LLR provides useful information about the risks and uncertainties.

The LLR model has been implemented also in map-based interface (www.vesinetti.fi) and it can be run for a single lake or water body. Water body-specific input data comes automatically from the VEMALA simulation results.

2.1.3. Earth observations and automatic measurements to support ecological classification

Earth observation. Water quality maps were based on the MERIS satellite images, from which chlorophyll a, turbidity and Secchi disk transparency were interpreted. MERIS does not provide useful data for small lakes and straits, because its spatial resolution is 300 m. Chlorophyll a and turbidity were interpreted from the MERIS images of 2010 and 2011 using the Boreal lake processor (part of the BEAM software package (Doerffer and Schiller, 2008)), which is based on the concentration ranges and optical properties of Finnish lakes. We have developed a new method for Secchi transparency estimation by combining the output of a Boreal processor and a bio-optical model (Schroeder et al., 2007; Doerffer and Schiller, 2008; Koponen et al., 2008 and Kallio, 2012).

Automatic measurements included chlorophyll a and phycocyanin fluorescence, turbidity, nitrate, oxygen water temperature and salinity, but variables varied between pilot areas. Automatic stations were piloted in the lakes of Pien-Saimaa, Vanajavesi and Pyhäjärvi, as well

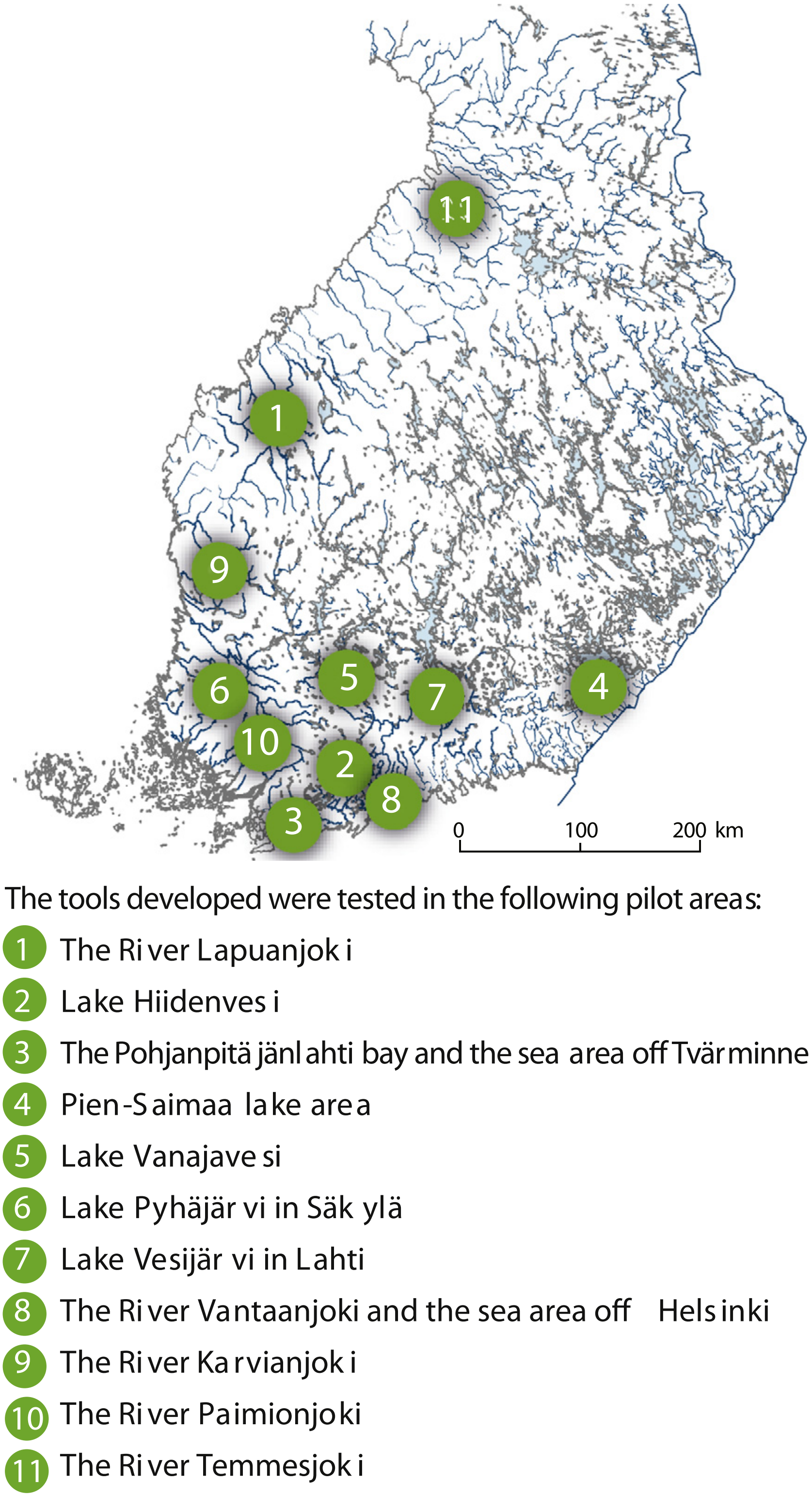

Fig. 2. The pilot areas in the GisBloom project.

