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INSTITUTE 15 | 2008

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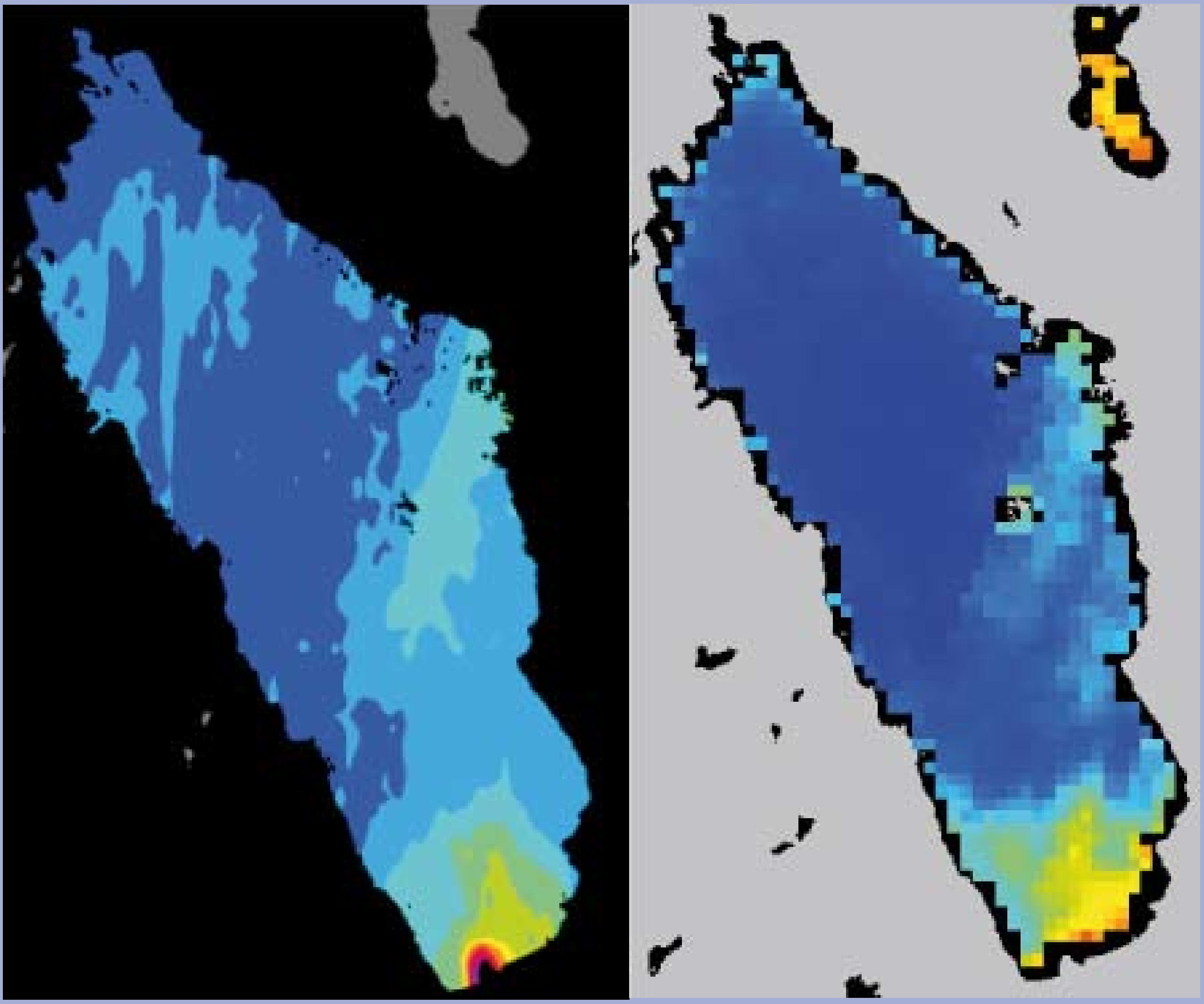

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Helsinki 2008

Finnish Environment Institute

Authors of this report:
Ahti Lepistö, Kirsti Granlund, Pekka Härmä, Kari Kallio, Jari Koskiaho, Olli Malve, Timo Pyhälahti, Sirkka Tattari, Markus Törmä
Finnish Environment Institute SYKE, P.O.Box 140, FIN-00251 Helsinki, Finland

Timo Huttula, Niina Kotamäki
Finnish Environment Institute SYKE, P.O.Box 35, FI-40014 University of Jyväskylä, Finland

Ilona Bärlund
University of Kassel, Center for Environmental Systems Research (CESR), Kurt-Wolters-Strasse 3, D-34125 Kassel, Germany

Mikko Kiirikki, Antti Lindfors
Luode Consulting Oy, Sandfallintie 85, FI-21600 Parainen, Finland

Teija Kirkkala
Pyhäjärvi Institute, Ruukinpuisto, Sepäntie 127, 27500 Kauttua, Finland

Sampsa Koponen
Helsinki University of Technology TKK, Laboratory of Space Technology, P.O.Box 3000, FIN-02015 TKK, Finland:

Further information:
Ahti Lepistö
project co-ordinator, SYKE
e-mail: firstname.secondname@ymparisto.fi

This publication should be cited as:
Lepistö, A., Huttula, T, Bärlund, I., Granlund, K, Härmä, P., Kallio, K, Kiirikki, M., Kirkkala, T., Koponen, S., Koskiaho, J., Kotamäki, N., Lindfors, A., Malve, O., Pyhälahti, T., Tattari, S & Törmä. M. 2008. New measurement technology, modelling and remote sensing in the Säkylän Pyhäjärvi area – CatchLake. Reports of Finnish Environment Institute 15 | 2008, 73 p.

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SYKE

REPORTS OF FINNISH ENVIRONMENT
INSTITUTE 15 | 2008
Finnish Environment Institute
Research Department

Page layout: Seija Turunen

Cover: Turbidity values at Lake Pyhäjärvi on 9.5.2006, just after ice-break. On the left: turbidity interpolated from transect data by Luode Consulting Oy, and on the right: turbidity estimated from MERIS reflectances on the same day, by TKK Laboratory of Space Technology.

The publication is also available in the Internet:
www.environment.fi/publications

ISBN 987-952-11-3125-7 (PDF)
ISSN 1796-1726 (verkkoj.)

Preface

New environmental technologies, such as the use of high resolution measurements together with advanced mathematical models, are increasingly required in monitoring and environmental research for water protection. Sensors, wireless techniques, remote sensing and models are continually progressing. Climate change -induced mild winters challenge the traditional measures to reduce diffuse loading, and suggest a need for further development of environmental monitoring schemes. Innovative measuring technologies offer new possibilities for this work.

Lake Pyhäjärvi (154 km2) is of great importance both regionally and nationally. A large number of management options have been applied both in the catchment and in the lake itself, but more real-time, detailed data and model-based scenarios are required for water protection studies. CatchLake is a co-operative project between the Finnish Environment Institute and the Laboratory of Space Technology at Helsinki University of Technology (TKK), the Pyhäjärvi Institute in Eura, and other participants at the University of Kassel, Germany, Luode Consulting Oy, and Pyhäjärvi Protection Fund (see: http://www.ymparisto.fi/syke/catchlake).

This report, an output from the CatchLake1 project (2006-2007), presents recent knowledge concerning new measurement technologies, and is also a basis for future work. The project was divided into three parts: modelling, lake and catchment measurements, and remote sensing. Integrated catchment models (SWAT and INCA-N) were applied at the Yläneenjoki catchment to simulate suspended solids, phosphorous and nitrogen loading to the lake. Intensive measurements from measuring campaigns over the whole river catchment were utilized in modelling. A custom-made flow-through method was used to collect high resolution transect datasets of water quality information from Lake Pyhäjärvi in six campaigns. Remote sensing methods were applied to retrieve spatial water quality information from Lake Pyhäjärvi, which was consistent with surface measurements from a boat.

In the ongoing CatchLake2 project (2008-2009), the three-dimensional model Coherens will be applied to Lake Pyhäjärvi to simulate the spatial heterogeneity of water quality. In addition, measuring techniques, remote sensing time series and linking of catchment and lake models will be developed.

We would like to thank the project team and other persons who have contributed for their active participation and co-operation,

Ahti Lepistö and Timo Huttula (eds.)

SYKE
Helsinki and Jyväskylä, May 2008

SISÄLLYS

Preface ... 3

1 Introduction ... 7

- **1.1 Catchment subtask - the development of process-based modelling and measuring technology** ... 7
- **1.2 Lake subtask – spatial measurements and modelling of lake water quality** ... 8

2 Lake Pyhäjärvi and its catchment ... 9

- **2.1 Lake Pyhäjärvi catchment** ... 9
- **2.2 Lake Pyhäjärvi** ... 10

3 Measurements and catchment modelling ... 13

- **3.1 Measurement technology** ... 13
    - 3.1.1 Rivers and nutrient loading ... 13
    - 3.1.2. Automatic weather station at the Lake Pyhäjärvi ... 26
    - 3.1.3. Production of phenological information for nutrient modelling from remote sensing data ... 28
- **3.2 Catchment modelling** ... 31
    - 3.2.1 The SWAT model ... 32
    - 3.2.2 The INCA-N model ... 38

4 Lake Pyhäjärvi water quality and modelling ... 44

- **4.1 Field campaigns** ... 44
    - 4.1.1 Water sampling ... 44
    - 4.1.2 Transect measurements ... 45
    - 4.1.3 Spectrometer measurements ... 48
- **4.2 Spatial water quality and remote sensing** ... 48
    - 4.2.1 Methods and results ... 50
- **4.3 Conclusions of spatial water quality sub-task** ... 56
- **4.4 Lake modelling with the LakeState model** ... 57
    - 4.4.1 Model ... 57
    - 4.4.2 Phosphorous modelling and prediction of phytoplankton biomass with given management options ... 57
- **4.5 Linking catchment and lake models** ... 59

5 Conclusions and future plans ... 61

6 Acknowledgements ... 64

7. References ... 65

APPENDIX 1: Sensitivity analysis for the SWAT model ... 67

APPENDIX 2: Atmospheric correction of MERIS data ... 69

DOCUMENTATION PAGE ... 71

KUVAILULEHTI ... 72

PRESENTATIONSBLAD ... 73

1 Introduction

Ahti Lepistö and Timo Huttula

Lake Pyhäjärvi (154 km^2) in Säkylä is a highly valuable lake in terms of water supply and recreational use, and serves as the pilot area of the CatchLake project, together with its 306 km^2 catchment. Increased eutrophication of the Lake Pyhäjärvi has been a major concern since the late 1980s as Cyanobacteria blooms have become more and more frequent. One reason for this might be recent mild winters: nutrient loads to watercourses are increasing because flood periods with high nutrient loads may occur during any time between November and April, instead of predictable spring-floods. This shows that new tools, such as intensive measurements together with advanced mathematical models, are increasingly needed in water protection and environmental research.

In the CatchLake1 project (2006-2007), funded by Tekes (Finnish Funding Agency for Technology and Innovation), integrated use of catchment and lake models was developed by i) utilizing remote sensing technology, and ii) by intensive measurements with water quality sensors coupled with wireless data transmission technology. The project is followed by CatchLake2 project (2008-2009), discussed more in Chapter 5.

In the CatchLake1 project, satellite images were used together with other sources of observation data in environmental modelling. On the other hand, spot sampling was used for quality assurance and evaluation of the remote sensing data. Mathematical models produce information for the support of decision-making. Models help to understand the processes and mechanisms of ecosystems, and they can be used for testing of scientific hypotheses, as well as for evaluations of optional scenarios on e.g. how to reduce the environmental loading cost-efficiently. The exploitability of the models not only depends on the validity of the incorporated processes, but also on the available input data.

CatchLake is a co-operation project between Finnish Environment Institute and the Laboratory of Space Technology of the Helsinki University of Technology (TKK), together with Pyhäjärvi Institute in Eura, and other participants http://www.ymparisto.fi/syke/catchlake. The project has direct links i) with the research made in the EU's 6th Framework Programme (Euro-limpacs project), ii) with the GMES (Global Monitoring of Environment and Security) programme coordinated by EU and ESA, and iii) with GSE Land Information Services of ESA.

The project was divided into two subtasks, (1) **Catch**ment and (2) **Lake**:

1.1

Catchment subtask - the development of process-based modelling and measuring technology

In the catchment subtask, integrated catchment models (SWAT and INCA) were applied at the Yläneenjoki catchment, to simulate suspended solids, phosphorous and nitrogen loading to the lake. Moreover, intensive measurements from the measuring campaigns over the whole river catchment were utilized in modelling.

SWAT is a GIS-based catchment model developed in the Texas A&M University, USA (Arnold et al., 1998). It can be used for simulations of nutrient and sediment transport from catchments with a 1-day timestep. The basic input data consists of three types of GIS data; (i) elevation, (ii) soil type and (iii) land use. Based on these data, a channel network with sub-catchments was created. The functioning of the model and the validity of the process descriptions was evaluated against the intensive measurements.

INCA-N is a dynamic, process-based nitrogen model for simulations of nutrient leaching and the underlying factors at catchment-scale (Whitehead et al. 1998, Wade et al. 2002). The INCA model takes into account all major sources of nutrients and simulates the transformation processes, nutrient pathways, water flow and nutrient concentrations in selected spots along a river channel. The model has being developed jointly with the INCA (EU 5th framework), and Euro-limpacs (6th framework) projects. Also here the water quality data obtained from the intensive measurements was utilized.

One of the aims of the CatchLake project was to develop environmental measuring technology. This involves utilizing intensive water quality measurements by on-line sensors. These data are very valuable for process-based catchment models. Intensive measurements also provide valuable information of leaching and erosion processes, and make more accurate nutrient load estimates available. Measuring campaigns were organized in Yläneenjoki river (Vanhakartano) to obtain accurate load estimates for Lake Pyhäjärvi, and also on its sub-catchment Peräsuonoja, and along the whole of Yläneenjoki river entering to the lake.

1.2

Lake subtask – spatial measurements and modelling of lake water quality

Spatial water quality (turbidity/suspended solids, chlorophyll-a) maps of the Lake Pyhäjärvi were constructed by interpretations of the time series of satellite images taken from the lake. This was done by the interpretation algorithms developed at SYKE and TKK, for the observations made with American (NASA) MODIS and the European (ESA) MERIS instruments. The algorithms are able to integrate the satellite data with any relevant in situ observations in a mathematically optimized way.

High resolution spatial measuring means here measurement technology where water quality variables (measurements of absorption and attenuation, fluorometric measurements, and measurements of temperature, conductivity and turbidity) are determined from a rapidly moving boat with GPS, in order to efficiently cover a large area during a short period of time. The collected information was compared with the data obtained by remote sensing technology.

A non linear dynamic model called LakeState, based on total phosphorus and nitrogen mass balances and phytoplankton kinetics, was used to simulate the main driving processes between nutrient loading, algae and zooplankton in a lake. The model calculates the concentrations of total P and total N in water column as well as the processes between water and sediment. The model is suitable for long term simulations in whole lake scale.

Methods to link catchment and lake models are discussed, together with future use of detailed, spatial surface water quality data in 3-d lake modeling. The new remote sensing and spatial in situ -measurements confirmed spatial heterogeneity in Lake Pyhäjärvi, and the need for models with horizontal dimensions.

2 Lake Pyhäjärvi and its catchment

Olli Malve, Sirkka Tattari, Ahti Lepistö and Timo Huttula

2.1

Lake Pyhäjärvi catchment

Two major rivers, Yläneenjoki and Pyhäjoki, discharge into Lake Pyhäjärvi. Yläneenjoki river basin is considerably larger (233 km^2) than that of Pyhäjoki river (78 km^2). In addition, four main ditches (catchment areas between 6-20 km^2), located in the nearby catchment area, flow directly into the lake. The river mouths of both Yläneenjoki and Pyhäjoki have been regularly monitored and hence the loading estimates to the lake are easily available. On the contrary, the diffuse load from direct, nearby catchments is much more difficult to assess due to the contingency of water level, sediment and nutrient measurements.

The Yläneenjoki river catchment is located on the coastal plains of south-western Finland, thus the landscape ranges in altitude only from 50 to 100 m a.s.l. The soils in the river valley are mainly clay and silt, whereas tills and organic soils dominate elsewhere in the catchment. Long-term (1961–1990) average annual precipitation is 630 mm of which approximately 11% falls as snow (Hyvärinen, 1999). Average discharge measured in the Yläneenjoki main channel is 2.1 m^{3}s^{-1} (Mattila et al. 2001), which equates to an annual water yield of 242 mm (1980–1990). The highest discharges typically occur during the spring and late autumn months.

Agriculture in the Yläneenjoki catchment consists of mainly cereal production and poultry husbandry. According to surveys performed in 2000–2002, 75% of the agricultural area is planted for spring cereals and 5–10% for winter cereals (Pyykkönen et al. 2004). Agriculture in the Yläneenjoki catchment is intensive for Finland. The Yläneenjoki catchment is responsible for over 60 % of the external nutrient loading into the Lake Pyhäjärvi (Ekholm et al. 1997).

The regular monitoring of water quality of the river Yläneenjoki started already in the 1970s. The nutrient load into the Lake Pyhäjärvi via the river has been estimated from the (generally) bi-weekly water sampling results and daily water flow records at Vanhakartano measuring site. Furthermore, water quality has been monitored on a monthly basis in three additional points in the main channel in the 1990s, and in 13 tributaries flowing into the river Yläneenjoki.

Several management efforts have been applied to reduce non point loading in the Pyhäjärvi catchment area, and farmers have participated in these efforts in the water protection projects, started by the Southwest Finland Regional Environment Centre (SFREC) since 1991. In recent years, several various water protection measures have been taken in the catchment: fifty experimental sites have contributed to actions such as filtering ditches and sandfilter fields, utilizing lime or other materials for binding of phosphorus, series of small dams, small chemical treatment units to treat waters from dairy and cattle farms, sewage water treatment of rural houses and village planning as a new method for promoting environmentally sound development of the rural areas.

2.2
Lake Pyhäjärvi

Increased eutrophication of the Lake Pyhäjärvi has been a major concern since the late 1980s as Cyanobacteria blooms have become more frequent. Hydrologic and hydrobiological research of the lake has decades long traditions in the environmental administration and in the University of Turku. Water chemistry and hydrology of Pyhäjärvi have been monitored from the 1960s until now. Intensified monitoring of nutrients and plankton community started in 1980. From the early 1990s on, Pyhäjärvi restoration project funded by local industry, municipalities, associations and by the state, have been testing and implementing several management actions in the lake and in its watershed. Local Regional Environment Centre (SFREC) has the main responsibility of the management planning and environmental monitoring of the lake. Finnish Environmental Institute (SYKE) has the responsibility in national level, to research and to monitor hydrology, chemistry and biology of surface waters, to develop and integrate modeling and management activities necessary for the improvement of usability and ecological status of surface waters.

Hydrologic, hydrodynamic and water quality models have been developed and used by SYKE to aid regulation and management of the lake. Rainfall-runoff model of Lake Pyhäjärvi catchment is a part of SYKE's nationwide flood and runoff forecasting system WSFS, that covers more than 80% of the state surface area. 2D and 3D hydrodynamic models have been used to study sediment transport and water quality in the lake, as well as to dimension external nutrient loading reduction to the attainment of lower and less frequent algal blooming (Huttula 1994, Malve et al., 1994).

The main management options that have been applied are reduction of external nutrient load and management of fisheries. Nutrient load abatement has direct impact (often with long delay) on blooming, but may become very expensive. Fisheries management has proved to be a cost-efficient additional tool for the minimization of algal blooms. Commercial fishing has been directed to manipulate fish stocks and phytoplankton community to limit algal blooming. However, algal blooming frequency has not yet reduced in expected extend due to the long detention time of nutrients in the water body and in the unconsolidated surface sediments in transportation and erosion bottom areas.

Lake Pyhäjärvi is *a shallow mesotrophic lake*. Between 1970 and 1992 the phosphorus (P) and nitrogen (N) concentrations increased in the lake by 30 % (Ekholm et al., 1997) and P concentration has even doubled until now. Field cultivation and animal husbandry contribute 55 % of the external P load on Pyhäjärvi and 39 % of N load, and atmospheric deposition 20 % and 33 %, respectively. In the whole Eurajoki catchment (Fig. 1), total N load is estimated as 917 tonnes N a^{-1} of which on average of 583 tonnes N a^{-1} reaches the sea, i.e. average N retention for the whole catchment is 36% (Lepistö et al., 2006).

Blue green algae blooms in the Lake Pyhäjärvi have been observed frequently in the 1990s. According to sediment studies, the lake productivity started increase in the 1950s in response to intensified cultivation and use of industrial fertilizers. Pyhäjärvi has an unusually high catch of fish, and the average annual catch has been estimated to be even three times higher than the average catch in Finnish lakes (Sarvala et al., 1998).

Fig. 2 illustrates eutrophication of Lake Pyhäjärvi: changes in nutrient concentrations, Chl-a, and Secchi depth in Pyhäjärvi during the past 25 years (Ventelä et al., 2007). Total nitrogen (N) concentrations have varied from 364 to 534 µg l-1 during 1980–2005, increasing up to 1990, and slightly decreasing since then (Fig. 2). Total P concentrations in the lake noticeably increased in the 1980s and 1990s. During the past few years total P has been decreasing, probably partly because of lower external loading due to a dry period and water protection actions in the catchment, and partly because of efficient fish removal. Also, Chl-a concentrations have been decreasing during the past few years due to lower phytoplankton biomasses (Fig. 2). Secchi depth has varied from 2.4 to 3.9 m during the open water season during 1980–2005 (Fig. 2). During the past 10 years Secchi depths have been lower than in the earlier years and seldom >3 m. (Ventelä et al., 2007).

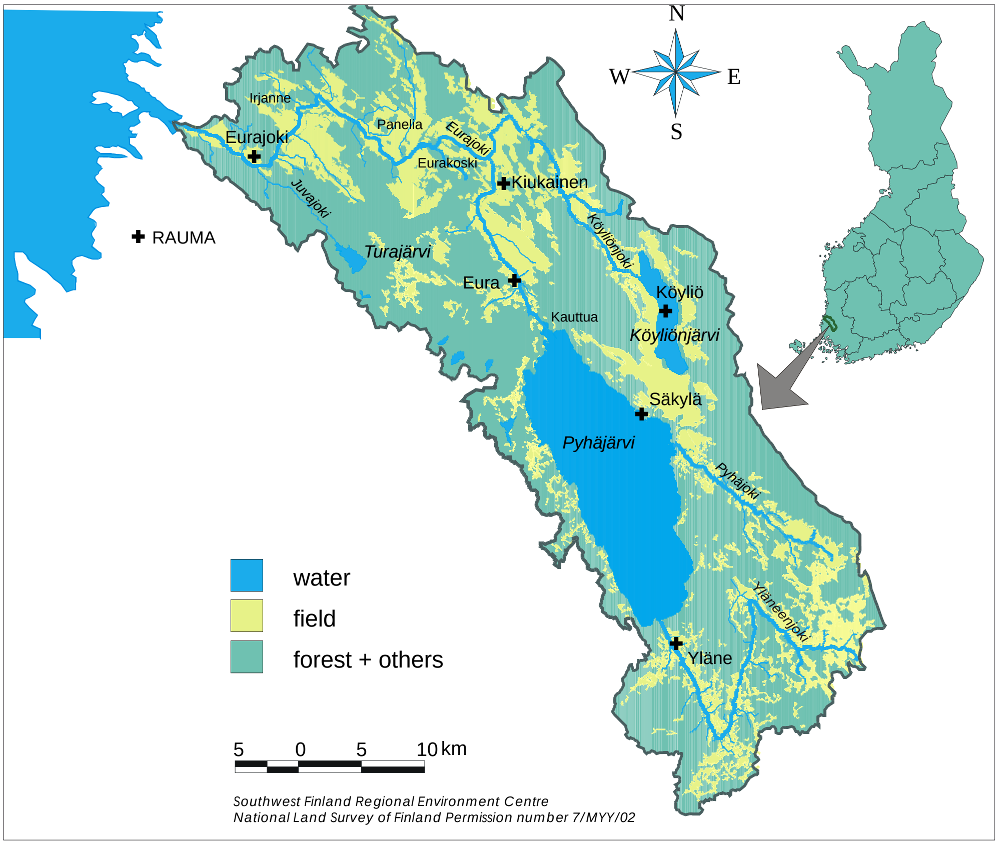

Fig 1. Säkylän Pyhäjärvi (154 km^2), together with its 306-km^2 catchment, serves as the pilot area of the project. The whole Eurajoki catchment (1336 km^2) covers also areas between Lake Pyhäjärvi and the sea.