Table 1
Loading from the whole land and field areas according to different loading models in Lake Vanajavesi.

Total phosphorus (kg/km^2)	Lake Vanajavesi
VEMALA, whole land area, inflow	43
Statistical loading model, whole land area, outflow	31–65
VEMALA, field area	95
VIHMA, field area	100
Statistical loading model, field area, outflow	38–49
Total nitrogen (kg/km^2)	**Lake Vanajavesi**
VEMALA, whole land area, inflow	1360
Statistical loading model, whole land area, outflow	553–740
VEMALA, field area	2029
VIHMA, field area	1440
Statistical loading model, field area, outflow	556–609

as the Helsinki sea area. Automatic measurements can help identify explanations for algal blooms, particularly if temperature and oxygen sensors are available in addition to sensor measuring phytoplankton (Lepistö et al., 2008).

2.1.4. Socio-economic estimation and decision-making support tools

KUTOVA is a spreadsheet tool developed in SYKE to estimate the cost-effectiveness of phosphorus loading mitigation measures at the catchment scale. The tool can be used to compare single measures by their cost-effectiveness or achievable phosphorus loading reduction rate. It is also possible to build cost-effective combinations of measures, where the interactions of the measures are taken into account. The tool includes 19 different measures from agriculture, forestry, scattered settlements and peat mining (Hjerppe and Väisänen, 2015).

In this study, KUTOVA was used to determine the cost-effective mitigation measures and to build a cost-effective combination of measures for eight pilot areas. The cost-effective combinations of measures were compared to the PoMs of the pilot areas.

The VIRVA model, another spreadsheet model developed by SYKE, estimates the recreational value of water bodies. It can also be used to evaluate the benefits for recreation from improved water quality. The recreational value of a water body is calculated for two user groups, which are i) waterfront properties and ii) other users. The recreational activities taken into account are swimming, fishing, boating, enjoyment of scenery and water use for sauna and washing purposes. In this study the VIRVA model was used to evaluate the recreational benefits of river basin management planning for seven pilot areas.

2.2. Interactive dialogue with stakeholders

Borowski and Hare (2007) highlight the importance of interaction between scientists/modelers and the water managers for the successful use of models and tools in water management. Therefore, demonstration, testing and evaluation of the above-mentioned tools were carried out together with stakeholders and the public in a way suggested by (Raadgever et al., 2012). First, the key stakeholders were identified, as were their roles in the project. Second, methods and tools for communication were defined, a timetable was designed and the plan for the evaluation was compiled. Third, authorities and local stakeholders were invited to workshops. The number of stakeholders in the workshops varied between five and 25. Three consecutive workshops were organized for same stakeholders. In the first meeting methods and tools were presented and feedback from all involved actors were collected. In the second one the operations model and the tools developed according to the feedback were demonstrated and evaluated by participants. In the end, the final conclusions, statements and development needs were formulated. After each workshop a feedback survey was conducted. Collected feedback was analyzed and used in model development. The analysis of feedback included in the identification of remaining gaps, development needs and commitment for the mobilization of tools and operations model. The workshops were important to incorporate local knowledge and values into the assessment and evaluation process. The workshops were also an important forum for model developers to get feedback from stakeholders on the transparency and understandability of the methods. These comments were taken into account when the user interfaces were developed and when the models and their results were presented and demonstrated later. The workshops also played an important role in model quality assessment, which supported the validation of methods and tools demonstrated.

3. Results

The operations model was tested in 11 pilot areas (Fig. 2) representing different geographical, climatic and soil conditions. The applied models were selected based on the local stakeholders preferences collected in interactive pilot area workshops.