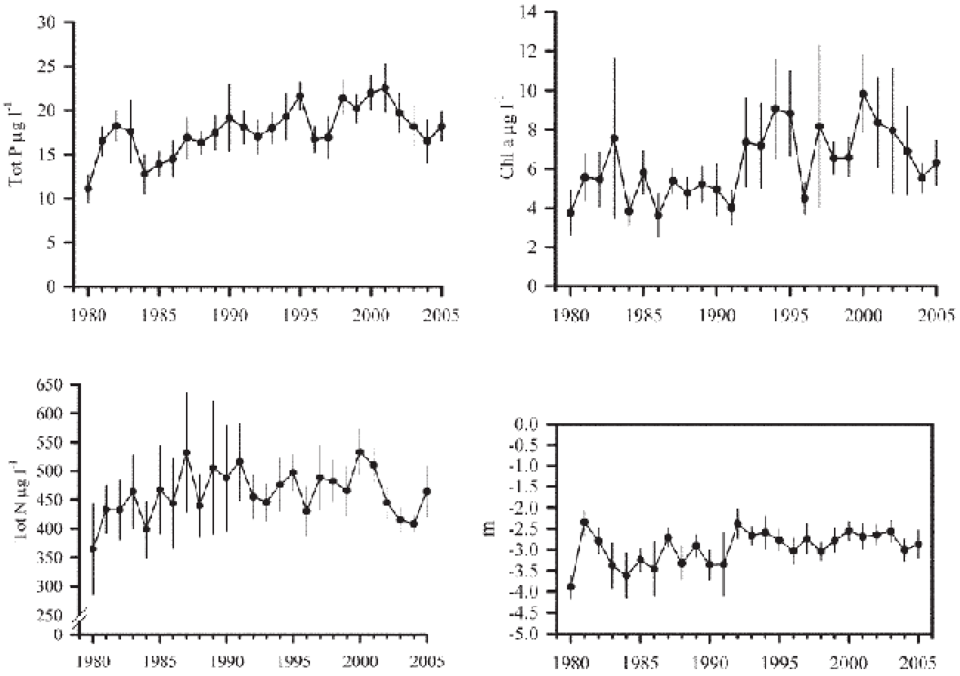

Fig. 2. Mean total P, total N and Chl-a concentrations and Secchi depth in Pyhäjärvi during the open water season (May-Oct) in 1980-2005. Vertical lines denote 95% confidence limits (Ventelä et al., 2007).

Internal processes contribute considerably to eutrophication of Pyhäjärvi (Ekholm et al., 1997). Total phosphorus concentrations in Pyhäjärvi rise in the late summer, although the external load is small at that time. It has been estimated (Lehtoranta and Gran, 2001) that 2180 kg P a^{-1} (12,5 % of the total phosphorus load) was released from the bottom sediments in 1997-1998. The annual nitrogen load from the sediment is estimated to be 106 000 kg N a^{-1}, which is 25 % of the total nitrogen load. Phosphorus release is due to both low oxygen concentration and to the resuspension of bottom sediments during high wind periods (Huttula 1994, Ekholm et al., 1997). Sarvala et al. (1998) have shown that interannual variations of the chlorophyll and P concentrations in Pyhäjärvi are associated with the changes in the total biomass of planktivorous fish. Strong stocks of planktivorous fish are accompanied by depressed zooplankton biomass, the practical disappearance of larger cladocerans, and high chlorophyll levels. One-third of the total variation in chlorophyll is attributed to changes in zooplankton biomass, and another third to changes in phosphorus concentrations.

The commercial fishery keeps vendace stock, the dominant planktivore in Pyhäjärvi, small and water quality effects moderate (Sarvala et al., 2000). That is why Pyhäjärvi has been biomanipulated by commercial fisheries. After the reduction of vendace stock in the beginning of 1990s, however, other fish stocks increased deteriorating the water quality. During the 1990s the fishing of smelt, roach, ruffe and small perch has been subsidized and this fishing has successfully reduced smelt and roach (Sarvala et al., 2000).

3 Measurements and catchment modelling

Intensive measurements were utilized in modeling, as well as different measuring campaigns at the river catchment were conducted. The integrated catchment models (SWAT and INCA) were applied at the Yläneenjoki catchment, utilizing also data from these recent measuring campaigns.

3.1

Measurement technology

3.1.1

Rivers and nutrient loading

Jari Koskiaho, Ahti Lepistö, Sirkka Tattari, Timo Huttula, Mikko Kiirikki and Teija Kirkkala

3.1.1.1

Methods

Automatic water quality stations at Yläneenjoki

Two measurement stations supplied by Luode Consulting Oy (LUODE in the later text) were established at Vanhakartano near the mouth of the river Yläneenjoki and at Peräsuonoja at the upper reaches of the Yläneenjoki river basin (Fig. 3). Both stations consisted of turbidity, conductivity, water temperature and water level sensors, as well as a datalogger collecting the data from the sensors. The dataloggers were equipped with transmitters using GSM mobile phone network in order to automatically transfer the data from the measurement stations into the receiving computers of LUODE.

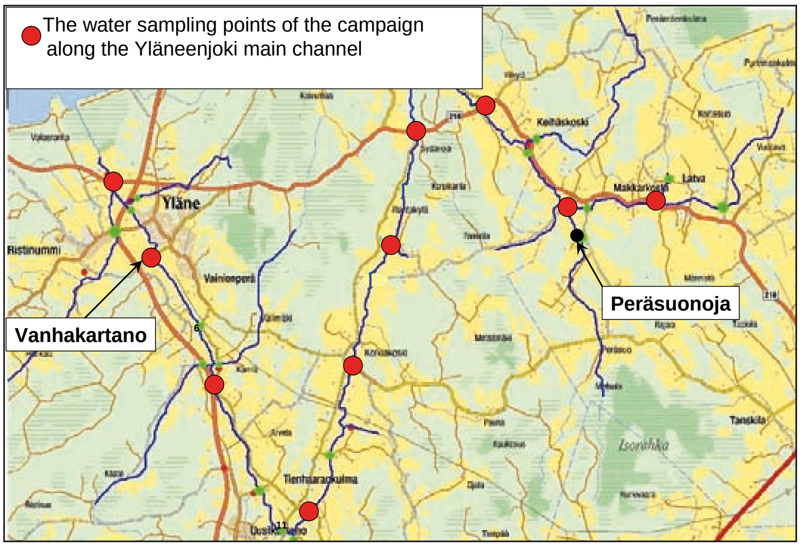

Fig. 3. Location of the measurement sites in the Yläneenjoki basin.

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Measurements were conducted on hourly basis in four seasons as follows:

- Spring 2006; from 17 March to 2 May (46 days)
- Autumn 2006; from 11 September to 3 November (53 days)
- Winter 2006-07; from 18 December to 30 January (43 days)
- Spring 2007; from 12 March to 27 April (46 days) at Peräsuonoja, from 27 March to 27 May (31 days) at Vanhakartano
- Autumn 2007; from 4 October to 20 November (47 days)

In addition, sensors for nitrate (NO_3N) and dissolved organic carbon (DOC) determination were employed at Vanhakartano during the spring and autumn (until 7 November, 34 days) 2007. In terms of turbidity, NO_3N and DOC, these 'raw' data were then compared with laboratory measured water samples (5-8 samples per season except for winter 2006-2007), and regression equations were derived and/or unaccurate values were removed to obtain corrected values. These corrected data sets were used in the following assessments.

Automatic sampling station at Vanhakartano

ISCO water sampler was installed to take samples from Yläneenjoki, just before the Vanhakartano overflow weir (Fig. 3). Sampler was programmed to take samples four times in a day (6-h intervals). Samples were combined to composite samples, representing that day. Sampling period was in autumn 2006 from 21 September to 22 October thus producing a 31-day dataset. The samples were analysed for turbidity (TBY), total suspended solids (TSS), total nitrogen (TN), nitrite-nitrogen (NO_2N), nitrate-nitrogen (NO_3N), ammonia-nitrogen (NH_4N), total phosphorus (TP) and dissolved reactive phosphorus (PO_4P) at the laboratory of Water Protection Association of Southwest-Finland (WPASF) in Turku. In addition to water sampling, a recording precipitation gauge, equipped with a GSM modem was assembled in the ISCO sampler.

Water sampling campaigns along the main channel of river Yläneenjoki

Water samples were taken manually on 26th March and 7th November 2007 from 10 points in the Yläneenjoki main channel. The sampling points covered whole channel from near the lake's mouth to the uppermost reaches of the river. The 10 samples were analysed for TBY, TSS, conductivity (CTY), TP, PO_4-P and DOC at the laboratory of WPASF. Locations of the measurement sites are shown in Fig. 3.

3.1.1.2

Automatic station data vs. monitoring data - Vanhakartano and Peräsuonoja

The basic statistics of the measurements are presented in Table 1.

Turbidity varied from almost zero to 730 NTU at Vanhakartano, and at Peräsuonoja from 12 to 690 NTU. The maximum value was recorded at Vanhakartano during the night between 9 and 10 January 2007 and at Peräsuonoja at noon on 10 November 2007. In spring 2007 turbidity was low at both stations. As seen in Fig. 4, turbidity variations tended to coincide with flow variations.

Table 1. Basic statistics of the data collected by the LUODE measurement stations from spring 2006 through autumn 2007 at both Vanhakartano and Peräsuonoja simultaneously.

	Vanhakartano			**Peräsuonoja**		
Variable	Min	Mean	Max	Min	Mean	Max
Turbidity (NTU)	2	33	731	12	44	690
Conductivity (µS/cm)	10	70	186	6	59	200
Water temperature (°C)	0	4.7	17.7	0	4.0	14.3
NO$_3$-N (mg l^{-1})	1.7	3.2	6.5	-	-	-
DOC (mg l^{-1})	18	23	32	-	-	-
Flow (m^3 s^{-1})	0	2.6	19.6	0	0.27	2.01
Runoff (l s^{-1}km^{-2})	0.03	11.2	84.3	0.64	13.4	100

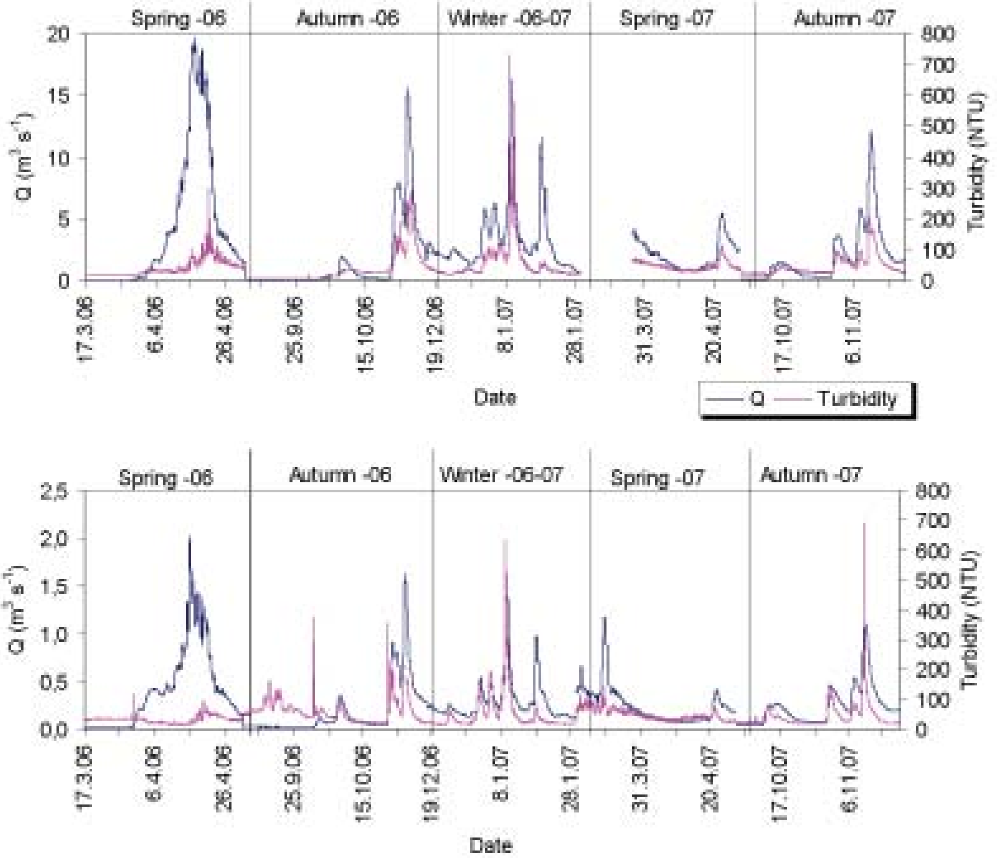

Fig. 4. Turbidity (NTU) and discharge (m^3 s^{-1}) at Vanhakartano (upper graph) and Peräsuonoja (lower graph) measurement stations.

Conductivity at Vanhakartano varied from 10 to 190 µS/cm and at Peräsuonoja from 6 to 200 µS/cm. The maximum values were recorded at Vanhakartano at the end of March 2006 and at Peräsuonoja at the end of October 2007. In autumn 2006 conductivity was in both stations clearly lower than during the other seasons (Fig. 5). As opposed to turbidity conductivity showed, particularly in spring 2006, reversed relationship with flow (Fig. 5). This was probably due to the dilution of ion-rich runoff waters by high amounts of snowmelt waters.

Water temperature varied from near zero to 17.7 ºC at Vanhakartano and to 14.3 ºC at Peräsuonoja. The maximum values were recorded in the afternoon of 14 September 2006. The diurnal variation in spring was much stronger at Peräsuonoja than at Vanhakartano (Fig. 6).

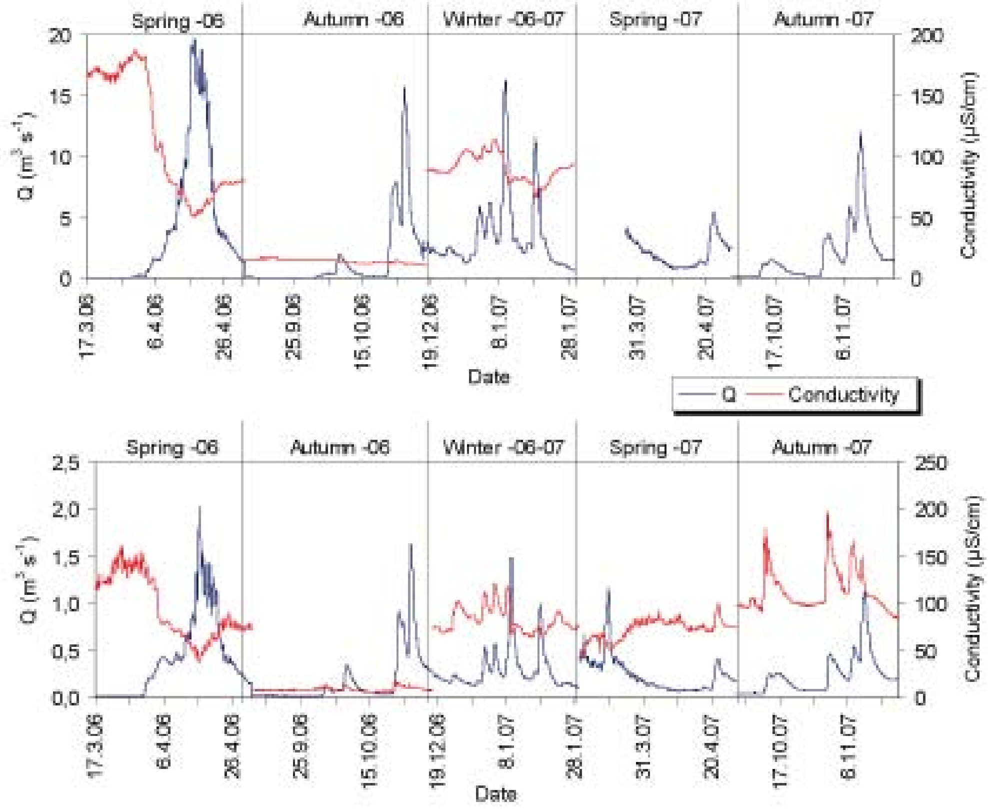

Fig. 5. Conductivity (µS/cm) and flow (m3 s-1) at Vanhakartano (upper graph) and Peräsuonoja (lower graph) measurement stations.

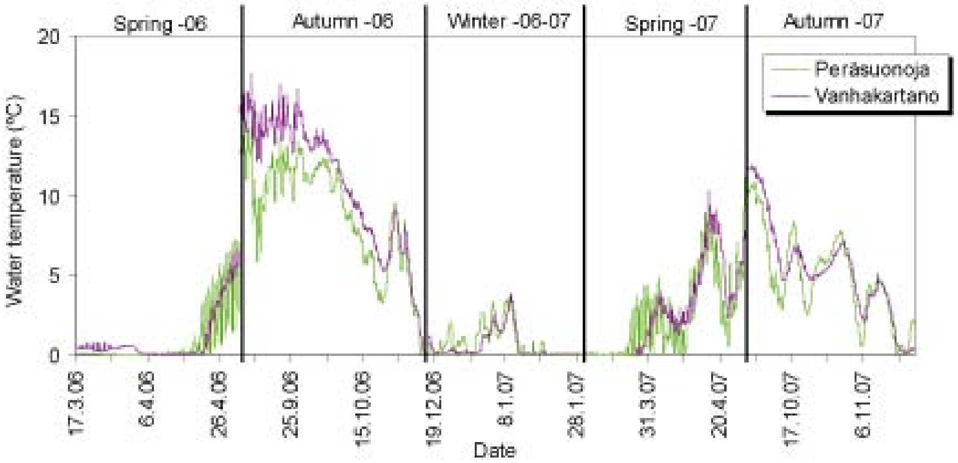

Fig. 6. Water temperature (°C) at Vanhakartano and Peräsuonoja measurement stations.

Water discharge was not directly measured in neither of the stations. Instead, water level sensors and known stage-discharge relationships were employed. The relationship at Vanhakartano was reported as a discharge value corresponding each cm of water height exceeding the weir. For this data, we fitted 3rd degree power equations. For improved accuracy of low and medium discharge determination, this was done in three categories of water height as follows (Eqs 1a,b and c):

$$Q = 0.00004 \cdot W^3 + 0.00069 \cdot W^2 + 0.00673 \cdot W, \text{ when W} \leq 19 \text{ cm} \quad (\text{n} = 19, \text{p} < 0.001) \tag{1a}$$

$$Q = 0.00008 \cdot W^3 - 0.00172 \cdot W^2 + 0.04689 \cdot W - 0.12, \text{ when } 19 \text{ cm} < \text{W} \leq 51 \text{ cm} \ (\text{n} = 33, \text{p} < 0.001) \tag{1b}$$

$$Q = 0.00018 \cdot W^3 - 0.02474 \cdot W^2 + 1.60453 \cdot W - 32.7, \text{ when W} > 51 \text{ cm} \ (\text{n} = 31, \text{p} < 0.001) \tag{1c}$$

where Q = discharge ($m^3 s^{-1}$) and W = water height (cm)

At Peräsuonoja there did not exist any weir with an accurate stage-discharge relationship. However, there were available some discharge measurements, conducted in 1990s by local authorities. For this data, we fitted a 2nd degree power equation (2).

$$Q = 0.000035 \cdot W^2 + 0.00104 \cdot W \qquad (\text{n} = 7, \text{p} < 0.001) \tag{2}$$

Regular discharge monitoring is carried out by the environmental administration at Vanhakartano. Hence, there we had comparison material for our own data. The discharge at Vanhakartano as determined by CatchLake measurements vs. the "official" discharge monitoring data is presented in Fig. 7. At low and medium flow, the results were in very good agreement with each other. Meanwhile the flood peaks as well as the downward limb of the spring 2006 hydrograph were somewhat underestimated when compared with the official data. According to our measurements mean discharge at Vanhakartano was 2.7 $m^3 s^{-1}$. The maximum (19.6 $m^3 s^{-1}$) was observed on 17 April 2006 at 7 p.m.

At Peräsuonoja, there was not any comparison data available like at Vanhakartano. The area of Peräsuonoja sub-catchment above the measurement station is 20.1 km^2 i.e. ca 10% of that above the Vanhakartano measurement station. Thus, discharge at Peräsuonoja should at least roughly follow the 10%-ratio of the discharge measured at Vanhakartano. As presented in Table 2, discharge at Peräsuonoja was, on average, somewhat higher than 10% of that at Vanhakartano. The deviation from the "10%-rule" was at highest during autumn 2006.

Table 2. Mean discharge at Vanhakartano and Peräsuonoja measurement stations.

Period	**Vanhakartano**	**Peräsuonoja**	**Ratio**
	$m^3 s^{-1}$		
Spring 2006	4.0	0.48	11.9%
Autumn 2006	1.5	0.23	15.8%
Winter 2006-07	3.3	0.37	11.0%
Spring 2007	2.1	0.21	10.1%
Autumn 2007	1.9	0.23	12.3%
Mean	**2.7**	**0.33**	**12.2%**

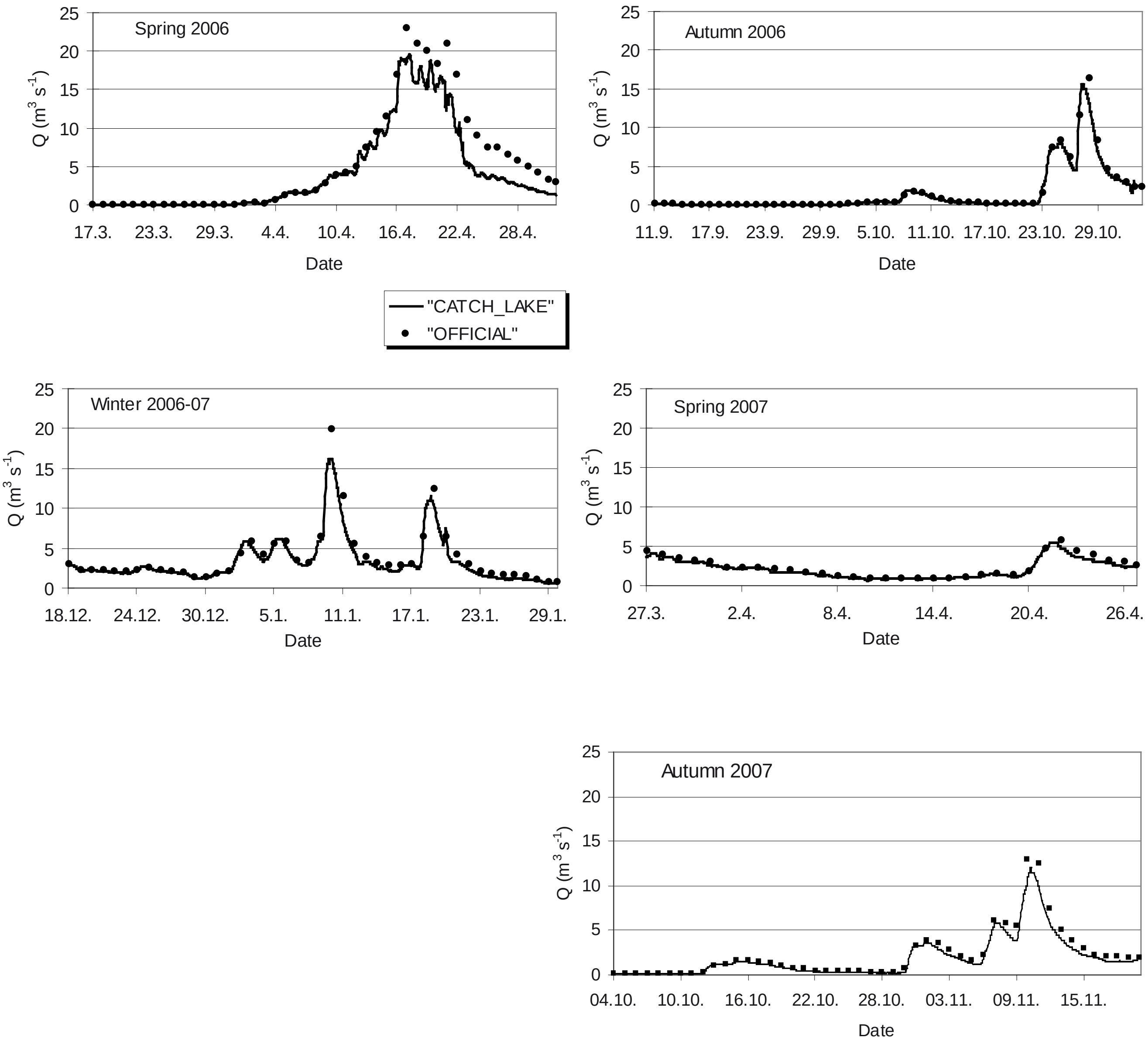

Fig. 7. Discharge at 5 seasons during 2006–2007 at the Vanhakartano measurement station as determined by water height observed by a sensor in the CatchLake project coupled with stage-discharge relationship (curve), compared with official monitoring data (dots).

As shown in Fig. 8, the hydrograph of Peräsuonoja mostly followed the form of that of Vanhakartano. In spring and autumn 2006, the discharge at Peräsuonoja was more than 10% of that measured at Vanhakartano at the beginning of the flow events as well as during the highest peaks.

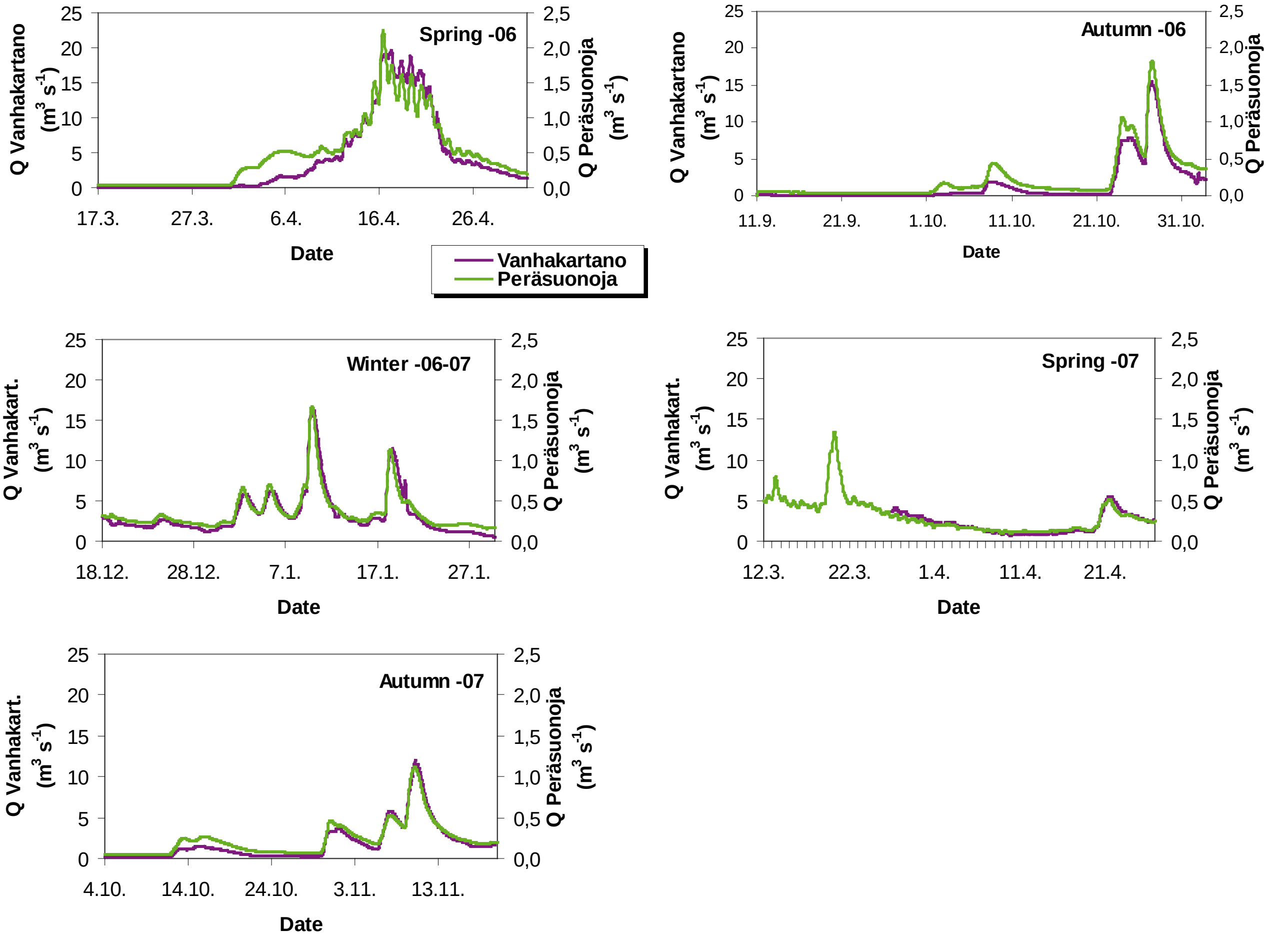

Fig. 8. Hydrographs of the Vanhakartano and Peräsuonoja measurement stations as determined by water heights and stage-discharge relationships.

Turbidity and NO_3-N

The results obtained by LUODE sensors were compared with the corresponding water sample data reported in the HERTTA database maintained by the environmental administration. In terms of turbidity (Fig. 9), the HERTTA values mostly fell into the ranges determined by the hourly LUODE data for the corresponding day. Only in spring 2006 at Vanhakartano and on 9 October 2006 at Peräsuonoja this was not the case.

NO_3N was measured with sensors during spring and autumn 2007. The checked data fitted well with the HERTTA results (Fig. 10).

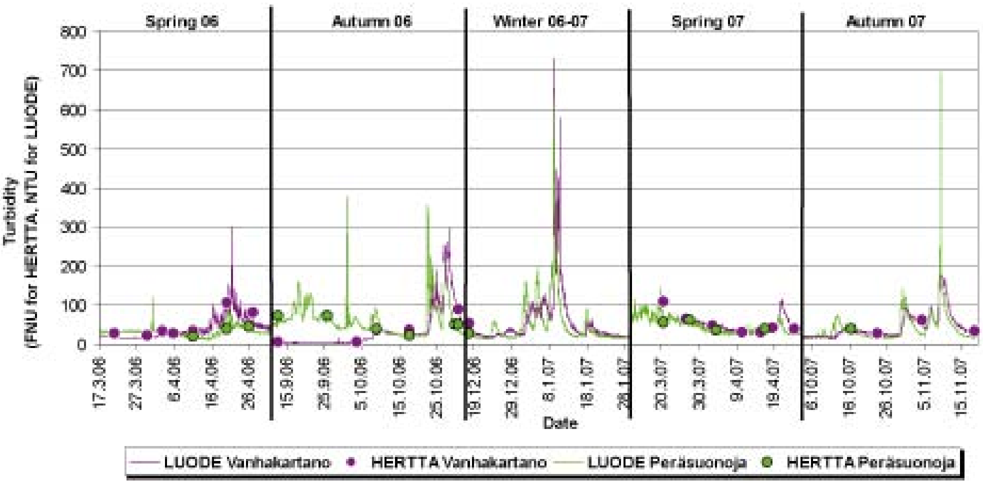

Fig. 9. Hourly corrected turbidity values by LUODE sensors and manual samples from HERTTA at Vanhakartano and Peräsuonoja measurement stations between spring 2006 and spring 2007.

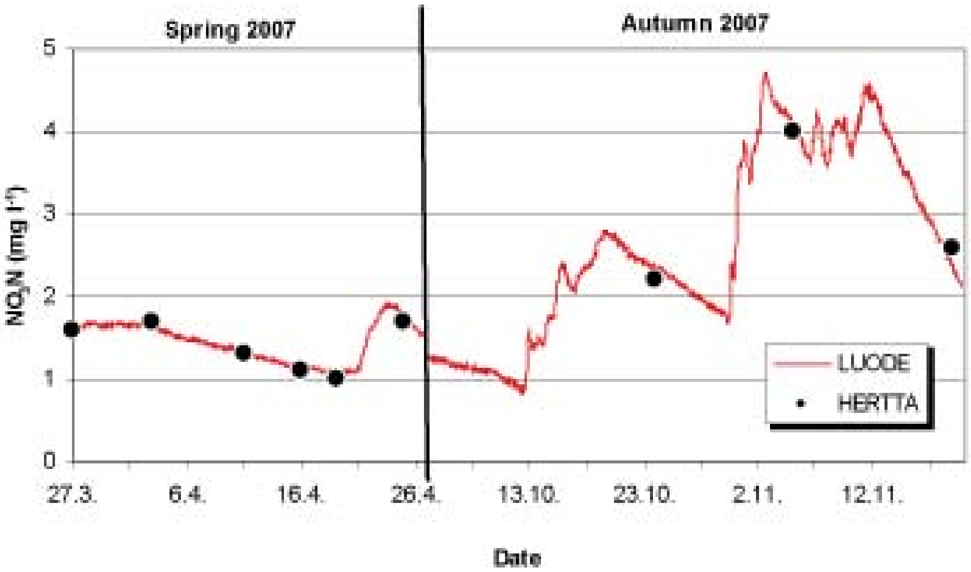

Fig. 10. Hourly corrected NO_3-N concentration by LUODE sensors at Vanhakartano measurement station in spring and autumn 2007. The seven dots denote manually sampled values obtained from the HERTTA database.

3.1.1.3

Automated water quality sampling at Vanhakartano

As shown in Fig. 11, the water quality parameters sampled by the ISCO sampler and analysed in laboratory in daily time step were in rather good agreement with those found in the HERTTA database. In nitrogen determination, however, some discrepancies were present.

3.1.1.4

Water sampling campaigns along the main channel of river Yläneenjoki

Previous assessments of the long-term monitoring data suggest that the concentrations of water quality constituents tend to increase along the river Yläneenjoki from its mouth to the upper reaches. Similar tendency was found in the results of the main channel campaigns on 26 March and 7 November 2007. Particularly TP and NO_3N concentrations increased pronouncedly both being twice higher in the uppermost than in the lowermost sampling location. Exceptional behaviour was shown by dissolved organic carbon (DOC) by remaining constant all the way and NH_4N during the autumn campaign by decreasing in the uppermost sampling point into the same level as in the near-lake sampling points (Fig. 12).

The measured concentrations were higher in autumn than in spring, particularly TN and NO_3-N more than twofold. An exception was made by NH_4-N that was higher in the spring than in the autumn. One obvious reason exists for the increased concentrations; the proportion of agricultural land is higher in the upper than in the lower reaches of the Yläneenjoki basin, together with higher point-type nutrient loads from farms.

3.1.1.5

Precipitation measurements by recording ISCO gauge

The rain gauge readings that were wirelessly transmitted into a laptop PC at our office were recorded in 10-minute intervals (Fig. 13, upper graph). The highest value (1 mm) was recorded on 29 October at two consecutive 10-min. periods at 2:50 and 3:00 p.m. However, since these two readings were divided for different hours, the highest summed-up hourly value in our data (2 mm) occurred on 1 October (Fig. 13, lower graph).

In total, 99 mm precipitation was recorded between 26 September and 30 October 2006 by the precipitation gauge assembled in the ISCO sampler. This was less than that (143 mm) observed during the corresponding period in a weather station of the Finnish Meteorological Institute (FMI) few kilometers away from Vanhakartano. As revealed by Fig. 14, particularly on 7th and 26th of October the difference was big, which could be due to a piece of crap gotten into the gauge. Nevertheless, according the FMI data, October 2006 was the wettest month experienced during the period 1991–2006. During this 16-year period, the second wettest October (130 mm) occurred in 1999 and the mean of the October precipitations was 70 mm.

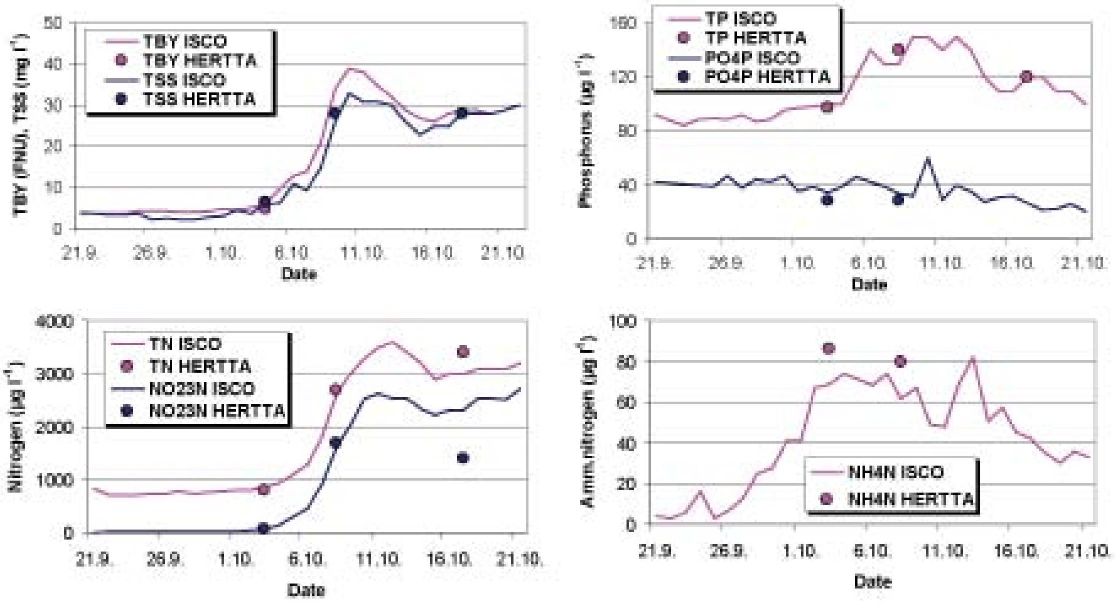

Fig. 11. Water quality as measured with the ISCO sampler (curves) compard with monitoring data (HERTTA database, dots) at the Vanhakartano measurement station during September-October 2006.

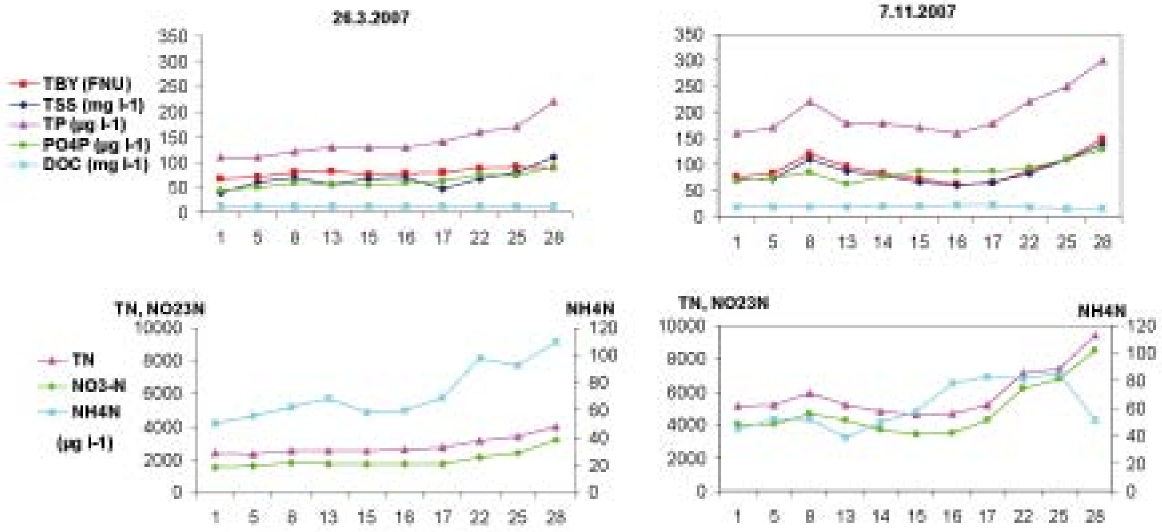

Fig. 12. Water quality as sampled within the main channel campaigns along the river Yläneenjoki on 26 March (the graphs on the left side), and on 7 November (the graphs on the right side) 2007. The x-axis values denote sampling points from the lake towards the upper reaches.

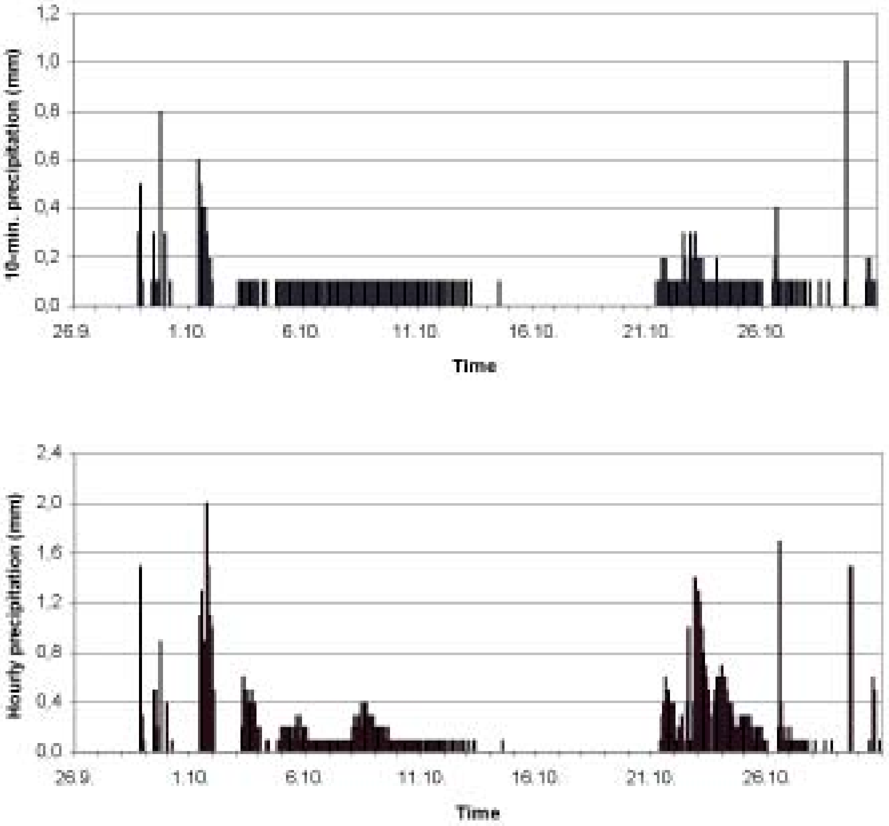

Fig. 13. Precipitation between 26 September and 30 October 2006 recorded at 10-minute intervals (upper graph) and the summed hourly precipitation (lower graph) at Vanhakartano by a precipitation gauge assembled in the ISCO sampler.

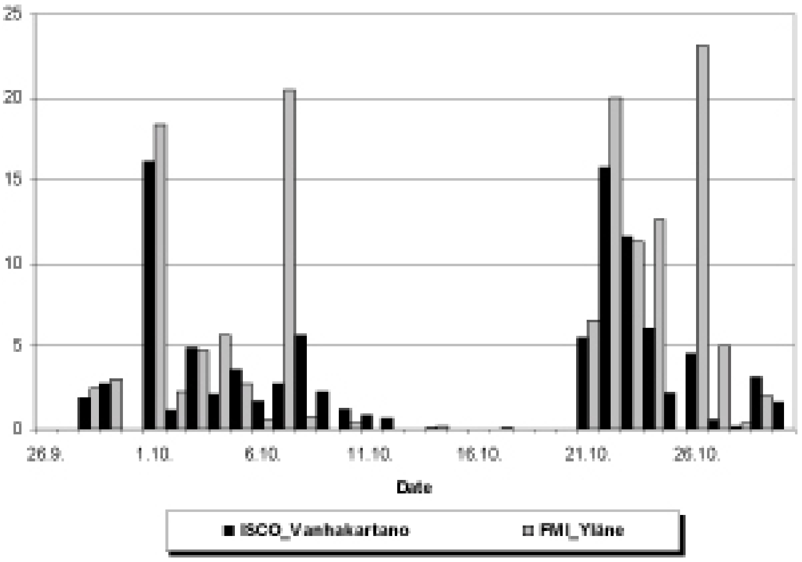

Fig. 14. Precipitation recorded at the Vanhakartano measurement station by a precipitation gauge assembled in the ISCO sampler of the CatchLake project, and at Yläne weather station of the Finnish Meteorological Institute (few kms away from Vanhakartano) between 26 September and 30 October 2006.

3.1.1.6

Measurement technology – rivers and suspended solids (SS) loading

Frequent, automatically recorded water quality data provides advantages over manually sampled data. As an example, SS loadings via the river Yläneenjoki into the lake Pyhäjärvi as calculated with concentrations determined by these two methods are compared in the following.

As shown in Fig. 15, turbidity (corrected data) and SS concentration at Vanhakartano correlate very highly with each other. Hence, it seems reasonable to use frequent, automatically recorded turbidity data for SS load calculations instead of, or at least supporting of sparsely collected water samples. To find out how much the SS loading estimates determined by automatically recorded turbidity and by manual water samples differ from each other, we calculated five monthly estimates (April and October 2006 and January, April and October 2007) with both data. With the automatically recorded data, we calculated hourly SS loadings and summed them up as monthly values. For manually sampled data, the monthly values were calculated by simply multiplying the monthly mean flow with the monthly mean SS concentration. In case of January 2007, when no samples were taken at Vanhakartano, we determined the mean concentration for that month as an average of the samples taken in the neighboring months, i.e by method routinely used for estimation of riverine loadings.

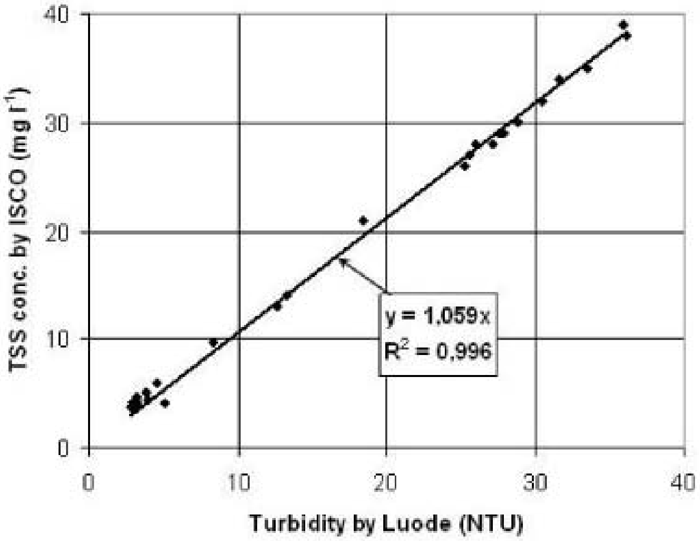

Fig 15. Daily suspended solids (SS) concentration (21.9 - 22.10. 2006) determined in the laboratory from the water samples taken by ISCO sampler vs. daily mean corrected turbidity, calculated from measured hourly data by LUODE sensors.

In total, 23 manual samples were taken at Vanhakartano during those months when automatic sensor measurements were conducted. In October 2006, sampling badly missed the most important flood periods (see Fig. 9) and, even worse, no samples were taken at all during an exceptionally wet midwinter in January 2007. In terms of SS loading estimates, this led to serious, 71% underestimation of "true" loading for these two periods (Table 3). Also in October 2007 both frequency and accuracy of sampling was poor. Meanwhile, more frequently and accurately sampled data in April 2006 yielded only 7% underestimation. In April 2007 the number of samples was equal to that one year earlier, but less accurate coinciding with the flow peak (Fig. 9) led to 35% underestimation.

Table 3. Monthly suspended solids (SS) loading (in tons) at Yläneenjoki, Vanhakartano, as calculated with two different source data. The automatically recorded data was based on the turbidity measurements. Error was calculated as deviation of the manually sampled result from the automatically measured result.

	Period				
Source data	April 2006	October 2006	January 2007	April 2007	October 2007
Manually sampled	1004	219	340	169	36
Automatically recorded	1078	749	1163	259	64
Error	7%	71%	71%	35%	43%

The measurements made in the CatchLake project in the Yläneenjoki area were successful. The collected data has proven its value and usability in many ways. Firstly, the frequent data has revealed cause-effect relationships between runoff and transport of soil and nutrients and thus improved understanding of the leaching/transport processes. Hence, the data has been welcome for parameterization of the transport models SWAT and INCA. Secondly, more accurate estimates of the loading from the Yläneenjoki basin into the Lake Pyhäjärvi were obtained and the deficiencies of the manually sampled data were clearly demonstrated. Particularly in mild winters when the periods of high runoff and transport may occur during any time between November and April instead of predictable spring-floods, automatic, continuous data recording is superior to traditional sampling schemes. However, as proven by the main channel water sampling campaigns, there are research issues where manual sampling is a better solution. At the present, automatic measurement techniques still have limited amount of variables available. Moreover, the accuracy of the sensor-produced data is greatly improved by calibration with simultaneous water samples taken in different flow situations.

3.1.2.

Automatic weather station at the Lake Pyhäjärvi

Niina Kotamäki

Säkylä weather station was installed in May 2006 on an islet in the Lake Pyhäjärvi about 1 km off Säkylä (Fig. 16). The weather station has instruments that measure e.g. air temperature, barometric pressure, humidity, wind speed, wind direction and precipitation. The results presented here are from period from 30 May to 1 September 2006. The measurements were made at 10-minute intervals. Due to malfunctioning of the devices, the results from 16 June to 16 July are missing, as well as the night time measures starting from 10 August.

Fig. 16. Location (red dot) of the weather station at the Lake Pyhäjärvi.

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Imputation of wind data

Wind data are very important as input for lake hydrodynamic and water quality modeling. As so many wind observations were missing, the data was imputed with linear regression using the data from Jokioinen weather observatory of FMI 65 km southeast of Säkylä. First the cross and main axis wind components were calculated as follows:

$$W\_main = W*\sin(\theta) \tag{3}$$

$$W\_cross=W*\cos(\theta) \text{ and } \theta = 90 - \alpha + 315 \ / \ 180*\pi \tag{4}$$

where W is wind speed (m s^{-1}) and α is wind direction (rad).

Linear regression equations to main and cross axis wind at Säkylä weather station were:

$$W\_main = 0.54 + 0.58*WN - 0.70*W_E \qquad (5)$$
$$W\_cross = -0.19 + 0.78*WN + 0.31*W_E \qquad (6)$$

where WN is north wind component and WE is east wind component at Jokioinen observatory.

Both models fit reasonably well to the data: all the coefficients of the models are significant and the adjusted R^2 values (the square of the correlation coefficient) are rather high. The adjusted R^2 value for model (6) is 0.61. Thus, over 60 % of the variation in the cross axis wind of Säkylä weather station can be explained by the two wind components from Jokioinen data. The R^2 value for model (5) is 0.56. The more detailed results are shown in tables 4 and 5.

Table 4. Results of the main axis wind (5) regression model.

	Coefficients	**Standard Error**	**t Stat**	**P-value**
Intercept	0.536	0.121	4.442	0.000
Wn	0.576	0.044	12.992	0.000
We	-0.704	0.051	-13.885	0.000
Adjusted R^2	0.56			
Residual standard error	1.98			
N	293			

Table 5. Results of the cross axis wind (6) regression model

	Coefficients	**Standard Error**	**t Stat**	**P-value**
Intercept	-0.187	0.106	-1.765	0.079
Wn	0.784	0.039	20.171	0.000
We	0.308	0.044	6.939	0.000
Adjusted R^2	0.61			
Residual standard error	1.73			
N	293			

These equations are very useful for predicting local wind components from Jokioinen observatory data, which are always available. Imputed data (three hour means) are shown in Fig. 17.