In this article, we present the results from one pilot area, i.e. Lake Vanajavesi which is situated in Southern Finland (number 5 in Fig. 2). The lake area is 120 km^2 and the catchment area is 2739 km^2, of which 27% is agricultural land. Both diffuse and point source loadings

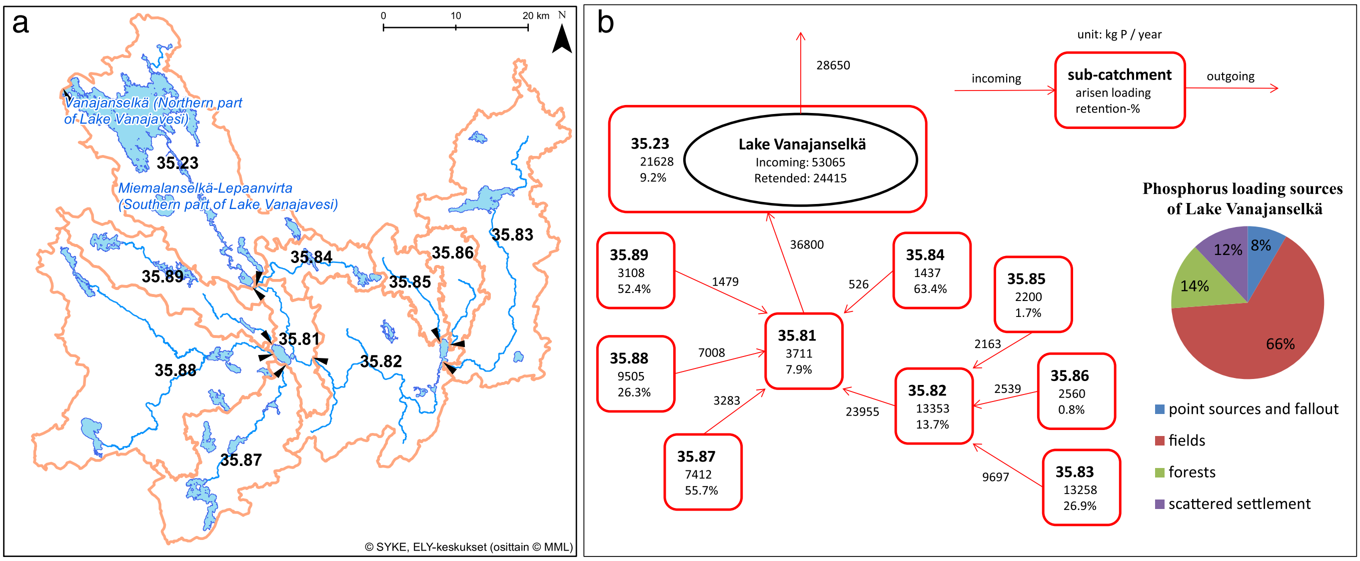

Fig. 3. Phosphorus mass balance diagram of Lake Vanajavesi, schematic representation sheet. Rounded rectangles represent sub-catchments and the oval represents the sub-basin.