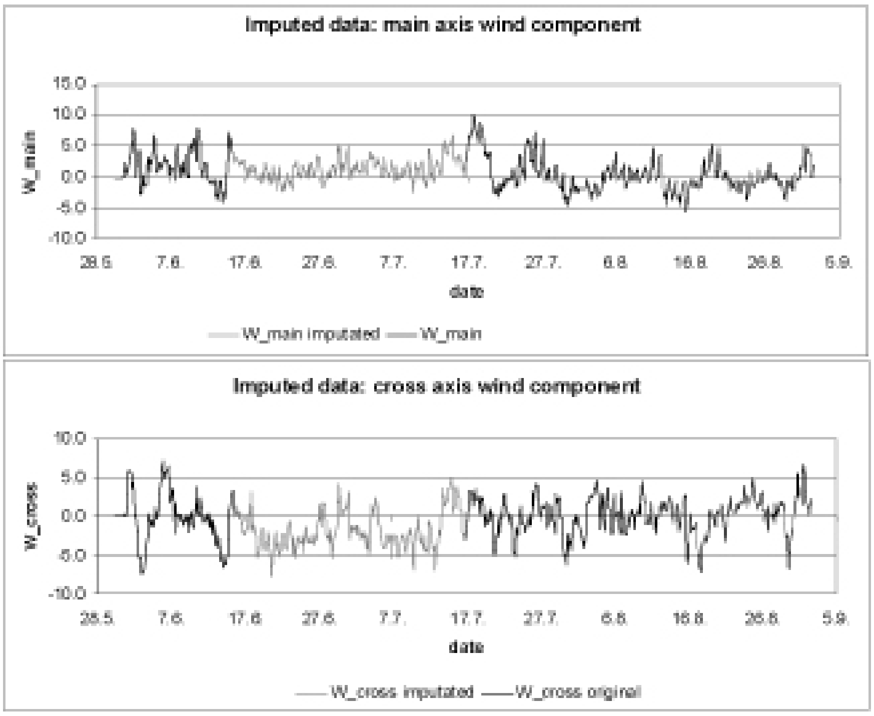


Fig.17. Main axis (upper graph) and cross axis (lower graph) wind components (three hour means) imputed with linear regression.

3.1.3.

Production of phenological information for nutrient modelling from remote sensing data

Markus Törmä and Pekka Härmä

Methods were developed for production of phenological information from remote-sensed data (MODIS). Particularly of interest are the start date and length of growing period, and growth curve based on leaf area index (LAI). Preliminary experiments have been carried out in order to use phenological information for tuning the paramaters of INCA-N model (Törmä et al, 2007).

Processing of remote sensing data

SYKE has operational processing system for satellite images (Anttila et al., 2005). MODIS images (1-2 daily) are received from Finnish Meteorological Institute, Sodankylä Receiving Station. HDFEOS extracts single files from MODIS hdf-file and does radiometric, atmospheric and geometric correction (Andersson, 2005). Radiometric correction to TOA reflectance was done using the calibration coefficients and solar zenith angles. The SMAC4 model (Rahman and Dedieu, 1994) was used for carrying out atmospheric corrections. The result data was normalised to a nadir view with sun zenith angle of 45°, and geometric correction was done using latitude and longitude files (Andersson, 2005). Latitude and longitude arrays contain the geodetic latitudes and longitudes for the center of the corresponding 1km Earth view frames. Clouds were detected using differences in brightness temperatures measured in different

MODIS-bands. Resulting cloud mask was visually checked and manually corrected if needed. Method seems to work rather well during summer but early spring and late autumns cause difficulties, because land temperature can be on the same level as cloud temperature.

Time-series describing the phenological development was formed by computing vegetation index-images from daily MODIS-images from early April to mid-October 2006. Used vegetation index was Normalized Difference Vegetation Index (NDVI). Cloudy areas were masked out from MODIS-images. Then weekly mosaics were constructed by selecting the maximum NDVI-value for a pixel from all daily NDVI-values within that week.

Finally, NDVI-values were transformed to Proportion of Vegetation Cover (PVC) using locally developed statistical quadratic model presented in Fig. 18. Model is used to estimate PVC if NDVI is larger than 0.2, otherwise PVC is 0. Ground measurements for model development were made by taking digital photos of agricultural fields during growing season, estimating the PVC for each field and PVC was estimated for each MODIS pixel as areally weighted average of PVCs of individual fields. Photos were taken at period from early May to mid-September, 12 times at Viikki and 7 times at Haltiala in Helsinki as well as 8 times at Yläneenjoki catchment, at Oripää, SW Finland. The estimation of PVC from digital photo is made by classifying the photo to vegetated or non-vegetated pixels and then computing the proportion of vegetated pixels. Pixel is classified as vegetated if: 1) green channel value is larger than others, 2) blue channel is larger than red channel, and 3) pixel is bright enough. Agricultural fields were delineated using Finnish national CORINE land cover database (25 meter raster). Since the spatial resolution of MODIS data is 250 meters, phenological time series were calculated only for large, homogenous agricultural areas for level-2 drainage basins.

Figure 19 presents an example of phenological time-series of agricultural areas in three different parts of Finland. Oripää is situated in South-West, Joensuu in Eastern and Savukoski in Northern Finland. Horizontal axis presents time in weeks and vertical axis proportion of vegetation cover (PVC).

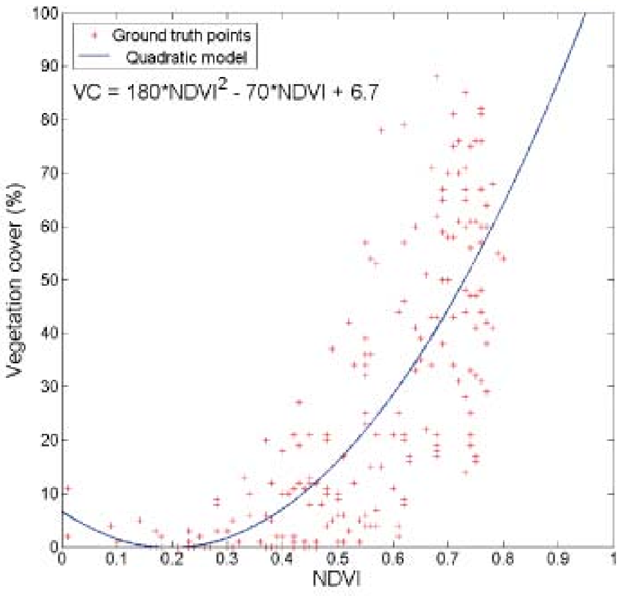


Fig. 18. Statistical model used to estimate the proportion of vegetation cover (PVC).

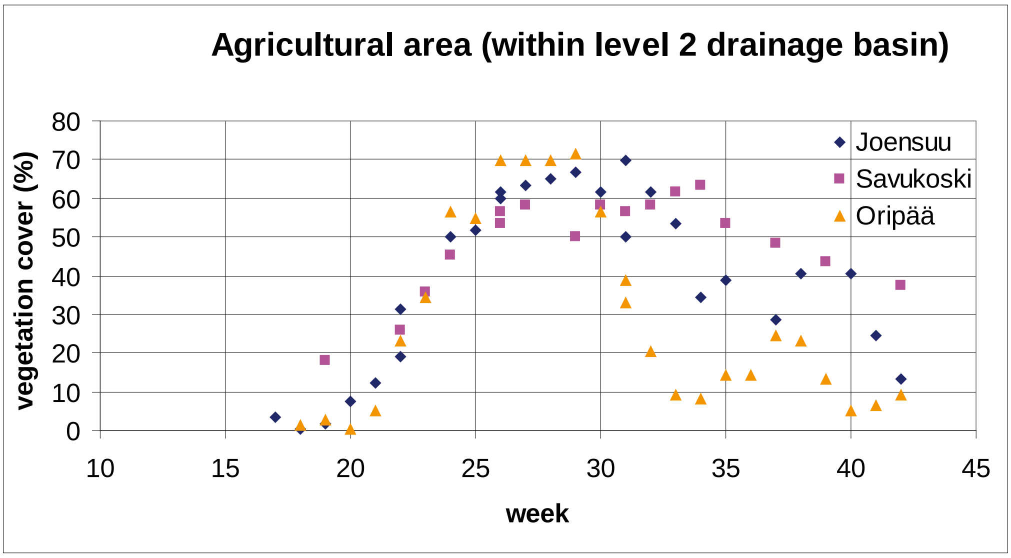


Fig. 19. An example of phenological time-series of agricultural areas in three different parts of Finland Horizontal axis presents time in weeks and vertical axis PVC.

Validation, remote sensing data

Figs. 20 and 21 present the relationship between PVC estimated on the ground (blue dots) and estimated from NDVI-mosaicks (red dots) for Viikki and Oripää agricultural areas. Generally, ground and satellite estimates follow each other rather well, but ground estimates are smaller than satellite estimates. It is likely that ground estimates of PVC are too small because some parts of plants are in shadow in digital photos and therefore are not taken into account, and during senescence ground estimate of PVC decreases much faster than satellite estimate.

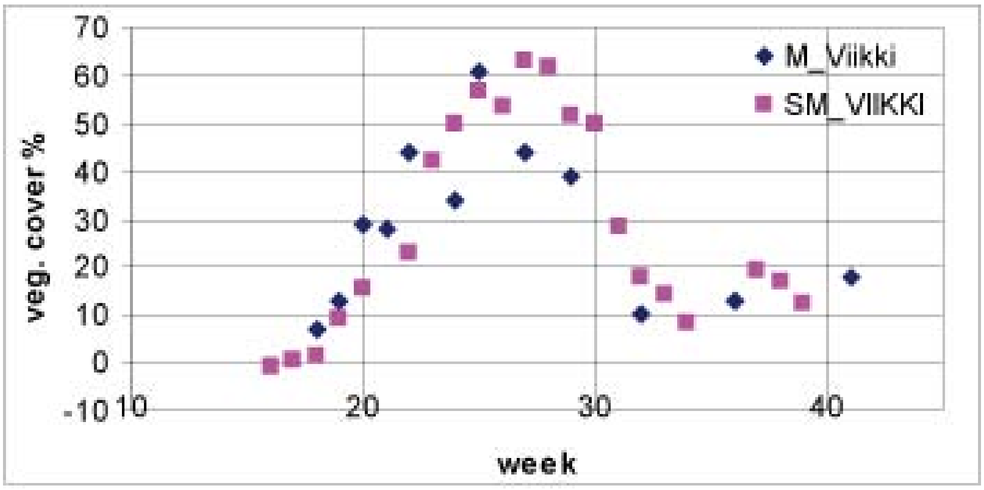


Fig. 20. The relationship between PVC estimated on the ground (blue dots) and estimated from NDVI-mosaics (red dots) at Viikki agricultural area.

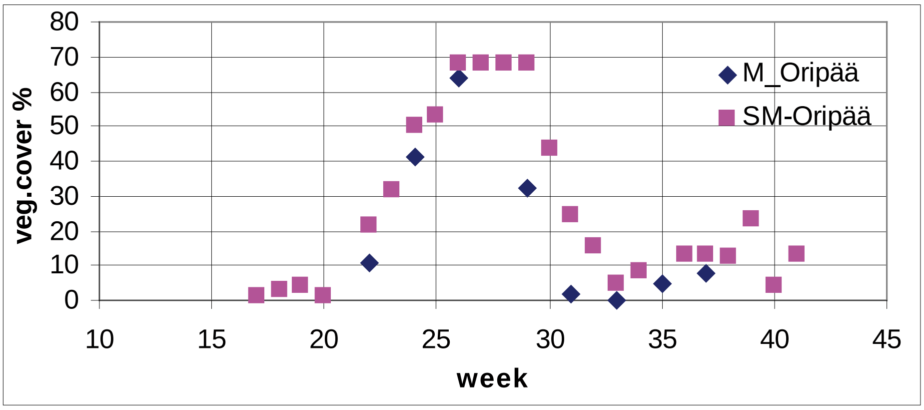


Fig. 21. The relationship between PVC estimated on the ground (blue dots) and estimated from NDVI-mosaics (red dots) at Oripää agricultural area.

The phenological time series has been used in nutrient leaching model in relatively simple way by changing the start date and length of growing period. In more advanced approach the growth curve could be calibrated against observed time series. Because growth curve is based on LAI in several nutrient leaching models, deriving LAI from vegetation index values may improve the applicability of the phenological time series in catchment modelling. Another useful variable is Fraction of Photosynthetically Absorbed Radiation (FPAR) which is used in wide variety of environmental models as input. Drawback is that some other vegetation index should be used because NDVI loses sensitivity to LAI quite fast as LAI increases.

The main problem of time-series is that it is not necessarily possible to determine vegetation index value for some place due to excessive cloudiness. For example, during year 2006 there were holes in weekly maximum vegetation index mosaic, and during year 2007 this problem was even worse. Therefore, a method is needed to fill these holes in the mosaics. Another way to develop phenological time-series is to automatically extract important features, such as start and end of growing season, as well as the season's peak. If that kind of information is combined with information about snow cover, lengths of bare-ground times in spring and autumn - when nutrient loading is highest - could be estimated using satellite images.

3.2

Catchment modelling

Tools are needed to assess loading from agricultural sources to water bodies as well as the effect of alternative management options in varying environmental conditions. For this demand, mathematical models like SWAT (Arnold et al., 1998) and INCA-N (Whitehead et al. 1998; Wade et al., 2002) offer an attractive option. In addition to loading estimates, SWAT also offers a possibility to include various agricultural management practices like fertilization, tillage practices, choice of cultivated plants, buffer strips, sedimentation ponds and constructed wetlands (CWs) in the modeling set-up. INCA-N can simulate effects of fertilization, choice of cultivated plants, and other land use changes on nitrogen leaching. Effects of tillage practices can be taken into account by calibrating soil processes, e.g. mineralization and nitrification in catchment soils.

Parameterization of SWAT model was developed here (chapter 3.2.1) particularly in terms of flow dynamics and sediment fluxes, together with a sensitivity analysis. Moreover, modeling strategies with dominant land uses and soil types vs. land uses and soil types exceeding certain thresholds within subcatchments were compared. In the "thresholds-exploiting SWAT project" agricultural land was divided into 5 classes whereas the "competing" project only had 2 classes. These SWAT modeling exercises were performed for a 2nd order catchment (Yläneenjoki, 233 km^2). The Yläneenjoki catchment has been intensively monitored during more than 10 years. Hence, there is abundant background information available for both parameter setup and calibration. Moreover, information on local agricultural practices and the implemented and planned protective measures are readily available, thanks to aware farmers and active authorities. Thus it was possible to make some initial management scenarios and assess their effects on loading with SWAT. In addition, the usability of continuously monitored turbidity data is discussed.

Application of the INCA-N model (chapter 3.2.2) aimed at developing a model set-up that can be further used for estimating inorganic nitrogen load to Lake Pyhäjärvi in changing climatic conditions, together with changing agricultural practices. Special emphasis was given to evaluate the usefulness of the new continuous sensor measurements of nitrate nitrogen for model calibration.

3.2.1

The SWAT model

Sirkka Tattari, Jari Koskiaho and Ilona Bärlund

The SWAT model is a continuous time model that operates on a daily time step at catchment scale. It can be used to simulate water and nutrient cycles in agriculturally dominated landscapes. The catchment is generally partitioned into a number of subbasins where the smallest unit of discretization is a unique combination of soil and land use overlay referred to as a hydrologic response unit (HRU). It is a process based model including also empirical relationships. The model has been widely used but also further developed in Europe (e.g. Eckhardt et al. 2002, Krysanova et al. 1999, van Griensven et al. 2002). SWAT was chosen for the CatchLake project for three main reasons: its ability to simulate suspended sediment –as well as nutrient loading on catchment scale, its European wide use, and its potential to include agricultural management actions. SWAT has already been found to have potential with respect to the future requirements set by WFD in Scotland (Dilks et al. 2003) and in Finland (Bärlund et al. 2007).

3.2.1.1

Background data

For the SWAT simulations, the available data on elevation, land use and soil types had to be aggregated. The vertical resolution (5 m) of the digital elevation model (DEM) proved to inadequate for a successful set-up for the Yläneenjoki catchment. Hence, we used a modified DEM where the main channels of the catchment were somewhat deepened to emphasize the actual routes of water.

The standard land use GIS data available (CORINE 2000) recognizes three types of agricultural land; (i) actively cultivated fields, (ii) grasslands and pasture and (iii) fragmented agricultural land. Here, in the case of Yläneenjoki basin, the agricultural areas were based on the Farm statistics data which was further generalized into 5 classes i.e. autumn cereals, spring cereals, root crops, grasses and gardens, (Fig. 22) and the rest was classified as forested areas. Four soil types (clay, moraine, silt and peat) were separated (Table 6).

Table 6. Distribution of land use and soil type in the Yläneenjoki area.

Land use	Percentage of the catchment area	Soil type	Percentage of the catchment area
Autumn cereals	2.2	Silt	2
Spring cereals	18.2	Peat	14
Root crops	1	Clay	42
Grasslands	5.6	Moraine	42
Gardens	0.6		
Forest	72.4		

3.2.1.2

The modelling approach

The wider-scope modelling strategy in the Pyhäjärvi area is based on linking the Yläneenjoki catchment – from which most of the loading comes into the lake – with Lake Pyhäjärvi (Bärlund et al. 2007). The task of the SWAT model is hence to assess the possibility to reach this target using a variety of management options such as buffer strips, artificial wetlands, as well as changes in fertilization or tillage practices.

The SWAT project for the Yläneenjoki catchment resulted in 28 subcatchments. In the project, threshold values (soil: 10%, land use: 1%) were used to distinguish different land use and soil types within each subcatchment. For example, if more than 1% of a subcatchment was under grass and these areas were divided on clay and silt soils both soil types representing more than 10% of the subcatchment area, this would make the HRUs "grass-clay" and "grass-silt" for this subcatchment. This approach resulted in 257 HRUs in the project .

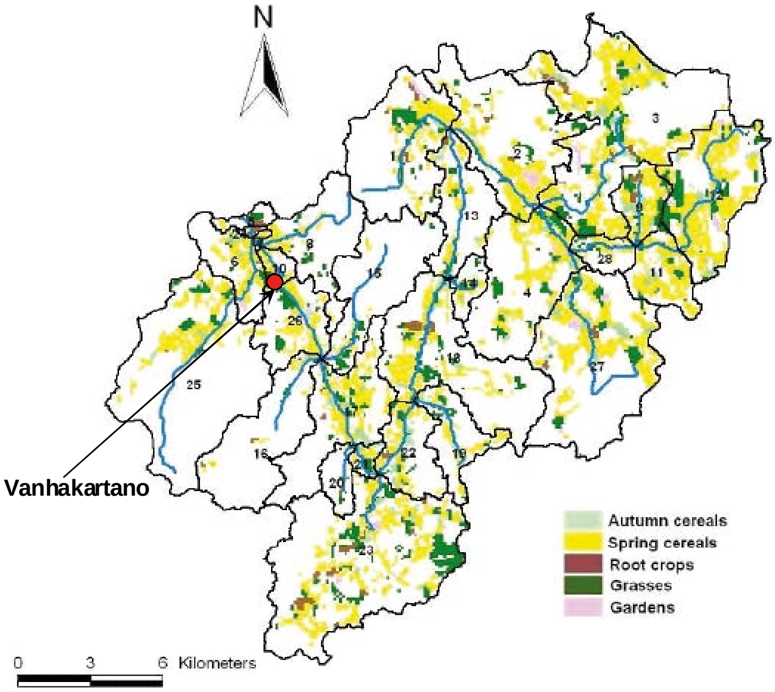


Fig. 22. Division of the Yläneenjoki subcatchments and agricultural land use data situation in the year 2004. The white areas mostly represent forest. Data from Information Centre of Ministry of Agriculture and Forestry (Generalized field plot data).

3.2.1.3
Results and discussion

Sensitivity analysis

Sensitivity analysis can be seen as an instrument to analyse the impact of model input on model output as well as for model calibration, validation and reduction of uncertainty. The sensitivity analysis method implemented in SWAT is called Latin Hypercube One-factor-At-a-Time (LH-OAT) (Morris 1991). Sensitivity is expressed by a dimensionless index I, which is calculated as the ratio between the relative change in model output and the relative change of a parameter.

In this study, the sensitivity analysis (Appendix 1) was performed for thirty-three parameters selected for the analysis. The range for each parameter was first estimated based on earlier SWAT sensitivity studies and expert knowledge. We ended up decreasing the default ranges in order make them more realistic for the conditions in the Yläneenjoki basin and to quicken the sensitivity analysis runs.

Model calibration

The years 1995–1999 were chosen as the calibration period. The years differed hydrologically quite much from each other (Fig. 23). The year 1999, for example, represents a typical runoff pattern with dry summer and distinct spring and autumn peaks. Meanwhile, in 1998 runoff peaks occurred throughout the year.

We utilized the autocalibration tool available in the 2005 version of SWAT (Neitsch et al. 2005). As suggested by the sensitivity analysis, some parameters (GWQMN, TIMP, ESCO, SOL_AWC, CN2 (agric. land), SMTMP, SFTMP and SURLAG) were chosen for autocalibration runs made for daily discharge with observed data. The observed data was from the Vanhakartano measurement station, and hence the results for the outlet of sub-catchment 26 were examined (Fig. 22). Autocalibration results are presented in Appendix1 (Table App1-2).

Figure 24 shows the improvement obtained by the calibration process in the fit between simulated and observed daily flow. Particularly in spring and autumn the amendment was clear: not only the simulated peaks were much closer to the observed, but also the autumnal low flow period appeared much more realistic. In mid-winter and summer the results remained, even after calibration, rather weak. As for annual average flow, the simulated values were generally lower than the measured. For nutrients and erosion, the compatibility between simulations and measured loads were examined only with annual values (Fig. 25).

In spite of the visual improvements in flow dynamics achieved by the autocalibration process, the fit between the simulated and observed daily flow remained poor when it was assessed by Nash-Sutcliffe (NS) coefficients. Hence, we calculated the NS coefficients for monthly average flows. Then, the best NS value for the project was 0.7.

In terms of surface runoff and sediment loading from differently cultivated fields, the SWAT output (Fig. 26) was in line with the results reported in Finnish studies (e.g. Puustinen et al. 2005). Also the lower runoff and sediment loss, as well as the higher evapotranspiration, from forest than from agricultural land were realistic. The high spatial variation of sediment loss in the class ”Spring cereals” indicates the high erosion risk from highly sloped fields with bare agricultural soil outside of the growing season. Moreover, the use of data from two precipitation gauges and differences in soil type may have increased the variation.

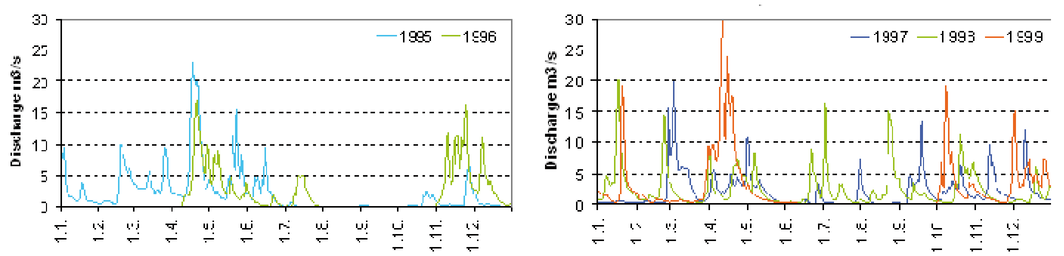


Fig. 23. Discharge from the Yläneenjoki catchment at the Vanhakartano measurement station during 1995–1999.

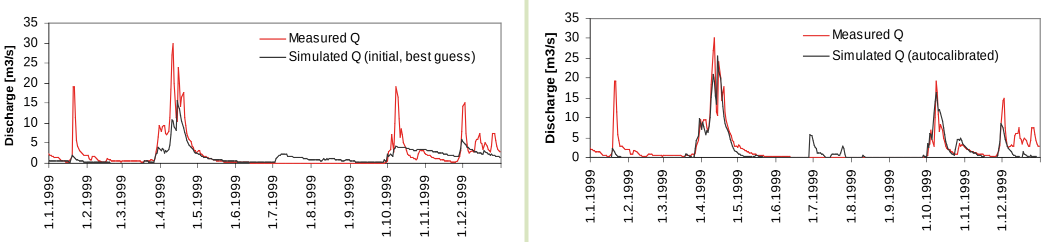


Fig. 24. Measured and modeled discharge at the Vanhakartano measurement station in 1999. The left graph with initial parameters and the right graph with autocalibrated parameters.

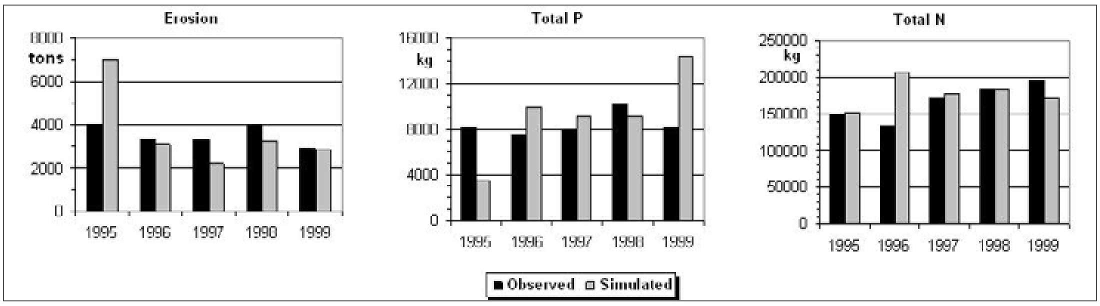


Fig. 25. Measured (black bars) and modeled (grey bars) annual erosion, total phosphorus and total nitrogen loads at Vanhakartano during 1995-1999.

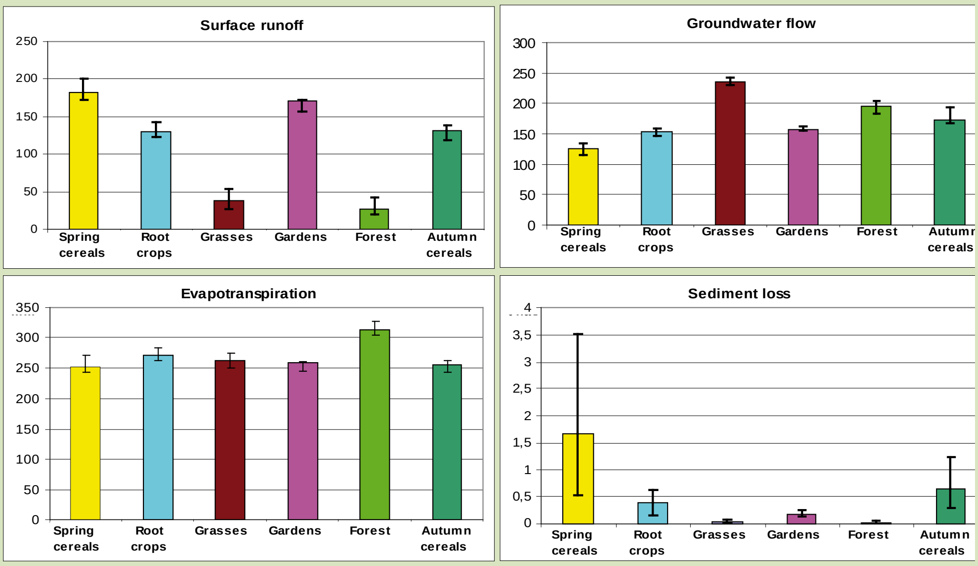


Fig. 26. Surface runoff, groundwater flow, evapotranspiration and sediment loss (5-year means) in the Yläneenjoki basin according to the SWAT project "threshold". The error bars denote spatial variation in HRUs of the project.

3.2.1.4

Management practice scenarios

When a satisfying flow dynamics was achieved at the yearly basis and the simulated nutrient and sediment losses were at the acceptable level, four different cultivation practice scenarios were formulated and thereafter the model was run separately for each scenario and the loads were compared with the ones made by 0-scenario (Table 7).

Buffer zones and wetlands

According to the plan made by SW Finland Regional Environment Centre, the need for buffer zones along the Yläneenjoki basin is 53 km. If the average width of the buffer zone is appr. 25 meters, the field area needed for buffer zones would be 133 ha. Currently, the buffer zone area is 70 ha, of which 53 ha is located in vulnerable areas. Hence the additional need would be around 80 ha. The SWAT 0-scenario represented a situation with no buffer zones. In scenario 1 the present situation was simulated with 21 meter width buffer zones along the main channel. In scenario 2 buffer zones were also placed along the tributaries. According to Bärlund et al. (2007), SWAT has a tendency to overestimate the buffer zone efficiency and therefore the width of buffer zones was decreased to get a better fit of the efficiency based on earlier field experiments (e.g. Uusi-Kämppä, 2005). Scenario 1 decreased total nitrogen load by 9 % and total phosphorus load by 19 % at the river outlet. For scenario 2 the corresponding decreases were 17 % (for nitrogen) and 36 % for phosphorus.

We did not make scenarios for wetlands due to the inadequencies in input data. However, based on some theoretical model runs and earlier know-how (Koskiaho, 2003) we concluded that a considerable decrease in nutrient load could be only achieved when the wetland area is of the same order than the area for buffer zones, e.g. more than 150 ha.

Ploughing date and technique & fertilization

The local farmers of Yläneenjoki advised us to make a simulation where the date for ploughing was delayed up to the 10. December. However, this action had only a minor effect on nitrogen load, decrease being around 2 %, while for phosphorus the result was slightly better, namely 8 %. Much more efficient action was to replace the normal ploughing by cultivation. Then the reduction in phosphorus load was 22 % but also in this case the effect on nitrogen was very small, 4 %.

The fertilization rates used in all three scenarios (average and maximum mineral fertilization) area presented in Table 8. The maximum fertilization rates (scenario 1) increased nitrogen load by 12 % and phosphorus load by 17%. When manure was applied for all grass covered fields, the phosphorus load increased considerably (by 25 %; chicken manure and by 27%; pig manure). Here again, the effect on nitrogen load was much lower, only around 5%.

Table 7. The different scenarios used in the Yläneenjoki SWAT-application.

	Action		
	Buffer zones	Date for autumn ploughing	Fertilization
0-scenario	No buffer zones	Ploughing 1. September (spring cereals), 20. October (beets)	Average fertilization levels used in Yläneenjoki region (Table 8)
Scenario 1	21 m wide buffer zones along the main channel for all sub basins and for spring cereals and beets	Ploughing for both spring cereals and beets on 10. December = delayed ploughing datum	Maximum fertilization levels used in Yläneenjoki region (Table 8)
Scenario 2	Buffer zones according to scenario 1 but additional 15 m wide buffer zones for all the other sub basins for spring cereals and beets	Dates for ploughing same as in scenario 0 but normal ploughing replaced by cultivation	Chicken manure 5000kg/ha for grass crops, other crops according to scenario 0. Pig manure 10000kg/ha for grass crops, Other crops according to scenario 0.

Table 8. The average and maximum fertilization rates used during 1998 in Yläneenjoki region based on MYTVAS report (Grönroos et al., 1998).

Crop	Average fert. rate N/P	Maximum fert. rate N/P
	kg/ha/year	
Autumn cereals	105/24	130/30
Spring cereals	105/24	130/30
Root crops	66/41	110/67
Grasses	168/27	238/38
Gardens	154/44	240/108

3.2.1.5

SWAT and automatic turbidity data

In this project, one aim was to utilize the continuous turbidity data to point out the weaknesses in our present modelling system. Due to the fact that we did not calibrate the model on daily basis, it was impending that the new continuous data would not fit well with simulations (Fig. 27). During spring 2006, the first peak is rather well simulated but the model keeps the concentration too long at a higher level and even formulates a new concentration peak not seen in the measurements. During winter 2007, the model fails to simulate the sediment dynamics totally.

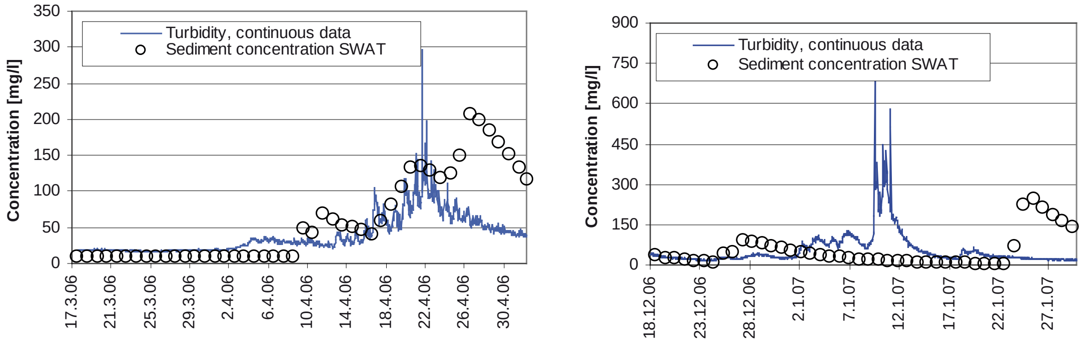


Fig. 27. Simulated sediment concentration and continuously measured turbidity at Vanhakartano during spring 2006 and winter 2007.

3.2.1.6
Conclusions and future work with SWAT

The sensitivity analysis proved to be useful by pointing out the most important parameters for calibration. Condensing the range of parameters probably improved the outcome. However, the condensations perhaps should have been made systematically for all parameters. Autocalibration tool proved useful by not only producing reasonable parameters but also by saving the modeller's time and systematizing the calibration process. In our case, it seems that it would have been better to keep a uniform set of parameters throughout the process.

The parameterization of the model, to obtain satisfactory calibration results in terms of flow and sediment dynamics, proved to be a laborious task. Obtaining satisfactory fit on daily basis is quite challenging for a long calibration period with varying flow patterns, and would require much more effort than has been done within the time limit of this project. The continuous turbidity data showed that the model is not able to catch all relevant erosion processes. This may partly result from unrepresentative precipitation data and partly also from inadequacies in snow melting process descriptions. SWAT is not an event based model and maybe such model is needed when continuous turbidity/sediment concentration data is available for calibration and testing. In the CachLake2 project, the SWAT will be further calibrated based on the new data.

Invaluable information is available by cooperative local farmers and authorities: about the agricultural management practices used, and protective measures implemented in the Yläneenjoki catchment so far, as well as about the measures planned for the future to protect the Lake Pyhäjärvi. By exploiting the good background information and local knowledge, efforts will be made to make even more realistic scenarios of the effects of agricultural management actions by using the model. Further, in CatchLake2 project, SWAT and INCA results will be compared which makes it possible to confirm whether the scenario simulations for nitrogen are reliable.

3.2.2
The INCA-N model

Kirsti Granlund

3.2.2.1
Model description

The Integrated Nutrients Model for Catchments – Nitrogen (INCA-N) (Whitehead et al. 1998, Wade et al. 2002) is a process-based and semi-distributed model that integrates hydrology, catchment and river N processes to simulate daily concentrations of NO_3-N and NH_4-N in the river system. In this study, the model version 1.11.1 was used, with a simple degree-day model to calculate snow pack depth and a process based function to calculate soil temperature from ambient air temperature (Rankinen et al., 2004a-c).

In the INCA-N model, hydrologically effective rainfall (HER) is the input to the soil water storage driving water flow and N fluxes through the catchment system (Whitehead et al., 1998). Catchment hydrology is modelled with a simple three-box approach, including direct runoff and reservoirs of water in the reactive soil zone and deeper groundwater zone. Flows from the soil and groundwater zones are controlled by time constants, representing residence time in the reservoirs. The catchment can be divided into sub-catchments. In each of them, INCA-N can simulate water flow and N processes in six land use classes. Base flow index (BFI) is used to calculate the proportion of water being transferred to the groundwater zone. Calculation of river flow is based on mass balance of flow and a multi-reach description of the river system. Flow variation within each reach is determined by a non-linear reservoir model (Whitehead et al., 1998).

3.2.2.2

Input data and calibration

In this study, the INCA-N model was calibrated in Yläneenjoki catchment for period 1995-1999 and tested for period 2003-2007. The daily hydrological input data (hydrologically effective rainfall, soil moisture deficit, air temperature and precipitation) was derived from the Watershed Simulation and Forecast System WSFS. It is an operational system widely used in Finland for simulation of hydrological cycle and for real-time flood forecasting (Vehviläinen 1994, Vehviläinen & Huttunen 2002).

The Yläneenjoki catchment was divided into five sub-catchments to allow comparison of modelled vs. available observed discharge and N concentration data (Table 9, Fig. 28). The division was based on the 3rd level delineation included in the WSFS. The land cover and agricultural information for the different sub-catchments was based on the VEPS decision support system (area of forests and agricultural area) and the report of the MYTVAS-study (agricultural practices) (Palva et al. 2001). Six land cover classes were included in the simulations: one for forest and five for field crops (spring cereals, autumn cereals, grass, set-aside and others) (Fig. 29). Hydrological input data for the five sub-catchments was derived by calculating area-weighted averages of the original 3rd level daily values.

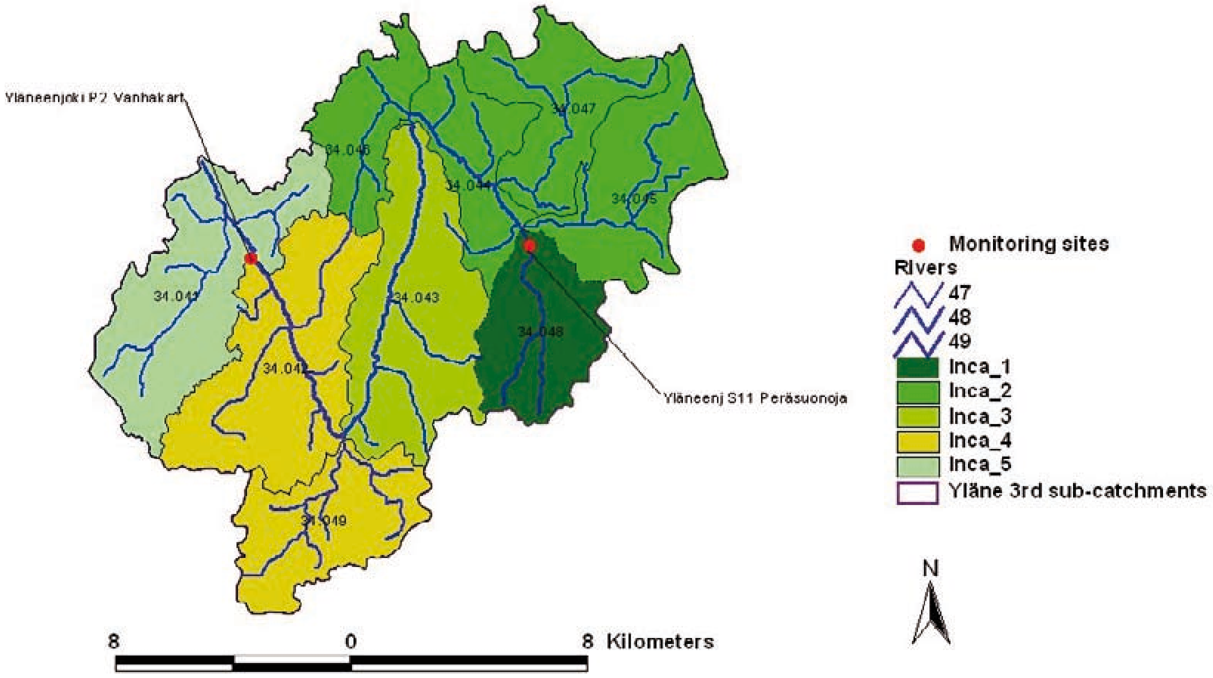


Fig. 28. Yläneenjoki catchment delineation for INCA-N application.

Table 9. Yläneenjoki sub-catchments for INCA-N simulation. See Fig. 28 for location of the sub-catchments.

INCA-N SUB-CATCHMENTS	3rd LEVEL SUB-CATCHMENTS	AREA (Km²)	AGRICULTURAL AREA (%)
1	34.048	20.08	28
2	34.044–34.047	78.18	42
3	34.043	37.09	26
4	34.042, 34.049	61.59	27
5	34.041	36.10	19

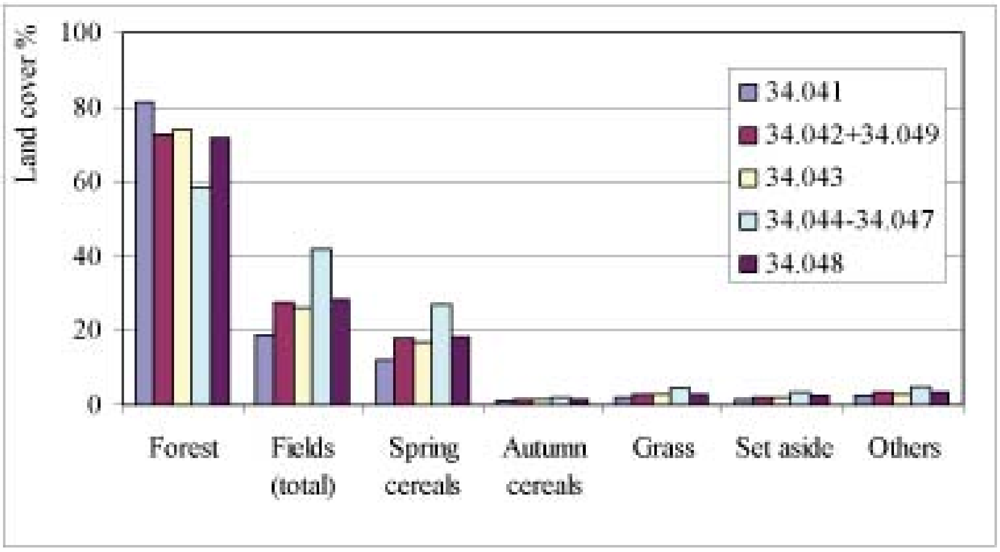


Fig. 29. Land cover types in the Yläneenjoki catchment for INCA-N simulation. See Fig. 28 for location of the sub-catchments 34.041–34.049.

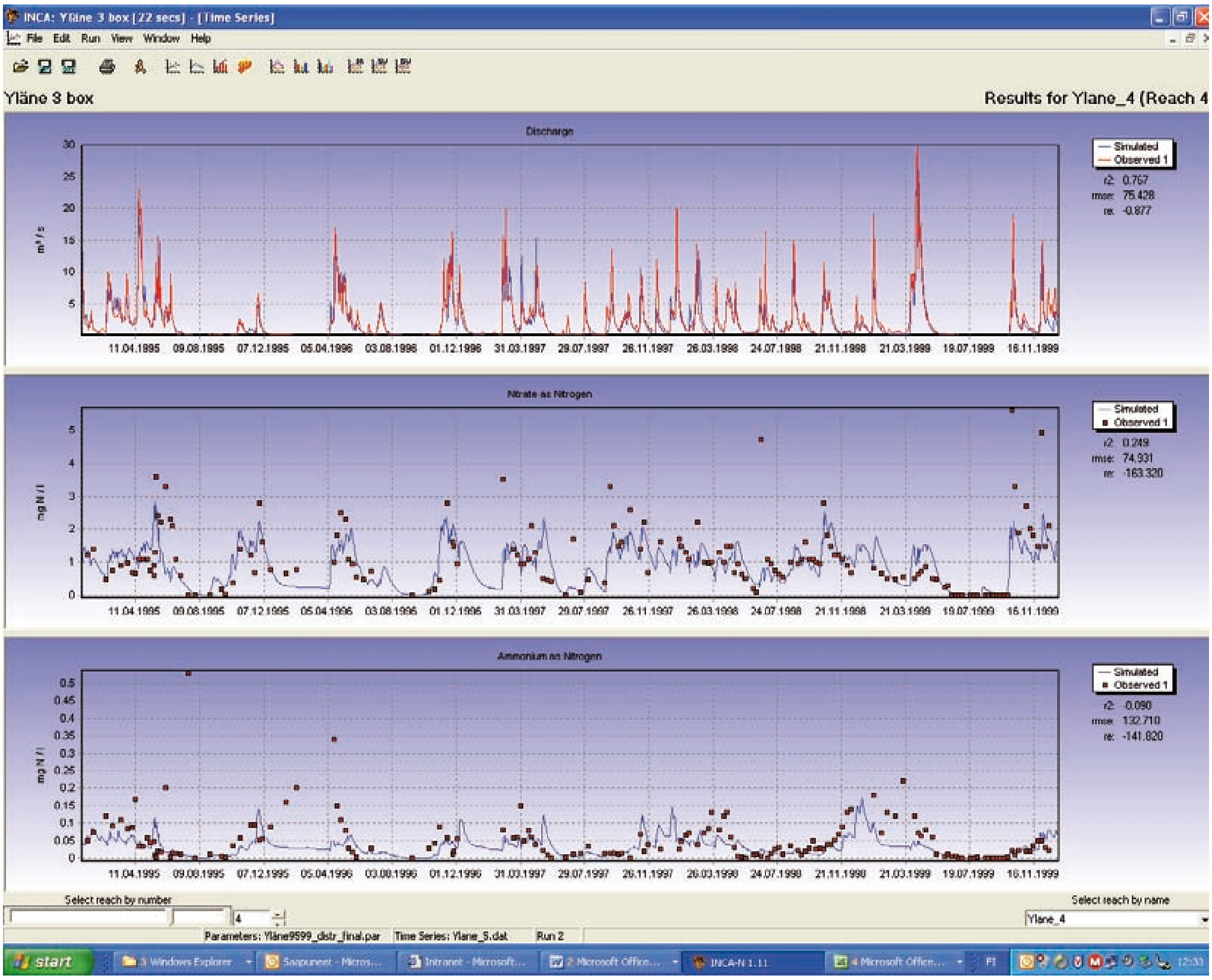
In addition to visually comparing modelled vs. observed values of discharge and inorganic N concentration, the performance of the model was assessed by calculating the Nash and Sutcliffe (1970) coefficient for model efficiency. Observed data for long-term calibration was available from two sites: Vanhakartano (P2, discharge and N concentration) and Peräsuonoja (S11, N concentration). Moreover, continuous in-situ sensor data from P2 was available for NO_3-N for two periods in 2007.

To calibrate daily discharge at P2, the time constants for surface runoff, soil and ground water flow, and the flow velocity parameters were adjusted until the simulated discharge closely matched that observed. After hydrological calibration the INCA-N model was calibrated for N processes. The N process parameters were adjusted until the annual process rates (e.g N uptake, mineralization rate) were in the range reported in the literature.

3.2.2.3
Results

The observed hydrological response of the Yläneenjoki catchment during 1995–1999 was rather fast. (Fig. 30). The correspondence between observed and simulated annual values was good at Vanhakartano; the Nash-Sutcliffe value was 0.77 for simulated vs. observed daily discharge. The timing and magnitude of the flow peaks was simulated well for the whole calibration period.

After hydrological calibration, representative literature information about typical N losses from different land use classes were used to further adjust the N process parameters. The calibrated model was able to simulate adequately the overall annual inorganic N dynamics in river water at Vanhakartano (Fig. 30). Discrepancies in the simulated versus observed concentrations during single peaks are probably partly related to under- or overestimation of instantaneous discharge and simplifications made during the whole modeling process.



Select reach by number: 4

Select reach by name: Ylane_4

Parameters: Yläne9599_distr_final.par

Time Series: Ylane_5.dat

Run 2

Fig. 30. INCA-N calibration results for the period 1995–1999 in Vanhakartano: discharge (m^3 s^{-1}) (upper figure), NO$_3$-N concentration (mg l-1) (in the middle) and NH$_4$-N concentration (mg l^{-1}) (lower figure).

The model performed well also for the testing period 2003–2007. Here the results are only presented for year 2007, in order to provide a detailed view of the hydrological response and N dynamics during the intensive monitoring period. The flow peaks in 2007 were simulated satisfactorily, except the small peak in the beginning of June (Fig. 31). This was probably due to the fact that summer rains typically occur locally in Finland, and in the model areal hydrologically effective precipitation data, covering the whole sub-basin, was used as input. Therefore, the observed discharge was higher than the simulated one. This discrepancy was also reflected in simulated N concentration: the model was not able to produce the concentration peak in the river (Fig. 31). Typically, in the beginning of growth period the field soils contain inorganic fertilizers which are susceptible for leaching. However, most of N is transported during spring high flow (and previous winter months during mild conditions) and during autumn, when soils are wet and contain mineralized inorganic N after ceasing of crop uptake.

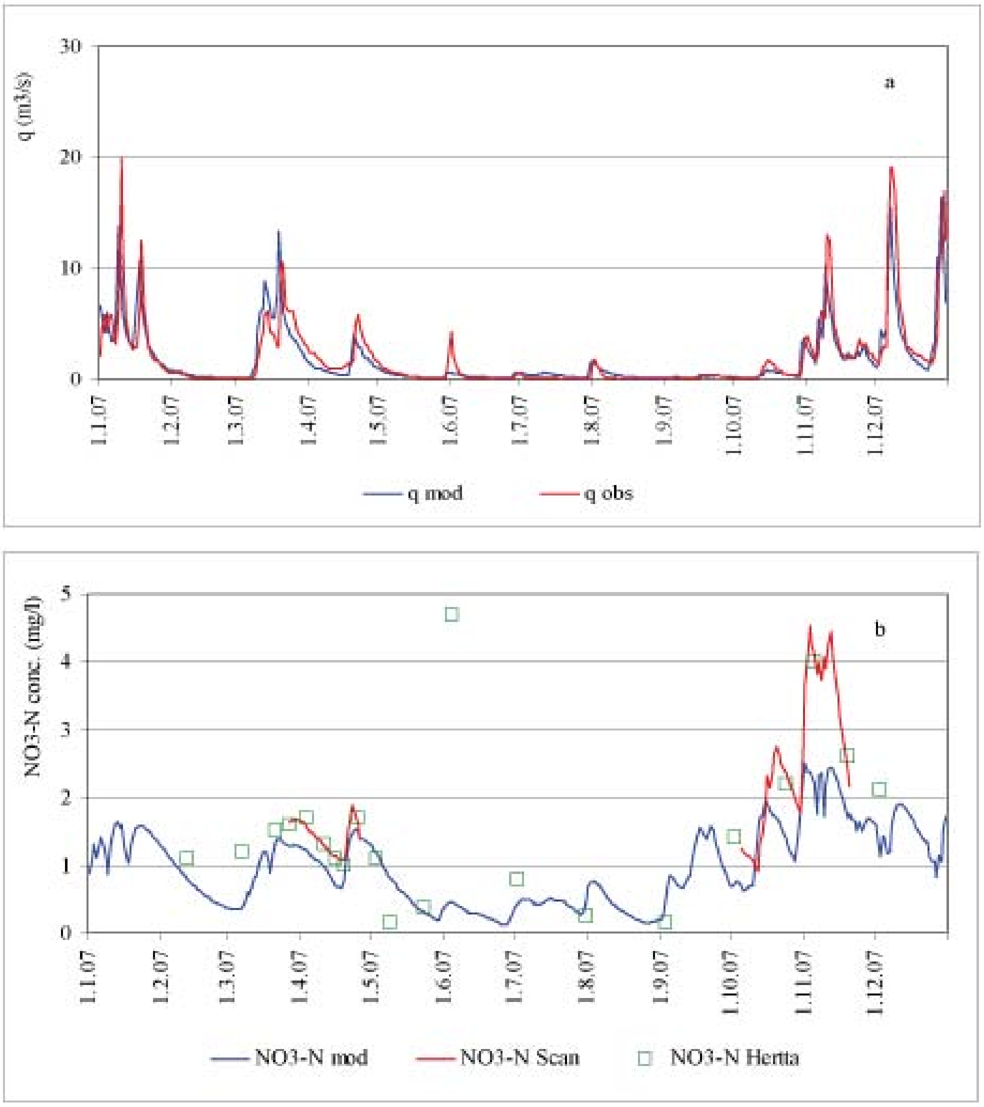


Fig. 31. INCA-N results for year 2007 in Vanhakartano: (a) modelled vs. observed discharge, (b) modelled vs. observed NO_3-N concentration.