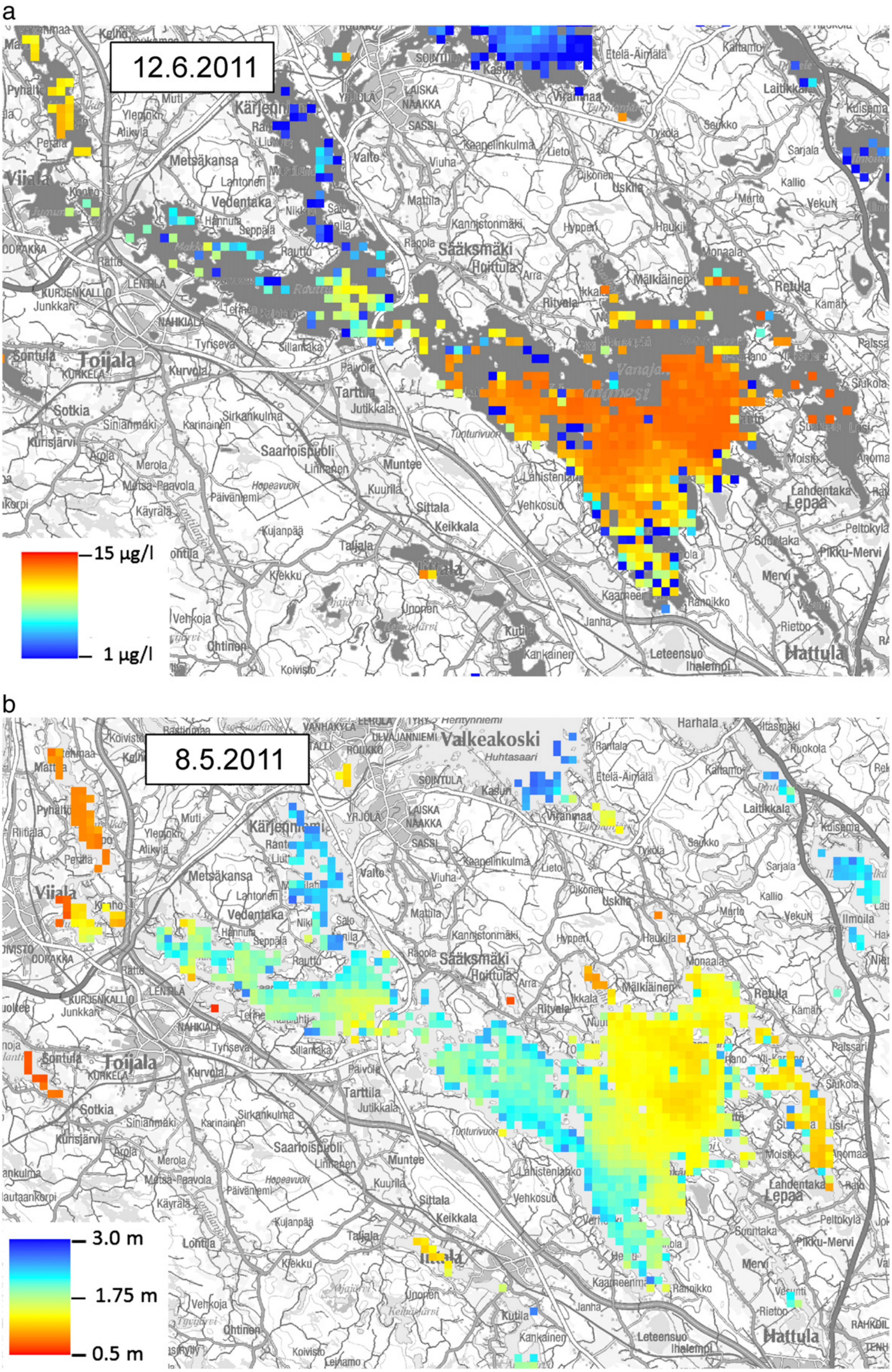

Fig. 4. Chlorophyll a concentration in 12.6.2011 (on top) and Secchi depth in 8.5.2011 (on bottom) in Lake Vanajavesi based on MERIS satellite images.

are significant in Lake Vanajavesi. The ecological status of the lake is moderate.

Results from other pilot areas can be found in Vesinetti.fi and in the guidance report of the GisBloom project (Väisänen, 2013).

3.1. Demonstration of the operational model in river basin management planning: case Vanajavesi

3.1.1. Nutrient loading

In order to recognize the pressures affecting the state of Lake Vanajavesi, VEMALA, VIHMA and statistical loading models were used to estimate the external nutrient loading to the lake. Estimated loads varied a lot revealing the differences in input data, model structure and parameterization as well as the temporal and spatial scale of the models. The total loading of the catchment area is between 31 to 65 kg P km^{-2} and 553 to 740 kg N km^{-2} according to the statistical loading model and 43 kg P km^{-2} and 1360 kg N km^{-2} according to VEMALA. The loading from the field area is 95 kg P km^{-2} and 2029 kg N km^{-2} according to VEMALA and 100 kg P km^{-2} and 1440 kg N km^{-2} according to VIHMA (Table 1).

The mass balance diagrams (Fig. 3) were used to allocate the nutrient loading mitigation measures spatially and to plan the implementation of measures of different loading sectors allocated in different sub-catchments. In Lake Vanajavesi the most efficient allocation of measures would be in sub-catchments 35.23 and 35.82, which generate more than half of the total incoming loading and where the retention is relatively low. The impact of retention is seen when comparing the results of the statistical loading model to the results of the VEMALA and VIHMA models.

3.1.2. Ecological classification and needed loading reduction

In Lake Vanajavesi, chlorophyll a and Secchi depth maps were generated from satellite images, which were used to evaluate the spatial variation in water quality (Fig. 4). Chlorophyll a concentration was also measured at an automatic station in the summer of 2012. Mean concentrations were calculated for these periods and used in the classification (Fig. 6).

The classification boundary between good and moderate ecological status in Lake Vanajavesi for chlorophyll a concentration is 11 μg l^{-1}. The classification period June–August mean concentration for years 2006–2012 was 16 μg l^{-1} based on the traditional water sampling. The chlorophyll a concentration in the novel data based on intensive (10 minute interval) measurements from 2012 was higher than the boundary concentration throughout the measurement period (Fig. 5), supporting the view that the ecological status was moderate.

The LLR model was used in the classification of the lake together with VEMALA loading estimates. The probability distributions of total nutrient and chlorophyll a concentrations were calculated, giving the most probable status class for two parts of Lake Vanajavesi. These classifications were then compared to the classification based on traditional water sampling (Table 2). For the Miemaalanselkä-Lepaanvirta part of the lake, the classifications were consistent, but for the Vanajanselkä part, the LLR model suggested a moderate status instead of good.

The LLR model was also used in Lake Vanajavesi to identify the nutrient loading reduction targets. In order to meet the target of good ecological status in different parts of the lake, phosphorus loading should be reduced by 15–38% and nitrogen loading by around 50%. The average P loading in the southern part of Lake Vanajavesi (Miemaalanselkä-Lepaanvirta, Fig. 6) is 30 g m^{-2} a^{-1} (44 kg a^{-1}) which corresponds to a phosphorus concentration of 62 μg l^{-1}. To meet the phosphorus standard (40 μg l^{-1}) the target phosphorus loading is 18 g m^{-2} a^{-1} (27 kg a^{-1}). Therefore, the phosphorus reduction is 38%. For nitrogen, the current average loading is 690 g m^{-2} a^{-1} (1015 kg a^{-1}) and the target loading 351 g m^{-2} a^{-1} (515 kg a^{-1}). Nitrogen loading should be reduced by 49% to achieve good N status in the Miemaalanselkä-Lepaanvirta water body.

3.1.3. Selection of cost-efficient program of management measures

The KUTOVA tool was used to recognize the cost-effective phosphorus loading mitigation measures and to compare the planned PoM with a cost-effective combination of measures. The most cost-effective measures in Lake Vanajavesi to reduce the external phosphorus loading are those of forestry (runoff control, wetlands) and steep slope fields (perennial grass, winter time vegetation cover, buffer zones). The measures planned in the first RBMP period would result in a 16% reduction in phosphorus loading with annual costs of EUR 6 million. With cost-effective measures and the budget of the same EUR 6 million, a reduction rate of 35% could theoretically be achieved (Table 3). This almost meets the phosphorus reduction target calculated with the LLR model, which means that the good ecological status could theoretically be achieved.

Finally the VIRVA model was used to calculate the recreational benefits of improved water quality, when good ecological status is achieved. In Lake Vanajavesi the recreational benefits were estimated to be around EUR 0.2 million annually. This is very small compared to the costs of the PoM, but it should be noted that the VIRVA model only estimates the recreational value, not other parts of the total economic value such as non-use values like existence value (see e.g. Turner, 1999). In addition, the lake is already close to good status according to total

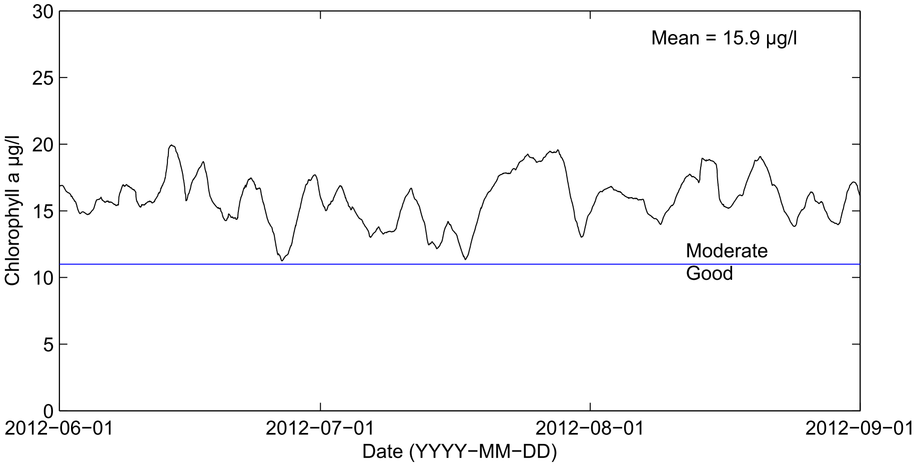

Fig. 5. Chlorophyll a concentration in the eastern part of Lake Vanajavesi (Ruskeenkärki station) based on automatic measurements from June 1st to August 31st in 2012. The horizontal line indicates the boundary concentration between good and moderate ecological status classes.

Table 2
Classification of different parts of Lake Vanajavesi, based on the LLR model and traditional water sampling. Gray shading denotes disagreement of the methods.

Site		Total phosphorus ($\mu g l^{-1}$)		Total nitrogen ($\mu g l^{-1}$)		Chlorophyll a ($mg l^{-1}$)	
Miemalanselkä-Lepaanvirta	LLR	62	Moderate (81%)	1227	Poor (96%)	40	Poor (100%)
(southern part of Lake Vanajavesi)	Traditional	59	Moderate	1200	Poor	36	Poor
Vanajanselkä	LLR	26	Moderate (100%)	1191	Poor (71%)	13	Moderate (88%)
(northern part of Lake Vanajavesi)	Traditional	24	Good (limit = 25)	980	Poor	16	Moderate

phosphorus concentration. The chlorophyll a concentration as a water quality indicator could have resulted in higher benefit estimates.