Figure 31 demonstrates clearly the importance and usefulness of continuous monitoring. During the spring time manual sampling provided a reasonable representation of the concentration peaks. The dynamics and magnitude of these peaks were also simulated well. However, during autumn, the continuous monitoring data reveals a high peak that is underestimated by the model. Manual sampling also shows higher concentrations, but is too sparse to provide information about actual variation of N concentrations during highly varying flow conditions. When comparing observed continuous and modelled NO_3-N concentration, it can be seen that the modelled N dynamics is rather similar to observed one. However, the modelled concentrations are a bit lower than observed ones. The N transport capacity of the model as such seems to work well, because the timing and shape of the peaks are reasonable. The difference in concentration level is probably related to underestimation of inorganic N content in soils. This can be due to several reasons. Firstly, manure application during autumn was not taken into account in this application. Secondly, it is possible that agricultural practices (such as autumn ploughing) have caused enhanced leaching of mineral N. It is also possible that the modelled N mineralization rate is too low during autumn conditions.

Plotting of the observed continuous NO_3-N sensor data vs. discharge separately for spring and autumn shows that concentrations in autumn can be much higher than in spring for similar discharge values (Fig. 32). This indicates that a high amount of inorganic N is leaching from catchment soils during late autumn, probably due to effective nitrification during late summer/autumn and high amounts of unused NO_3-N, available for leaching. Further, the actual flow paths differ in spring and autumn: during the snow melting period surface runoff is probably more important than in autumn, while in autumn the infiltration is higher providing a longer contact with soil, resulting in high N losses.

3.2.2.4
Conclusions

In this study the INCA-N model was reasonably well calibrated to Yläneenjoki catchment. The model was able to simulate annual dynamics of discharge and N flow. The simulation of peak NO_3-N concentrations were sometimes slightly under- or overestimated, due to discrepancies in simulated discharge and rather simple description of actual management practices. The continuous NO_3-N sensor data proved to be extremely valuable for analyzing N concentration dynamics especially during autumn high flow. Interpretation of the data suggested several ideas for better calibration of N leaching in autumn. It is very important to be able to model autumn-winter losses correctly, because most of N is transported from catchments during the dormant season (Rankinen et al. 2004 a-c).

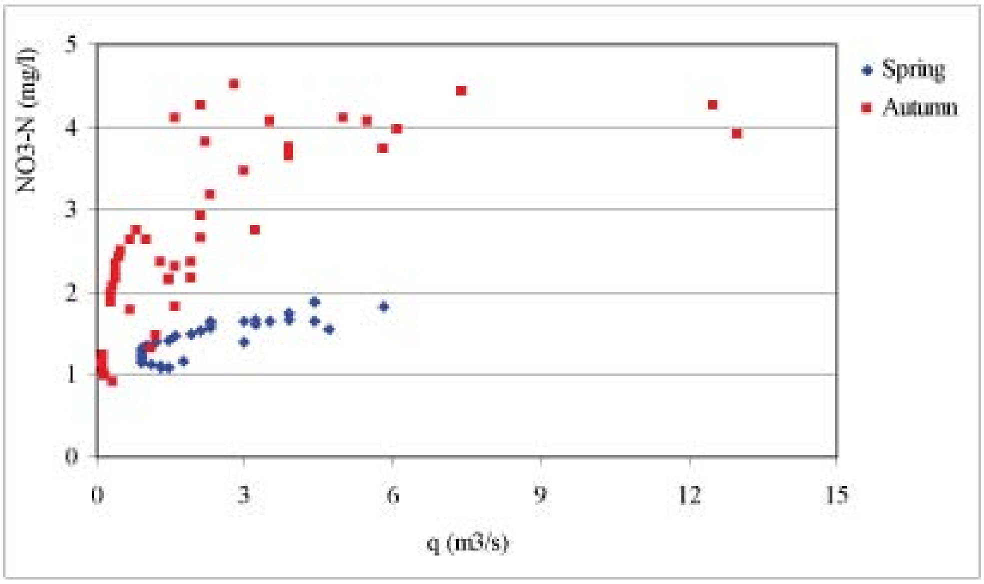


Fig. 32. Observed daily NO_3-N concentrations (based on continuous sensor data) vs. observed discharge during spring and autumn high flow periods in 2007 at Vanhakartano.

4 Lake Pyhäjärvi water quality and modelling

Sampsa Koponen, Kari Kallio, Timo Pyhälahti and Antti Lindfors

Increased eutrophication of the Lake Pyhäjärvi has been a major concern since the late 1980s as Cyanobacteria blooms have become more frequent. Spatial water quality of Lake Pyhäjärvi was studied with field campaigns (chapter 4.1), remote sensing (chapter 4.2, 4.3) and lake modeling (chapter 4.4).

4.1

Field campaigns

Six field campaigns were conducted at Lake Pyhäjärvi during the project in 2006-2007. The objective of the campaigns was to measure the spatial characteristics of various water quality parameters. This information was used in the development and validation of remote sensing methods, and will be used in the application of Coherens 3-d model in the ongoing second phase of the project.

In order to monitor the seasonal variability of water quality the campaigns were conducted during different times of the year:

1. Spring: Water from melting snow brings large amounts of inorganic particles, nutrients, humic and other substances from the drainage basin. This season is characterized by large spatial differences in the water quality of the lake.
2. Early summer: Biological activity is typically low and water quality parameters have low values. The lake is vertically mixed and spatial differences are small.
3. Late summer/early fall: Cyanobacteria blooms may occur.
4. Late fall: Water quality may be influenced by high river discharge and nutrient loads due to autumn rains.

The measurement dates were selected by analyzing satellite overflight data and weather reports. Cloud cover prevents the use of satellite images for water quality remote sensing, so the objective here was to find days when the satellite viewing geometry was good (small view angle) and the sky was clear of clouds.

The measurements were performed from a boat operated by Luode Consulting Oy, and included: 1) collection of water samples for laboratory analysis, 2) transect measurements and 3) spectrometer measurements for reflection estimation.

4.1.1

Water sampling

Water samples were collected from 5-9 locations on the field campaign days and analyzed at the laboratory of Water Protection Association of Southwest-Finland (WPASF) in Turku (Table 10). Most of the locations were determined beforehand to cover the different parts of the lake. A few water samples were additionally taken at locations, where the on-line transect measurements showed exceptional water quality (mainly near river inlets). The water quality results were used to: 1) estimate approximately water quality in the lake, 2) correct the transect measurements for bias, and 3) calibrate the remote sensing algorithms.

Sampling depth was 0.5 m in 2006, while in 2007 samples were taken as a composite sample from the surface down to the 0.5*Secchi depth. The concentration of total suspended solids (TSS) was measured in laboratory using gravimetric determination of the matter removed by a filter (Nuclepore polycarbonate 0.4 µm). Turbidity (FNU units) was determined by the Nephelometric method. The sum of chlorophyll *a* and phaeophytin *a* (Chl-a) was determined with a spectrophotometer after extraction with hot ethanol (GF/C filter). NO_2-N was determined by the azo colour method and NO_3-N was reduced with a Cd amalgam before the analyse. Absorption coefficient of colored dissolved organic matter at 400 nm(a_{cdom}(400)) was measured with a spectrophotometer (1 cm long cuvette) from a sample filtered through a Nuclepore polycarbonate 0.4 µm (in 2006) or 0.2 µm (in 2007) filter.

On 23.8.2007 an additional water quality sample was taken from the surface (0-3 cm) at station number 5, where surface accumulation of *Gloeotrichia* (cyanobacteria) was observed. Turbidity (6.4 FNU) and Chl-a (15 µg l^{-1}) were higher than in the 0-1.6 m composite sample (Table 10).

Table 10. Ranges of laboratory measured water quality and Secchi at 5-9 sampling locations in the field campaign days in Lake Pyhäjärvi in 2006 and 2007.

Date	9.5.2006	17.7.2006	13.9.2006	17.4.2007	23.8.2007	7.11.2007
Secchi (m)	-	2.0-2.8	2.5-3.2	1.4-2.2	3.3-3.6	-
Turbidity (FNU)	0.8-9.7	1.3-1.8	1.5-2.5	3.4-6.5	1.5-2.3	2.3-4.7
TSM (mg l^{-1})	1.2-11	1.7-2.8	2.0-3.8	4.3-6.8	1.8-2.1	3.1-5.8
Chl-a (µg l^{-1})	2.1-7.4	5.0-7.4	5.9-7.8	8.3-12.0	5.3-7.2	9.2-11
a_{cdom}(400) (m^{-1})	1.4-4.2	1.5-1.6	1.3-1.4	2.5-5.4	1.5-2.5	1.3-2.8
NO_2-N (µg l^{-1})	-	-	-	<3	<3	<3
NO_3-N (µg l^{-1})	-	-	-	160-200	< 5	<5-250
No of sampling stations	9	6	6	7	5	5

4.1.2

Transect measurements

A custom-made flow-through method by Luode Consulting Oy was used to collect high resolution transect datasets of water quality information from Lake Pyhäjärvi. In the flow-through method the sample water is pumped to measurement line from a fixed depth below boats hull. Typically intake is located ~0,5 m below lake surface. Pumped water is immediately analyzed with several optical and electrochemical sensors. System is operated from a moving boat, which allows the users to collect several thousands records of each measured parameter within one day (Table 11). Recorded data set is averaged with one second interval, which corresponds to 5-15 m distance depending on used velocity. All the recorded parameters are stored with GPS information.

Inherent optical properties of water are recorded with ac-9 (WetLabs Inc.). Ac-9 measured attenuation and absorption at nine wavelengths in the visible region of spectrum. Collected results were further analyzed with a bio-optical model and then calibrated against water samples. Optical data is used to calculate e.g. Chl-a concentrations, CDOM absorption and suspended matter concentration.

Auxiliary parameters temperature and conductivity, together with turbidity, are recorded with YSI 6600 multiparamerer sonde. In addition nitrate values are recorded either with ProPS (Trios) or spectro::lyser (s::can), which both are UV-VIS (ultraviolet to visible light) spectrometers that are using principle component analysis to determine the nitrate concentrations from the sample. Blue-green algal concentration was determined during three campaigns with a Micro-Blue (Trios) phycocyanin fluorometer. YSI 6600 produces turbidity in the NTU unit, while turbidity measured in laboratory is expressed as FNU unit. However, these units are directly comparable with each other.

Table 11. Number of collected samples and wind conditions during the transect measurements in Lake Pyhäjärvi.

Date	9.5.2006	17.7.2006	13.9.2006	17.4.2007	23.8.2007	7.11.2007
Number of flow-through samples	21.000	19.000	15.000	15.000	16.500	11.000
Number of nitrate samples	1.050	900	750	600	270	190
Number of blue-green algal samples	-	6.300	9.700	-	10.500	-
Wind speed (m/s) / direction	5-7 / N	1-5 / S	3-9 / SW	0-3 / N	0-2 / S	0-1 / N

Large spatial variability was observed in the lake in 9.5.2006, during the spring flood. (Fig. 33). The river inlets in the southern and eastern parts of the lake bring most of the measured nitrate into the lake. Also a small ditch in the north-west corner had a relatively strong effect. In the northern corner the current-structure in the lake formed an eddy that transported the nitrate rich waters away from the ditch into central part of the lake. During the mid-summer and autumn campaigns the nitrate had vanished completely from the surface layer and spatial variability was not detected. This is a typical example of nutrient seasonality in a lake environment.

The distribution of Cyanobacteria was mapped with a phycocyanin fluorometer. The results (Fig. 34) show clearly how changeable the algal biomass distribution in the lake can be. The results from July 2006 show that most of the cyanobacterial biomass was concentrated quite uniformly into northern part of lake while measurements done in September 2006 revealed high cyanobacterial concentrations in the eastern part of lake and western coastal areas. During the campaign in August 2007, cyanobacterial algae had formed bloom patterns which mainly concentrated to western part of lake.

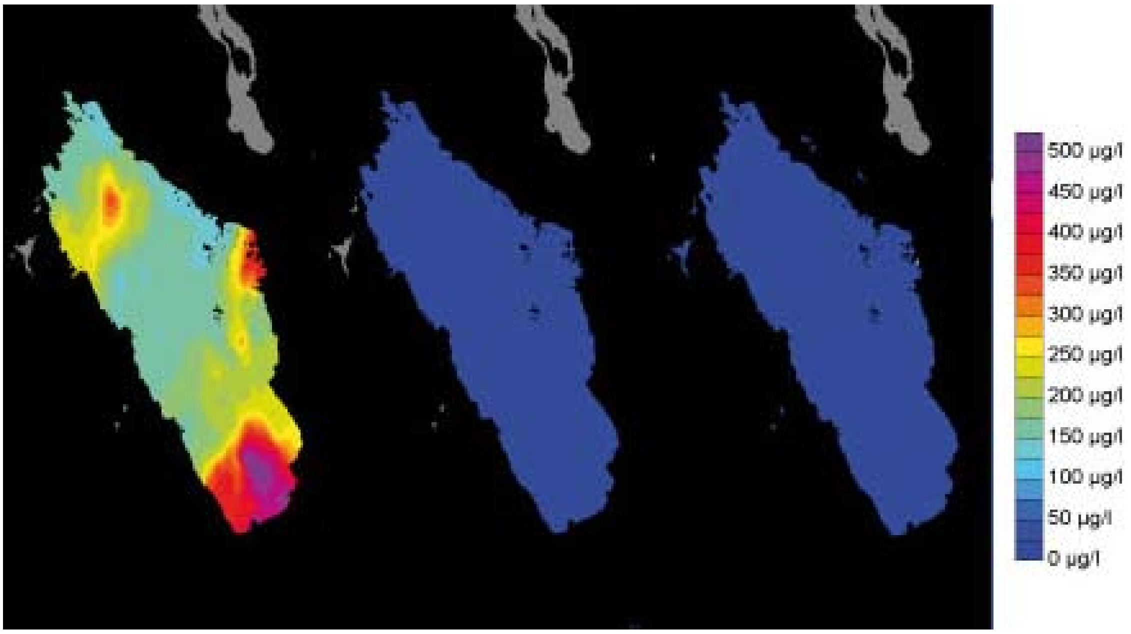


Fig. 33. Example dataset of nitrate variability during the year 2006. Corresponding dates are 9.5.2006, 17.7.2006 and 13.9.2006.

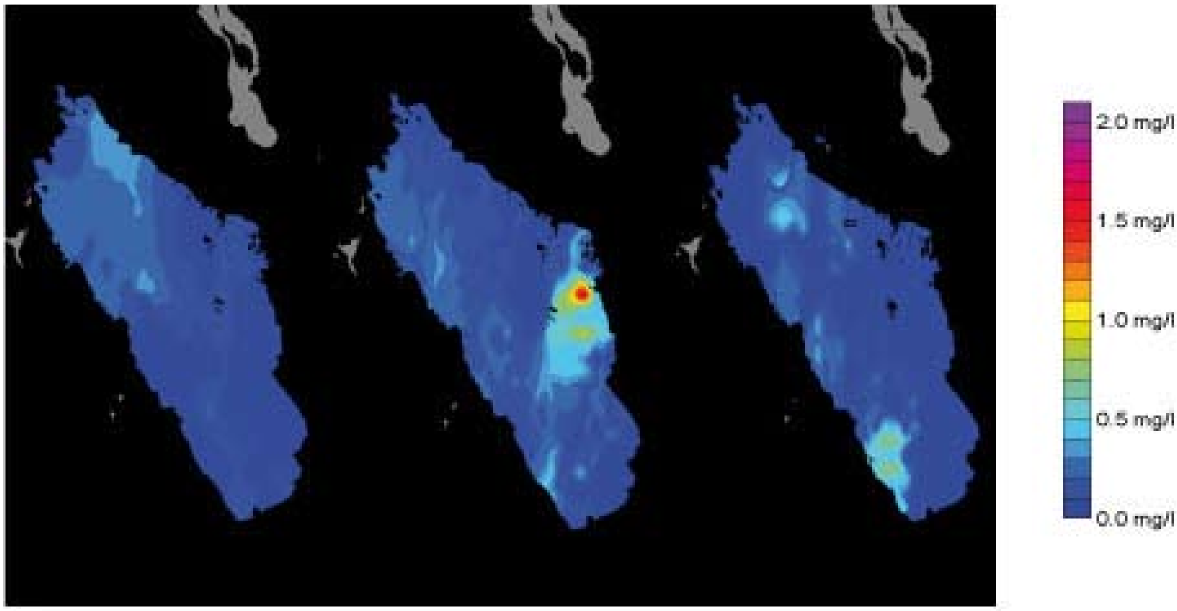


Fig. 34. Example dataset of cyanobacterial biomass variability during three campaigns. Corresponding dates are 17.7.2006, 13.9.2006 and 23.8.2007. Units are algal biomass wet weight.

4.1.3
Spectrometer measurements

Spectrometer measurements can be used to test the validity of the atmospheric correction procedure that removes the effects of the atmosphere from the radiance values measured at satellites.

During CatchLake1, the measurements were performed with two spectrometers manufactured by the Analytical Spectral Devices Inc (ASD): ASD HandHeld, and ASD Pro Jr. The spectral ranges of the spectrometers are 325-1075 nm and 350-2500 nm, respectively.

With the equipment available to the project, the water leaving reflectance can be estimated with the following two measurement configurations:

1. **Radiance and irradiance values measured above water.** In this configuration three parameters are measured: 1) The radiance just above the water surface (at an angle that minimizes sun glint, 40° elevation, 135° from the direction of the sun), 2) the radiance of blue sky (at an angle corresponding to the measurement of water leaving radiance), and 3) downwelling irradiance. The measurement of the sky radiance is needed to correct the specular reflection of sky from water. After this correction the radiance is divided by the irradiance in order to derive the reflectance.
2. **Measurement of radiance below water surface and irradiance above surface.** In this configuration the radiance is measured just below water surface towards nadir (0° elevation). The radiance values are then propagated through the surface using a coefficient and divided by the irradiance in order to derive the reflectance. This method is not prone to the effects of sky reflection. However, the measurements are more difficult to perform. For example, due to waves it can be difficult to maintain a constant depth for the sensor head.

During 2006, the 1st method was used while in 2007, both methods were used. The number of spectrometer stations varied from 3 to 6 (Table 12).

4.2
Spatial water quality and remote sensing

Satellite sensors operating in the optical wavelengths measure the solar radiation reflected by the target. Information about the target can be obtained by analyzing the spectra of the reflected radiation.

In water the main substances that affect light are:

1. Suspended material such as phytoplankton cells and inorganic particles
2. Phytoplankton pigments such as Chl-a
3. Colored dissolved organic matter (CDOM, humic substances)

In addition, parameters that can be estimated with remote sensing include turbidity and Secchi depth.

The satellite sensors used in CatchLake were MODerate Resolution Imaging Spectroradiometers (MODIS) onboard the TERRA and AQUA satellites and Medium Resolution Imaging Spectrometer (MERIS) onboard the Envisat satellite. MODIS has two channels with 250 m spatial resolution (pixel size) with wavelength ranges 620-670 nm and 841-876 nm. MODIS has more channels with 500 m and 1 km resolution. However, Finnish lakes often have an irregular shape (many bays, peninsulas and small islands) these channels can only be used with the largest lakes. In this research we have only used the 250 m MODIS data.

MERIS on the other hand has 15 channels in the optical to near infrared region with 300 m spatial resolution. The positions of the channels have been designed with the monitoring of water areas in mind. The higher number of channels allows the use of channel-ratio algorithms, which have been found to be effective in correcting errors caused by image geometry and atmospheric effects.

Information about the remote sensing measurements is shown in Table 14. On 17.4.2007 clouds covered most of Lake Pyhäjärvi during the satellite overpasses making the data from that date unusable. The condition in late fall are not optimal for optical remote sensing measurements due to the low elevation of the Sun. Therefore, on the last campaign day 7.11.2007 only water samples and transect data were collected (Tables 10 and 11). Thus the number of successful remote sensing measurement dates was four.

Table 12. Basic information related to remote sensing measurements.

Date	9.5.2006	17.7.2006	13.9.2006	17.4.2007	23.8.2007
Weather conditions	Good, light wind, no clouds	Average, cloud cover at some stations	Good, light wind, no clouds	Poor, cloud cover	Good, light wind, no clouds
Spatial differences in water quality	Large	Small	Small	-	Moderate
Spectrometer	HandHeld	Pro	Pro	-	Pro
Number of spectrometer stations	6	6	5	-	3
Number of water samples	9	6	6	-	5
Available satellite data* (GMT-time)	MODIS-Aqua (10:40) MERIS (9:13)	MODIS-Aqua (11:00) MERIS (09:47)	MODIS-Terra (09:37) MERIS (09:22)	-	MODIS-Terra (10:27) MERIS (9:13)
Satellite viewing angle (deg.) at Lake Pyhäjärvi	MODIS: 25 MERIS: 18	MODIS: 5 MERIS: 15	MODIS: 16 MERIS: 9	-	MODIS: 36 MERIS: 20
Quality of satellite data	MODIS: Good MERIS: Good	MODIS: Some clouds MERIS: Good	MODIS: Good MERIS: Good	-	MODIS: Good MERIS: Good

* In one day, there usually are two to four MODIS images available from Lake Pyhäjärvi. However, typically only one has good measurement geometry (i.e. small viewing angle). The approximate overpass time of the best MODIS image is given here.

4.2.1
Methods and results

4.2.1.1
Estimation of turbidity with MODIS data in SW Finland

Turbidity was observed to have a large variability (*in situ* values 0.8-9.7 FNU, Table 10) on the campaign date 9.5.2006 in Lake Pyhäjärvi. A cloud free MODIS image was registered concurrently with the *in situ* measurements. Together, these two datasets can be used to develop an algorithm that transforms MODIS data into turbidity values. The method was tested over a larger area, not just in Lake Pyhäjärvi. It is assumed that the atmospheric parameters are the same over the area of investigation.

First, the MODIS data were atmospherically corrected with the Simple Method for Atmospheric Correction (SMAC) (Rahman & Dedieu 1994) using daily parameter values measured at the atmospheric measurement station of Jokioinen (aerosol optical depth, humidity). Ozone concentration was obtained from the measurements of NOAA's Solar backscatter ultraviolet spectral radiometer SBUV/2. Next, an empirical algorithm was developed by fitting a linear equation with the data (Fig. 35). The data also included three data points from other lakes in the area (routinely corrected data from the HERTTA database). Next, the MODIS data from other dates were corrected with SMAC. Routinely corrected data were used to correct the bias error that may remain after the atmospheric correction. Clear lakes that have stable turbidity values were also used in the validation of the algorithm. The assumption was that these lakes will have low reflectance values during the whole summer period.

A sample result is shown in Fig. 36 (scatter plot) and Fig. 37 (thematic map). In the scatter plot, the in situ data collected near 5.7.2006 match the data used in the algorithm development quite well. There is only a small bias term. Also the data from the clear lakes match the modified algorithm well.

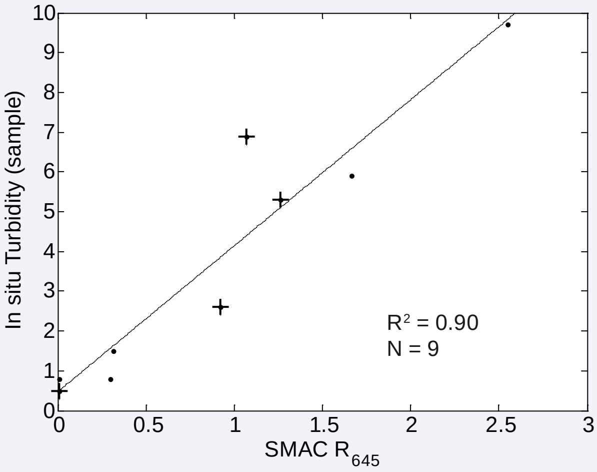


Fig. 35. Water sample turbidity (in FNU) vs. SMAC-corrected MODIS channel-1 (620-670 nm, center at 645 nm) reflectance on 9.5.2006. The data points marked with a dot are from Lake Säkylän Pyhäjärvi. The data points marked with a '+' are from routinely collected samples.

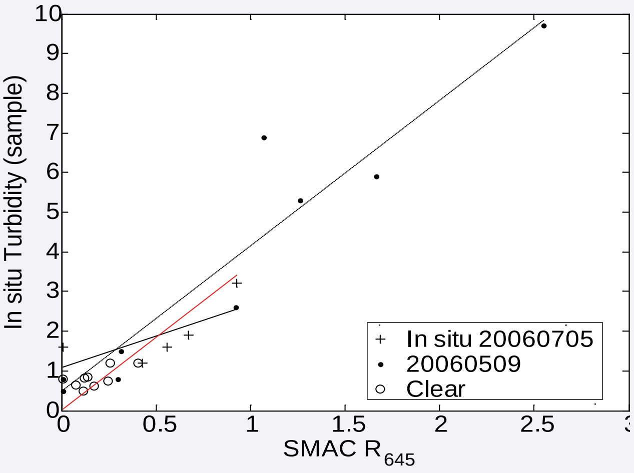


Fig. 36. The relationship between atmospherically corrected (SMAC with daily parameters) MODIS channel-1 (620-670 nm, center at 645 nm) reflectance and in situ turbidity on July 5, 2007. The data marked with '+' (In situ 20060705) are in situ data collected within three days of the satellite overpass; '•' the data used to develop the algorithm (measured on May 9, 2006; Fig. 29), and 'o' from lakes that have low turbidity values that do not change much in time (one outlier removed). The black solid line shows the algorithm based on the in situ data measured within three days of July 5, 2006. The black dashed-line (--) shows the trend line for the algorithm developed with May 9, 2006 data. The red solid line is the algorithm modified by adjusting the bias term with the in situ data. The coefficients of the red line are used to derive the thematic map in Fig. 37.