4. Discussion and conclusions

Our aim was to evaluate the cost-efficiency of our operations model and to enhance the commitment of stakeholders and public to it. The criteria for the evaluation were 1) improvement in the understanding, 2) easy access to data and models, 3) transferability of the operations model, 4) transparency of uncertainties and 5) activity of stakeholder involvement and participation.

This study addresses how to overcome fragmented and poorly coordinated monitoring, modeling and management processes, incapable of responding to challenges concerning water resource management and the estimation of the costs and benefits of planned management measures and poor stakeholder commitment.

As an improvement we present a new operations model in order to integrate monitoring and modeling and to improve efficiency of management process and to commit stakeholders to the implementation. The operations model and the tools were demonstrated in the 11 pilot areas (Fig. 2) but we present here only the results from Lake Vanajavesi. The development of the tools was an iterative process in which feedback from pilot areas was taken into account. Most of the material was collected to web-based map services (Vesinetti and Lakewiki) in order to disseminate model results, data and viewpoints, and to facilitate participatory river basin management.

The operations model and related tools produce a complete estimation of ecological status, nutrient loading and cost-efficient program of management measures. The same procedure was transferred successfully to eleven pilot areas. This was first real world demonstration with such a geographical extent in Finland.

Managers and stakeholders from pilot areas were committed to the work and adapted the model. While the tools operate better on a large scale and practical planning and restoration work takes place more locally it turned out to be necessary to improve performance in smaller areas. However, the small monitoring and modeling resources compared to the large number of water bodies in Finland force RBMP work in Finland to be implemented on a larger scale or to increase the model transferability.

Borowski and Hare (2007) found that both water managers and stakeholders showed little enthusiasm concerning time spent on outreach and education related to the correct use of the models. However in our study, managers and stakeholders actively participated in workshops dedicated to model development. We found that visual and transparent interfaces and guidance facilitated the use of the models, dissemination and the exchange of the results.

At present, water managers base their plans and decisions more on data and expert judgment in Finland. However, they committed to the participatory modeling and the integration of models. The role of models in management can be strengthened, provided that we overcame the lack of confidence in model results through intensified participation and collaborations with all involved actors (Junier and Mostert,

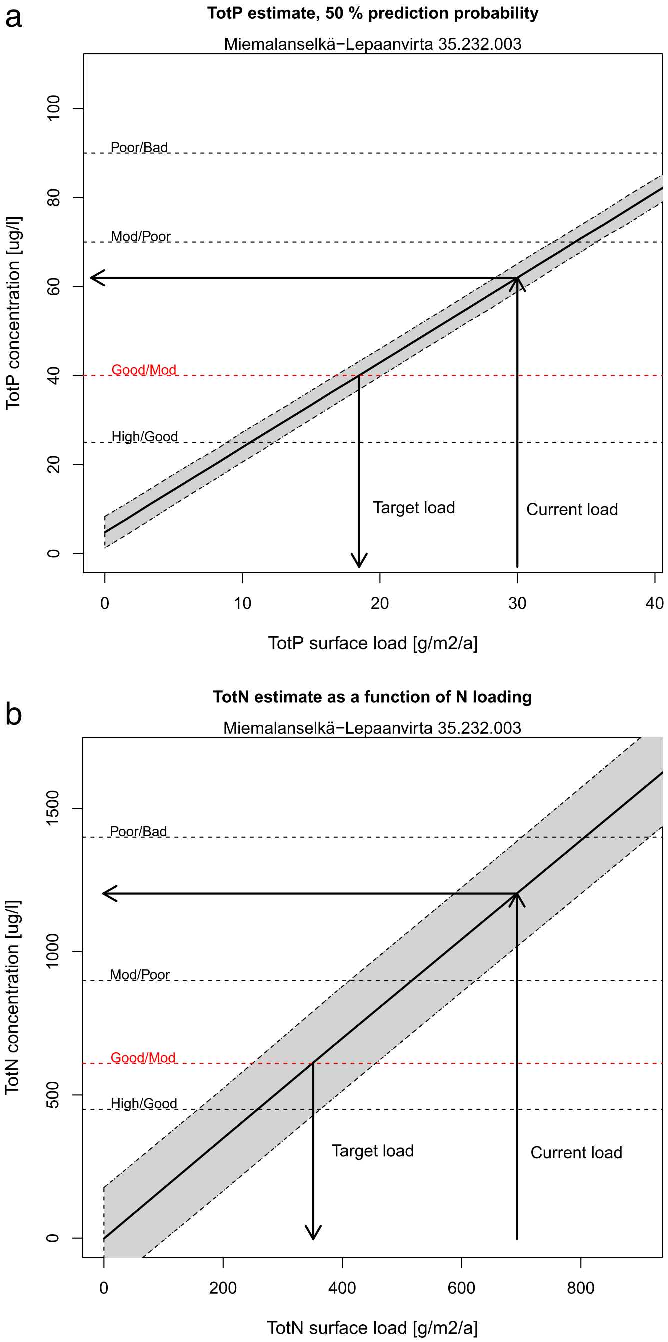

Fig. 6. The relationship between loading and nutrient concentrations in the southern part of Lake Vanajavesi. Phosphorus on the top and nitrogen on the bottom. The loading is announced as grams per lake m^2 per year.

Table 3
Measures included into the programme of measures (PoM) and the cost-effective alternative (KUTOVA tool) in Lake Vanajavesi. The costs of the combinations of measures are EUR 6 million annually.

Sector	Measure	PoM	KUTOVA tool
Agriculture	Buffer zones	270 ha	711 ha
	Constructed wetlands	46 wetlands	766 wetlands
	Wintertime vegetation cover	16,500 ha	18,500 ha
	Optimal fertilization	33,000 ha	53,000 ha
	Controlled drainage	800 ha	
Forestry	Buffer zones of logging area	78 ha	84 ha
	Peak runoff control		105 dams
Scattered settlements	Sewer network for scattered settlement	800 houses	
	New local wastewater treatment systems for scattered settlement	2600 houses	
	New local wastewater treatment systems for holiday housing	1700 houses	1700 houses
Peat mining	Overland flow	23 ha	23 ha
	Peak runoff control	131 ha	282 ha
Total reduction		16%	35%

2014). But as Raadgever et al. (2012) stated, stakeholders are not sufficiently motivated to collaborate and learn unless we organize 1) many meetings, 2) intensive discussion of perspectives, 3) active participation in the research, and 4) an equal input in and influence on the research process by all involved actors. For example, scientific community values the integration of data and models and the estimation of variance and confidence intervals of estimates, whereas administrators and stakeholder managers were on the one hand concerned about the assumptions and uncertainties in modeling, but on the other hand they expected explicit results. For example, as presented in the results section our nutrient loading estimates vary due to different model structures and data. The selection of an appropriate model depends on the spatial and temporal resolution needed in management work. Often the reason for the distinction in different model results can be explained based on the model resolution and structure.

Our operations model was in accordance with several recommendations made by Borowski and Hare (2007). It promoted the integration of fragmented thinking and social learning and improved the research community's understanding of the management and decision-making processes. We also adapted the modeler's timeline with that of the managers' and developed a joint, iterative process for participatory modeling and managing. That way our modelers learned how to support river basin management in practice. Web-based tools were used to further facilitate the participatory management process.

Integrated approach for the facilitation of social learning and participatory management needs further progress (Raadgever et al., 2012). The modelers at the Finnish Environment Institute also provided the software development and execution consultancy necessary for safeguarding the quality of tools with non-technical requirements such as the harmonization of tools and approaches, documentation and training. We also tackled the problem of transferability, parameterization and validation of the models in any new target basins. We tried to achieve technical transferability using statistical analysis of the extensive national monitoring data available (Malve and Qian, 2006; Malve, 2007; Kotamäki et al., 2015), not to forget 'cognitive transferability' i.e. teaching water managers how to transfer the findings of current models and apply them to similar river basins. During our demonstrations we also realized how important the funding is, not only for tool development but also for maintenance and consultancy for managers and stakeholders. As a result, we provided consultancy for model usage and the evaluation of results for managers.

The improved ecological status of waters will be a major long-term environmental benefit which, in turn, will bolster the commitment of stakeholders and the public to participate in the implementation of management plans. The strengthened commitment, new business opportunities and the fair sharing of costs and benefits between stakeholders will be among the most important long-term social impacts. The long-term savings and business opportunities are evident: the lower cost of unit nutrient loads; reduction of mitigation measures; improved water quality for recreation, fisheries, household and industrial water uses; and the spin-off of new private sector business opportunities using demonstrated tools and information technologies.

The approach of our operations model was not unique, as there are similar modeling frameworks (e.g. Klauer et al., 2012; Junier and Mostert, 2014) that have been reported earlier, as reviewed in the introduction. However, we presented an operations model that connected tools and data into participatory web portals and it was demonstrated widely in practical RBM work together with the water managers. What is noteworthy to academic discussion is that we critically evaluated our experiences and the difficulties in building models for the purposes of the RBMP process.