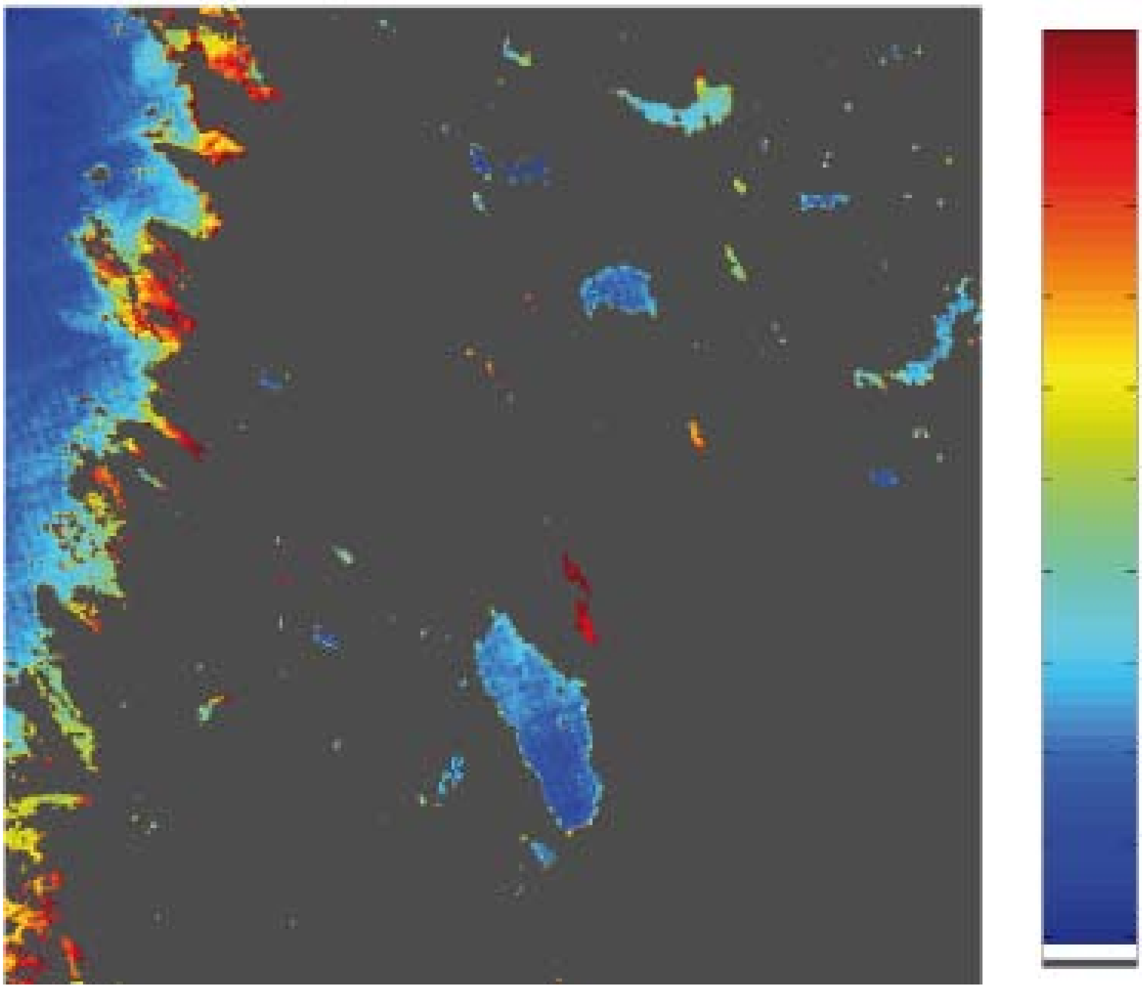


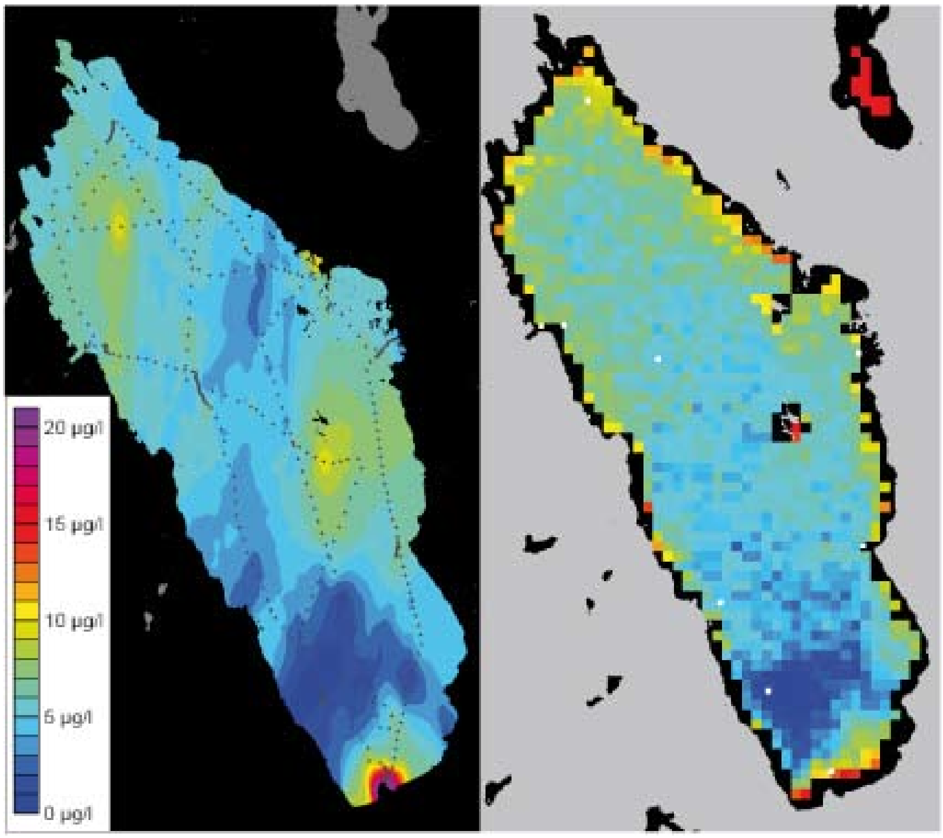
Fig. 37. Turbidity (FNU) estimated with MODIS data on 5.7.2006 in a 100 km x 100 km area around Lake Pyhäjärvi.

4.2.1.2

Estimation of turbidity, CDOM and Chl-a with MERIS in Lake Pyhäjärvi

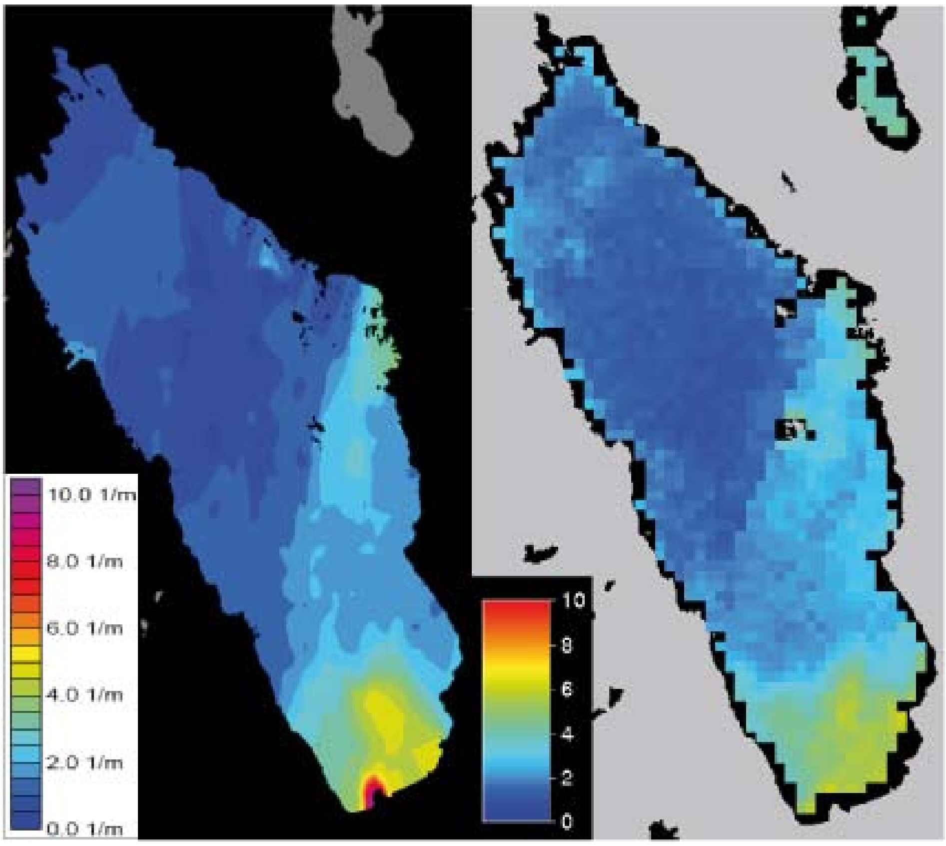
The channels available on the MERIS instrument allow the use of more elaborate retrieval algorithms. In earlier studies (Kallio et al. 2001, Koponen et al. 2002, Koponen et al. 2007), channel-ratio algorithms have been found to be applicable for the mapping of Chl-a and CDOM. These were tested with the MERIS data available from Lake Pyhäjärvi. As the spatial differences of water quality were largest during the 9.5.2006 campaign that date is the most interesting for the development and testing of remote sensing algorithms.

Fig. 38 shows a comparison of the interpolated result from transect data and MERIS channel ratio algorithm for Chl-a. Figs. 39 and 40 show the same for $a_{cdom}(400)$, and turbidity. The results for $a_{cdom}(400)$ and turbidity are very good. The features in the MERIS based estimate match the features visible in the boat data. For Chl-a the result is not as good, but some features (like the high and low concentrations at the southern end of the lake) still match.



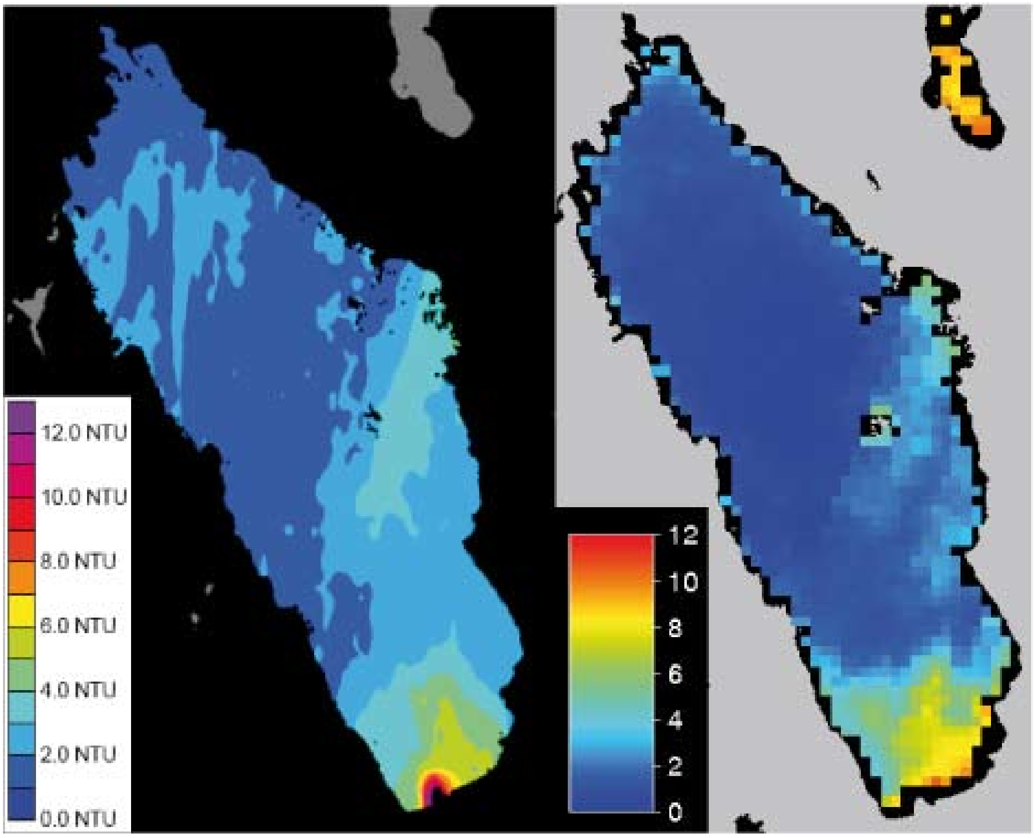
(a) (b)

Fig. 38. (a) Chl a interpolated from transect data, and (b) MERIS channel ratio (708nm/665nm) on 9.5.2006. The route of the boat is shown with gray dots in the transect data. The locations of the sampling stations are shown as white dots in the MERIS image. The color scale of the MERIS result is selected so that it corresponds with the in situ result. The MERIS pixels near shore are affected by the adjacency effect. This causes the higher values visible in the image.



(a) (b)

Fig. 39. Variability of humic substances at Lake Pyhäjärvi. $a_{cdom}(400)$ values (a) interpolated from transect data, and (b) estimated using a MERIS channel ratio (665nm/490nm) on 9.5.2006.



(a) (b)

Fig. 40. Turbidity values (a) interpolated from transect data, and (b) estimated from MERIS reflectances at 708 nm on 9.5.2006.

The atmospheric correction (SMAC) improved the estimation of turbidity by removing differences between dates, while in case of the channel-ratio algorithms the atmospheric correction did not change the results significantly (Appendix 2).

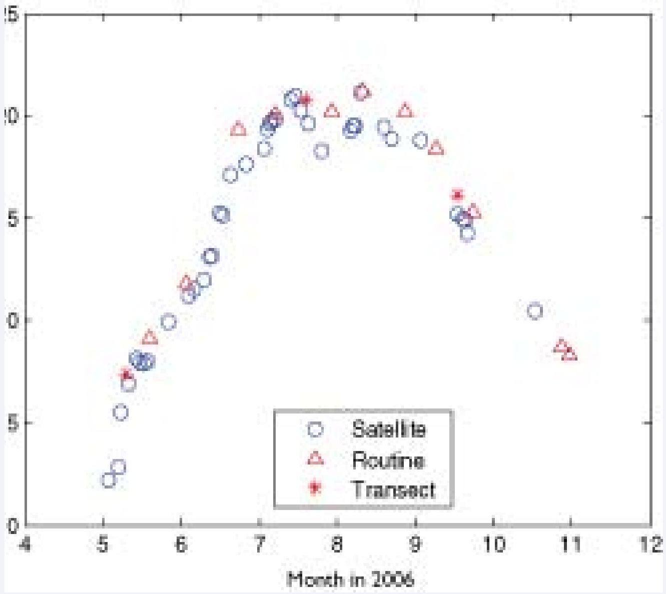
4.2.1.3
Estimation of surface temperature with AVHRR

Surface temperature of Lake Pyhäjärvi and other large lakes is calculated from satellite data on a daily basis at Finnish Environment Institute (SYKE). This service is based on the NOAA-AVHRR (National Oceanic and Atmospheric Administration-Advanced Very High Resolution Radiometer) satellite images, which have a resolution of 1-2 km (depending on the measurement angle). These estimations are available on the internet (http://wwwi4.ymparisto.fi/i4/fin/sst/2007/sst_sat_2007.html). Temperature is calculated using the Split Window –method. AVHRR images are acquired daily from the time period 0430-0700 local time and they are processed whenever conditions are cloudless. The estimate represents temperature in less than 1 mm thick surface layer.

The satellite based estimates were compared with the field measurements in 2006 (Fig. 41). The correspondence with field measurement is very good and the number temperature estimates is much higher for AVHRR than in case of conventional methods.

The satellite estimates of temperature are also usable in the detection of spatial differences of large lakes. In Lake Pyhäjärvi the spatial temperature differences can be distinctive in early spring, as demonstrated by the temperature map of 9.5.2006 (Fig. 42). Although the course spatial resolution of AVHRR enables only the mapping of the central parts of the lake, the same spatial pattern can be seen in the AVHRR temperature map as in the map interpolated from the transect measurements on 9.5.2006.

Fig. 41. Time series of water temperature in Lake Pyhäjärvi in 2006 based on three different data sources: AVHRR satellite images, routine monitoring at the deepest point (measured at 1 m depth) and the mean of the transect measurements (0.5 m depth). The AVHRR temperatures are the mean values of the image pixels in the lake (Fig. 42). Ticks on the x-axis refer to the first day of each month.



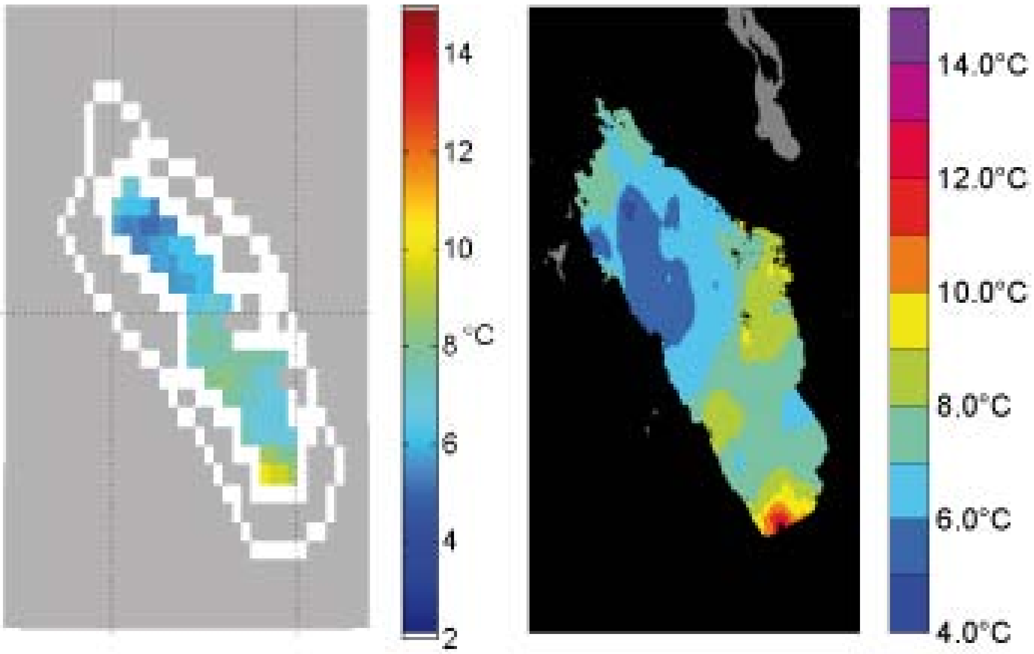


Fig. 42. Temperature map of Lake Pyhäjärvi on 9.5.2006 estimated with the AVHRR satellite instrument (left) and from transect measurements (right).

4.2.1.4

Results of spectrometer measurements

Figure 43 shows a sample reflectance spectra measured at Lake Pyhäjärvi on August 23, 2007. The in situ -values have been computed using the above water measurement configuration (see Chapter 4.13). The atmospherically corrected MERIS reflectances have been computed with the MERIS LAKES processor (the version used here is not the final version). The adjacency effect of the nearby land areas cause errors in the atmospheric correction. When the MERIS data have been preprocessed with another processor (ICOL), which reduces the adjacency effect, the match between *in situ* and MERIS derived spectra improves.

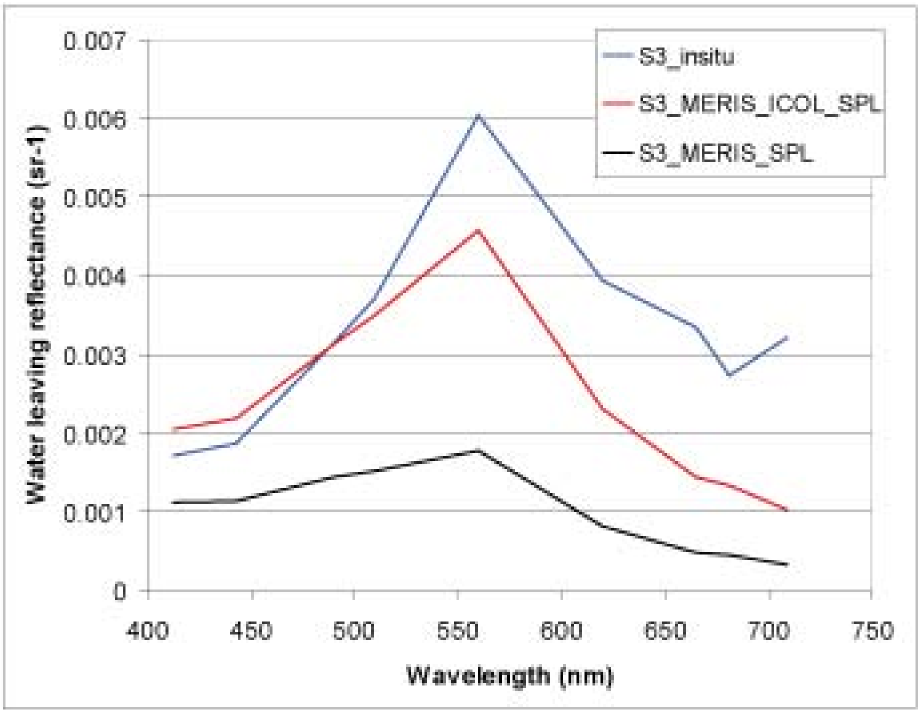


Fig. 43. Comparison of water leaving radiance reflectances at Lake Pyhäjärvi on August 23, 2007. The in situ values have been computed from the above water spectrometer measurements. MERIS_ICOL_SPL and MERIS_SPL are atmospherically corrected reflectances derived with the MERIS LAKES processor with and without ICOL correction.

4.2.1.5

The ULAPPA database system

ULAPPA refers to a target area based database system for (satellite) remote sensing as described in Pyhälahti et al (2002). ULAPPA is an application of SADB (Sensor Archive Data Base) technology developed in SYKE in order to implement the target area approach to an operative database system. It resides in a Microsoft SQL 2005 Server, which provides web services using SOAP (Simple Object Access Protocol), and the services available are defined with WSDL (Web Service Description Language). The services were used with a programming interface developed in MATLAB, which utilizes the MATLAB web services functions, thus masking the whole XML –based data exchange from the user. In principle, only a basic set of commands are exposed in the SADB programming interface: System initialization, execution of the possible SADB queries (which are pre-defined in the SADB database) and help information on the query syntax.

The geographical data within the ULAPPA system contain resolution areas for the Finnish coastal and lake waters suitable for remote sensing with medium/low resolution satellites, such as Envisat MERIS or Terra/Aqua MODIS. These resolution areas can be combined together to form monitoring areas, which then can be associated with estimates of different kinds of interpretations of the satellite observations - including parallel estimates using different methods of interpretation for the same environmental variable, such as turbidity. By using XML data, very complex sets of information for e.g. modeling input data purposes can be included in the database to describe the properties of a given monitoring area or a group of monitoring areas.

The ULAPPA database contains currently test data for turbidity in the South-Western Finland for turbidity for certain cloudless images of summer 2006. It was extracted from Terra and Aqua MODIS data as part of the GSE Land project. In the CatchLake project, the ULAPPA functionality was demonstrated for the project participants. The demonstration data in the database includes the test area Lake Pyhäjärvi. The year 2007 turbidity dataset could not be processed into the database by the GSE Land project before the end of the CatchLake project, thus the main achievement was to plan for the lake modeling activities in the next phase, CatchLake2, as well as to test and improve the SADB technology for the modeling requirements.

4.3

Conclusions of spatial water quality sub-task

Remote sensing methods were able to retrieve water quality information from Lake Pyhäjärvi that is consistent with the surface measurements. The estimation of parameters such as turbidity and a_{cdom} is possible with simple algorithms when using MERIS data. The estimation of Chl-a still needs improvements. The quantitative estimation of water quality by the methods used here require concurrent *in situ* measurements for algorithms training.

Even a simple atmospheric correction method was able to reduce the effects of the atmosphere in turbidity estimation. When a ratio algorithm was used (e.g. for a_{cdom}) the use of atmospheric correction did not affect the results significantly.

During an ESA funded MERIS LAKES project, a processor that transforms MERIS data into water quality information is being developed until summer 2008. The processor is based on analytical methods and once ready will be employed in the CatchLake2 project. The main advantage of the analytic interpretation methods is that they better enable the estimation of water quality without concurrent *in situ* measurements. The analytical methods require that the specific inherent optical properties (SIOPs) of water are known. SIOPs are e.g. specific absorption of phytoplankton and non-algal particles as well as specific scattering coefficient of particles. The SIOPs related to absorption were measured in Lake Pyhäjärvi in 2007 and these results will be utilized in the MERIS LAKES processor. Also, the ability of the ICOL-processor to remove the errors caused by the adjacency effect in Finnish conditions will be tested further (see Figure 43).

4.4

Lake modelling with the LakeState model

Olli Malve

4.4.1

Model

A non linear dynamic model called LakeState, based on total phosphorus and nitrogen mass balances and phytoplankton kinetics, was used to simulate the main driving processes between nutrient loading, algae and zooplankton in a lake. Fish is not included, but the impact of fisheries management can be simulated by manipulating zooplankton biomass concentration, which is an independent input variable in the model. The model parameter estimation and predictions were done according to the Bayesian paradigm using Markov chain Monte Carlo (MCMC) simulation methods. The predicted posterior distributions were constructed to reveal the consequences of the uncertainties in the predictions.

Parameter estimation of the model. Using eight years of observations of the lake's water quality and hydrology parameters of the model were estimated (Malve, 2007), based on earlier work in EU BMW project. The model parameter estimation and predictions based on the model were done according to the Bayesian paradigm. The practical problem of computational complexity of the calculations is solved using Markov chain Monte Carlo (MCMC) simulation together with up-to-date adaptive computational schemes to make the simulations as effective as possible.