The brief conclusions of our work are:

- In the RBMP process, there is a demand for a systematic evaluation of the ecological and economic efficiency of mitigation measures of nutrient loads.
- Models need to be continuously developed, and more effectively automated and integrated.
- Uncertainty analysis should be introduced into each model.
- The web-based map services www.jarviwiki.fi and www.vesinetti.fi are useful for dissemination, education and in the participatory monitoring and management of river basins.
- Consultancy services for end users ought to be tailored and provided.
- More emphasis should be placed on the estimation of the economic benefits.

Acknowledgments

This work was funded by EU LIFE+ GisBloom project (LIFE09 ENV/FI/000569), the integrated EU project MARS ("Managing Aquatic ecosystems and water Resources under multiple Stress") within Framework Programme 7, Theme ENV.2013.6.2-1: Water resources management under complex, multi-stressor conditions (Contract No. 603378) and Maa-ja vesitekniikan tuki ry. The authors would like to thank all the participants of the GisBloom project, both the researchers, water managers and stakeholders from all river basin districts in Finland.

Appendix 1. Tested models and tools

Table A.1
Tested models and tools.

Category/tool/model	Input/sensors	Output	Main usage	Reference
Nutrient loading estimation tools				
WSFS-VEMALA	Daily meteorological data, daily hydrological data, water quality monitoring data, agricultural field data for all fields in Finland, annual point loads from VAHTI	Daily TP, TN and SS concentrations and loads in rivers and lakes	Simulations of nutrients loading to the lakes, nutrients concentrations, nutrients load source apportionment and climate change scenario effects on nutrient loading	Huttunen, I. et al. (accepted) (2015)
Mass balance diagrams	Total phosphorus, total nitrogen and suspended solids simulations from VEMALA	Annual mass balance calculations of sub-catchments and lakes and schematic representation of catchment structure and substance flows	Estimation of substance loading to lakes and estuaries, effects of different sources and sub-catchments	Malve et al. (2013) (in Finnish)
Statistical loading model	Land use (agricultural, forest, urban and lake area), wetlands, number of animals, point load, crop type, precipitation, clayey soils	Total average P and N	Nutrient load estimates, input for lake models, scenarios. Data can be used as background information for identification of the pressures	Malve et al. (2013) (in Finnish)
Tool for allocation of measures to control erosion and nutrient loading (VIHMA)	Soil, crop type, soil P status, steepness of fields, cultivation measures, buffer zones, wetlands	Erosion, particulate and dissolved reactive P, total and nitrate N	Evaluating agricultural loading and mitigation of measures at catchment scale	Puustinen et al. (2010)
Tools to support ecological status estimation				
Lake Load Response (LLR lake tool)	Inflow, total P and total N load and in lake concentrations (chlorophyll a included), volume, depth, lake or coastal water type. Additionally, nutrient fluxes and budget with flushing rate, calculated by Knudsen's equation, are needed for the estuarial application	Concentrations of total P, total N and chlorophyll a in lake and estuary waters	Estimation of necessary reduction of nutrient load to achieve good ecological status	Malve and Qian (2006); Malve (2007); Kotamäki et al. (2015)
Earth observation and automatic station data to support ecological classification				
Earth observation data (EO)	MERIS, AVHRR	Chl-a, turbidity, Secchi transparency, water temperature	Monitoring of spatial variation	Doerffer and Schiller (2008); Kallio (2012); Koponen et al. (2008); Schroeder et al. (2007)
Automatic measurements	Fluorometers, turbidity meter, temperature and salinity meter	Chl-a, cyanobacteria, turbidity, temperature, salinity	Monitoring of temporal variation	Kallio et al. (2010)
Socio-economic estimation and decision-making support tools				
Tool for cost-effectiveness analysis of phosphorus mitigation measures (KUTOVA)	Sector-specific loading, reduction rates of the measures, costs of the measures, maximum extent of the measures	Cost-effectiveness of single measures, cost-effective combination of measures	Choosing and dimensioning the measures for the cost-effective Program of Measures	Hjerppe and Väisänen (2015)
Tool for estimating the recreational benefits from improved water quality (VIRVA)	Number of waterfront properties, average price of waterfront properties, current number of other users of the water body, water quality, lake type, value function for the nutrient level and feasibility coefficient	Recreational value of the water body as a function of nutrient or chlorophyll concentration of the water body	Estimating the recreational benefits from improved water quality	Seppälä et al. (2014) (In Finnish)

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