4.4.2

Phosphorous modelling and prediction of phytoplankton biomass with given management options

Predictive limits of the observations were quite high compared to the limits of the fitted model, indicating that model is capable to capture major dynamics of total P in 1990-2001, but not all of the variation of observed concentrations either deterministic or random. Phosphorus model (Fig. 44) seems to fit to observations better than the nitrogen model.

The predictive posterior distributions based on the MCMC and Monte Carlo (MC) simulation of LakeState model were analysed more closely to predict the consequences of loading reduction and fisheries management and to find optimal combination of these to actions with the given target summer maximum Cyanobacteria biomass. This means that the density estimate of mean TotP and summer maximum Cyanobacteria biomass, conditioned on a set of TotP- loading and zooplankton biomass (summer maximum) ranges can be calculated from the MC sample. Based on these calculations, external phosphorus loading level and zooplankton biomass that attain target summer maximum Cyanobacteria biomass with the given margin of safety (for example 90 % percentile) can be estimated.

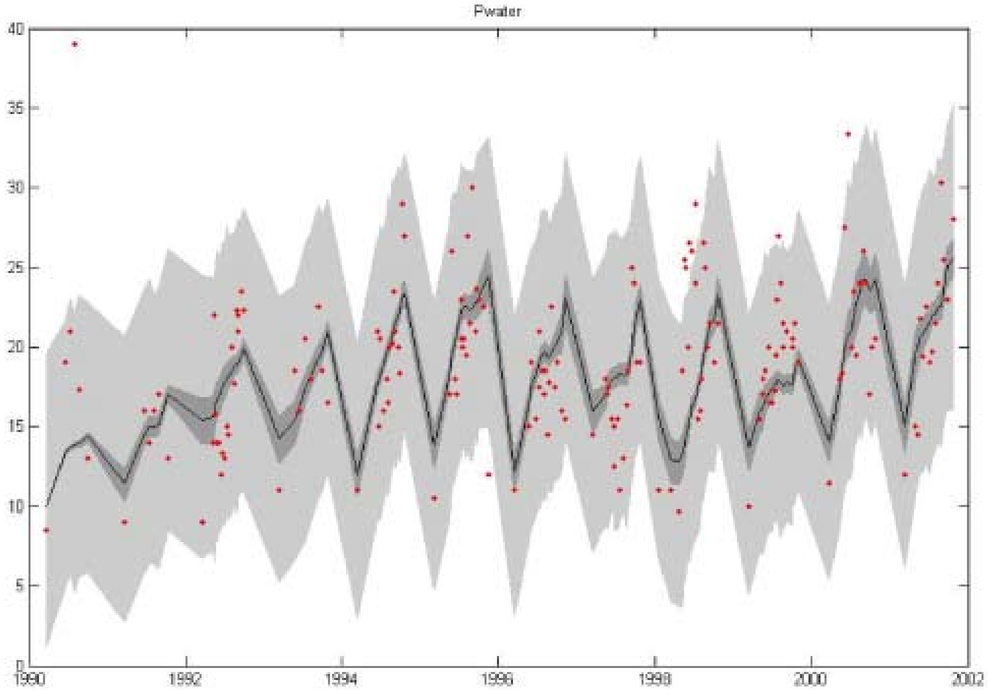


Fig. 44. Observed and fitted total phosphorus concentrations (µg/l) 1990-2001. The darker gray area correspond to 95 % predictive limits of the fitted model. Solid line is the median algae concentration. Lighter gray gives 95 % prediction limits for the observations (Malve, 2007) .

From the MC sample, all necessary percentiles of average TotP concentrations and summer maximum Cyanobacteria biomass were calculated as a function of MC-sampled combinations of TotP load and grazing zooplankton biomass (summer maximum) (Fig. 45). These results can be used to find the optimal combination of TotP load reduction and zooplankton biomass with the given range of certainty.

Bayes network software "Hugin" (www.hugin.com) was used to learn causal relationships and conditional probability tables from the Monte Carlo simulations of LakeState model, to represent uncertainty in causal linkages between nutrient load and cyanobacteria summer maximum biomass, to link LakeState model with the catchment model using a simple probabilistic expression and to estimate expected attainability of the water quality criteria with given management options.

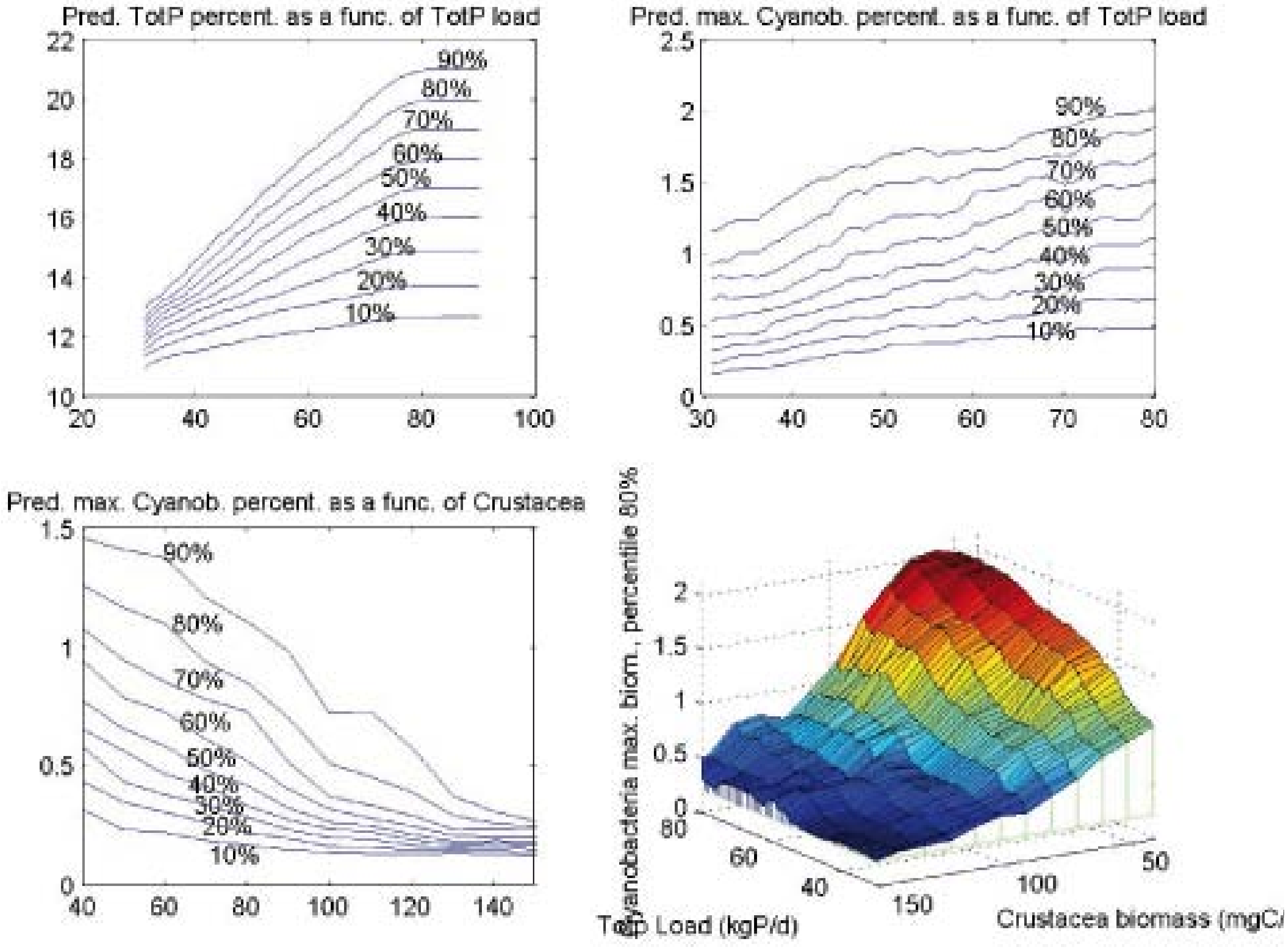


Fig. 45. Estimated TotP and summer maximum Cyanobacteria biomass percentiles (10% - 90%) as a function of TotP load and summer maximum grazing zooplankton biomass. (a) mean TotP percentiles as a function of TotP load; (b) Max. summer Cyanobacteria biomass as a function of TotP load (zooplankton biomass summer maximum fixed to the level [30 50] mgC/l); (c) Max. summer Cyanobacteria biomass as a function of zooplankton biomass (TotP load fixed to the level [30 40] kgP); (d) Summer maximum Cyanobacteria biomass 80 % percentile as a function of TotP load and summer maximum grazing zooplankton biomass. This response surface can be used in the optimization of load reduction and fisheries management (Malve, 2007).

4.5

Linking catchment and lake models

Timo Huttula, Olli Malve and Ahti Lepistö

As a part of an integrated river basin modelling, lake models can be linked to e.g. rainfall-runoff models, catchment nutrient models, river models and groundwater models. As many of the abatement measures are often done outside the lake domain, e.g. in the agricultural sector, there is a clear need by lake modellers to extend the modelling system "upstream", in order to be able to simulate the abatement measures more directly and realistically. From the catchment modelling point of view, there is a need to extend the system downstream, in order to study different catchment management options and their chemical and ecological responses in lake systems and/or estuaries.

Linking of models can be implemented e.g. by using output series from one model (such as SWAT or INCA) as input data series to the next model (such as LakeState, MyLake or Coherens), or by probabilistic linking. Usually linking is done in form of one-way feeding of information from one model to the next, but sometimes models are coupled so that the exchange of information between them is a two-way process, ongoing while the models are running.

Often 'straight', programmatic coupling of models is very challenging and many research groups rather use model chaining, i.e. use output series from one model to the next model. One example of model chaining in Euro-limpacs project consists of hydrological model HBV, the water chemistry models MAGIC and INCA-N, and the NIVA FJORD model, linked together and applied at the Bjerkreim river and estuary, southwestern Norway (Kaste et al, 2006).

LakeState model and a catchment model have been earlier linked together with Bayes network learning method, with Lake Pyhäjärvi as one case (Malve 2007). This linked model system made a more direct simulation of the actual management (abatement) operations possible. These models were linked to estimate attainment of the designated water quality criteria or goal (Cyanobacteria summer maximum biomass) with the set of management options: buffer strip width, wetland percentage, forestation percentage and planktivorous fisheries management. Management options were implemented by decision nodes and the attainment of the water quality goal with a discrete change node and a utility node. The Bayes network, decision nodes and utility nodes together formed an impact diagram which could be used to study management decisions and their expected utilities in terms of Cyanobacteria summer maximum biomass and attainment of the water quality criterion. The postulated fisheries management scenario, combined with moderate catchment measures yielded a high probability of attaining the water quality criterion (Malve 2007).

In the ongoing CatchLake2 project Coherens model is being applied to Lake Pyhäjärvi. The hydrological and nutrient fluxes from catchment models are planned to be taken as inputs to the model, to calculate the temporal and spatial distribution of water quality variables in the lake. Also the remote sensing data will be used for initial values for short term model predictions and validation the simulation results.

5 Conclusions and future plans

Ahti Lepistö and Timo Huttula

Lake Pyhäjärvi (154 km^2) in Säkylä is a highly valuable lake in terms of water supply and recreational use, and serves as the pilot area of the CatchLake project, together with its 306 km^2 catchment. Increased eutrophication of the Lake Pyhäjärvi has been a major concern since the late 1980s as Cyanobacteria blooms have become more and more frequent. In the CatchLake1 project (2006-2007), funded by Tekes, integrated use of catchment and lake models was developed by i) utilizing remote sensing technology, and ii) by intensive measurements with water quality sensors coupled with wireless data transmission technology. In the different sub-tasks, following conclusions were made together with future plans.

Intensive measurements in catchment
The measurements made in the CatchLake project during the years 2006-2007 in the Yläneenjoki catchment were successful. The collected data has proven its value and usability in many ways. Firstly, the frequent data has revealed cause-effect relationships between runoff and transport of soil and nutrients and thus improved understanding of the leaching and transport processes. Hence, the data has been welcome for parameterization of the catchment models SWAT and INCA. Secondly, more accurate estimates of the loading from the Yläneenjoki basin into the Lake Pyhäjärvi were obtained and the deficiencies of the manually sampled data were clearly demonstrated. Particularly in mild winters when the periods of high runoff and loading may occur during any time between November and April instead of predictable spring-floods, automatic, continuous data recording is superior to traditional sampling schemes. However, as proven by the main channel water sampling campaigns, there are research issues where manual sampling is a better solution. At the present, automatic measurement techniques still have limited amount of variables available. Moreover, the accuracy of the sensor-produced data is greatly improved by calibration with simultaneous water samples taken in different flow situations.

Land cover and phenology
So far, land cover and land use information has been based on Corine 2000 land cover classification and information about phenology has been derived from time-series of MODIS satellite images. At present, the update of Corine is under way and a new version, Corine 2006 will be finished in 2009. Also the production of phenology information will continue, most likely within Geoland2 -project. The main difference to previous product is that instead of MODIS-images MERIS-images willl be used.

The phenological time series has been used in nutrient leaching models in relatively simple way by changing the start date and length of growing period. In more advanced approach the growth curve could be calibrated against observed time series. Because growth curve is based on LAI in several nutrient leaching models, deriving

LAI from vegetation index values may improve the applicability of the phenological time series in catchment modelling.

Catchment models SWAT and INCA

The parameterization of the SWAT model, to obtain satisfactory calibration results in terms of flow and sediment dynamics, proved to be a laborious task. Obtaining satisfactory fit on daily basis was quite challenging for a long calibration period with varying flow patterns, and would require much more effort than has been done within the time limit of this project. The sensitivity analysis of the model proved to be useful by pointing out the most important parameters for calibration. Condensing the range of parameters probably improved the outcome. The continuous turbidity data showed that the model is not able to catch all relevant erosion processes. This may partly result from unrepresentative precipitation data and partly also from inadequacies in snow melting process descriptions. SWAT is not an event based model, and maybe such model is needed when continuous turbidity/suspended sediment concentration data is available for calibration and testing. In the CatchLake2 project, the SWAT will be further calibrated based on the new data.

The INCA-N model was reasonably well calibrated to Yläneenjoki catchment. The model was able to simulate annual dynamics of discharge and N flow. The simulation of peak NO_3-N concentrations were sometimes under- or overestimated, due to discrepancies in simulated discharge and rather simple description of actual management practices. The continuous NO_3-N sensor data proved to be extremely valuable for analyzing N concentration dynamics especially during autumn high flow. Interpretation of the data suggested several ideas for better calibration of N leaching in autumn. It is very important to be able to model autumn-winter losses correctly, because most of N is transported from catchments during the dormant season.

Incorporation of phenological and other, straighly remote-sensing based data will need much further work, and is one way to go forward. Further, in CatchLake2 project, SWAT and INCA results will be compared which makes it possible to confirm whether the SWAT scenario simulations for nitrogen are reliable. Invaluable information about the agricultural management practices used and protective measures implemented in the Yläneenjoki catchment so far, as well as about the measures planned for the future to protect the Lake Pyhäjärvi, is available by cooperative local farmers and authorities. By exploiting the good background information and local knowledge, efforts will be made to make even more realistic scenarios of the effects of agricultural management actions by using the catchment models.

In future, a special attention will also be paid for the significance of the coastal areas of the lake ("close-catchments" from where waters discharge directly into the lake instead of a distinct major channel), contributing to the total loading into the lake.

Spatial water quality: remote sensing and measurements

Remote sensing methods were able to retrieve spatial water quality information from Lake Pyhäjärvi, which is consistent with the surface measurements from the boat. The estimation of parameters such as turbidity and humic substances, a_{cdom}, is possible with simple algorithms when using MERIS data. The estimation of Chl-a still needs improvements. The quantitative estimation of water quality by the methods used here require concurrent *in situ* measurements for algorithms training.

Even a simple atmospheric correction method was able to reduce the effects of the atmosphere in turbidity estimation. When a ratio algorithm was used (e.g. for a_{cdom}) the use of atmospheric correction did not affect the results significantly.

During an ESA funded MERIS LAKES project, a processor that transforms MERIS data into water quality information is being developed until summer 2008. The processor is based on analytical methods and once ready will be employed in the

CatchLake2 project. The main advantage of the analytic interpretation methods is that they better enable the estimation of water quality without concurrent *in situ* measurements. The analytical methods require that the specific inherent optical properties (SIOPs) of water are known. SIOPs are e.g. specific absorption of phytoplankton and non-algal particles as well as specific scattering coefficient of particles. The SIOPs related to absorption were measured in Lake Pyhäjärvi in 2007 and these results will be utilized in the MERIS LAKES processor.

Lake modelling

LakeState model results were used to predict the consequences of loading reduction and fisheries management and to find optimal combination of these to actions with the given target summer maximum Cyanobacteria biomass. The model was capable to capture major dynamics of total P in 1990-2001, but not all of the variation of observed concentrations. In the ongoing CatchLake2 project, LakeState modeling will be further developed. Also a full three-dimensional model, Coherens (Luyten et al., 1999), will be applied to Lake Pyhäjärvi, to simulate the spatial heterogeneity of water quality which can be compared with observations from field campaigns. Temporal water quality variations in the lake under different loading scenarios will be simulated in the future work. Further, lake modeling will be developed for utilization of the water quality time series obtained from the satellite images, which are available on an almost-daily basis.

Changing climate, particularly mild winters increase diffuse pollution and threaten quality of freshwater resources. This means that new tools discussed and tested here, such as intensive measurements, together with advanced mathematical models and remote sensing, are increasingly needed in environmental research and water protection.

6 Acknowledgements

This work has been supported by Tekes (Finnish Funding Agency for Technology and Innovation). We would also like to acknowledge Dr Marjo Tarvainen and Dr Anne-Mari Ventelä from Pyhäjärvi Protection Fund, Kauttua, for co-operation, and Dr Andrew Wade, AERC Reading University, UK, for co-operation in INCA modelling.

7. References

Anttila, S., Metsämäki, S., Pullliainen, J. & Luojus, K. 2005. From EO Data to Snow Covered Area (SCA) End Products Using Automated Processing System. Proceedings of International Geoscience and Remote Sensing Symposium 2005, vol. 3. Pp. 1947–1950.

Andersson, K. 2005. Software for processing HDF-EOS data User's Guide Version 2.05. VTT Information Technology.

Arnold, J.G., Srinivasan, R., Muttiah, R.S. & Williams, J.R. 1998. Large area hydrologic modelling and Assessment part I: model development. Journal of American Water Resources Association 34(1): 73–89.

Bärlund, I., Kirkkala, T., Malve, O. & Kämäri, J. 2007. Assessing SWAT model performance in the evaluation of management actions for the implementation of the Water Framework Directive in a Finnish catchment. Environmental Modelling & Software 22(5): 719–724.

Dilks, C.F., Dunn, S.M. & Ferrier, R.C. 2003. Benchmarking models for the Water Framework Directive: evaluation of SWAT for use in the Ythan catchment, UK. In: Arnold, J. et al. (eds.). Condensed abstracts of the 2nd International SWAT Conference, 1.-4.7.2003, Bari, Italy. Pp 63–66.

Eckhardt, K., Haverkamp, S., Fohrer, N. & Frede, H.-G. 2002. SWAT-G, a version of SWAT99.2 modified for application to low mountain range catchments. Physics and Chemistry of the Earth 27: 641–644.

Ekholm, P., Malve, O. & Kirkkala, T. 1997. Internal and external loading as regulators of nutrient concentrations in the agriculturally loaded Lake Pyhäjärvi (southwest Finland). Hydrobiologia 345: 3–14.

van Griensven, A., Francos, A. & Bauwens, W. 2002. Sensitivity analysis and auto-calibration of an integral dynamic model for river water quality. Water Science and Technology 45(9): 325–332.

Grönroos, J., Rekolainen, S., Palva, R., Granlund, K., Bärlund, I., Nikander, A. & Laine, Y. 1998. Maatalouden ympäristötuki: toimenpiteiden toteutuminen ja vaikutukset v. 1995–1997. Finnish Environment 239. Finnish Environment Institute, Helsinki. 77 p. (In Finnish).

Huttula T. 1994. Suspended sediment transport in Lake Säkylän Pyhäjärvi. Aqua Fennica 24(2): 171–185.

Hyvärinen, V. (ed.). 1999. Hydrological Yearbook 1995. The Finnish Environment 280. Finnish Environment Institute, Helsinki. 151 p.

Kallio K., Kutser, T., Hannonen T., Kutser T., Koponen S., Pulliainen J. Vepsäläinen J. & Pyhälahti T. 2001. Retrieval of water quality variables from airborne spectrometry of various lake types in different seasons. The Science of The Total Environment 268: 59–77.

Kaste, O., Wright, R.F., Barkved, L.J., Bjerkeng, B., Engen-Skaugen, T., Magnusson, J. & Saelthun, N.R. 2006. Linking models to assess the impacts of climate change on nitrogen in a Norwegian river basin and fjord system. Science of Total Environment 365: 200-222.

Koponen, S., Pulliainen, J., Kallio, K. & Hallikainen, M. 2002. Lake water quality classification with airborne hyperspectral spectrometer and simulated MERIS-data. Remote Sensing of Environment 79(1): 51–59.

Koponen, S., Attila, J., Pulliainen, J., Kallio, K., Pyhälahti, T., Lindfors, A., Rasmus, K. & Hallikainen, M. 2007. A case study of airborne and satellite remote sensing of a spring bloom event in the Gulf of Finland. Continental Shelf Research 27(2): 228–244.

Koskiaho, J., Ekholm, P., Räty, M., Riihimäki, J. & Puustinen, M. 2003. Retaining agricultural nutrients in constructed wetlands - experiences under boreal conditions. Ecological Engineering 20(1): 89–103.

Krysanova, V., Bronstert, A. & Müller-Wohlfeil, D.-I. 1999. Modelling river discharge for large drainage basins: from lumped to distributed approach. Hydrological Sciences-Journal des Sciences Hydrologiqes 44(2): 313–331.

Lehtoranta, J. & Gran, V. 2002. Sedimentistä veteen vapautuvat ravinteet Pyhäjärvellä. Mimeograph series of the Finnish Environment Institute 247. Finnish Environment Institute, Helsinki. 31 p. (In Finnish).

Lepistö, A., Granlund, K., Kortelainen, P. & Räike, A. 2006. Nitrogen in river basins: Sources, retention in the surface waters and peatlands, and fluxes to estuaries in Finland. Science of Total Environment 365: 238-259.

Luyten, P.J., Jones, J.E., Proctor, R., Tabor, A., Tett, P. & Wild-Allen K. 1999. COHERENS – A coupled hydrodynamical-ecological model for regional and shelf seas: User documentation. MUMM Report, Management Unit of the Mathematical Models of the North Sea. 911 p.

Malve O., Ekholm, P., Kirkkala, T., Huttula, T. & Krogerus, K. 1994. Säkylän Pyhäjärven ravinnekuormitus ja rehevyystaso. Nutrient load and trophic level of Lake Pyhäjärvi (Säkylä). Publications of National Board of waters and the Environment. Series A 181. ISBN 951-47-9419-2.

Malve, O. 2007. Water quality prediction for river basin management. Doctoral dissertation. Helsinki University of Technology. Espoo, Finland. TKK-DISS-2292. ISBN 978-951-22-8749-9. http://lib.tkk.fi/Diss/2007/isbn9789512287505/

Mattila, H., Kirkkala, T., Salomaa, E., Sarvala, J. & Haliseva-Soila, M. (eds.). 2001. Pyhäjärvi. Pyhäjärvi-instituutin julkaisuja 26. Pyhäjärven suojelurahasto. 108 p. (In Finnish).

Morris, M.D. 1991. Factorial sampling plans for preliminary computational experiments. Technometrics 33(2): 161-174.

Nash, J.E. & Sutcliffe, J.V. 1970. River flow forecasting through conceptional models, Part 1 – A discussion of principles. Journal of Hydrology 10: 282–290.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. & Williams, J.R. 2005. Soil and Water Assessment Tool – Theoretical Documentation - Version 2005. Blackland Research Center – Agricultural Research Service, Texas, USA. 541 p.

Palva, R., Rankinen, K., Granlund, K., Grönroos, J., Nikander, A. & Rekolainen, S. 2001. Environmental Impacts of Agri-Environmental Support Scheme in 1995–1999. Final report of the MYTVAS-project. The Finnish Environment 478. Finnish Environment Institute, Helsinki. 92 p. (In Finnish with English abstract).

Puustinen, M., Koskiaho, J. & Peltonen, K. 2005. Influence of cultivation methods on suspended solids and phosphorus concentrations in surface runoff on clayey sloped fields in boreal climate. Agriculture, Ecosystems & Environment 105: 565–579.

Pyhälahti, T., Teiniranta, R., Kallio, K., Vepsäläinen, J., Koponen, S. & Pulliainen, J. 2002. Target Area Approach In Remote Sensing Of Lakes And Coastal Zone. Proceedings of the Ocean Optics XVI conference, Santa Fe, New Mexico, USA, November 18–22, 2002.

Pyykkönen, S., Grönroos, J., Rankinen, K., Laitinen, P., Karhu, E. & Granlund, K. 2004. Cultivation measures in 2000–2003 and their effects to the nutrient runoff to the waters in the farms committed to the Agri-Environmental Programme. The Finnish Environment 711. 119 p. (In Finnish with English abstract).

Rahman, H. & Dedieu G. 1994. SMAC: A Simplified Method for the Atmospheric Correction of Satellite Measurements in the Solar Spectrum. International Journal of Remote Sensing 15: 123–143.

Rankinen, K., Kaste, O. & Butterfield, D. 2004a. Adaptation of the Intergrated Nitrogen Model for Catchments (INCA) to seasonally snow-covered catchments. Hydrology And Earth System Sciences 8(4): 695–705.

Rankinen, K., Karvonen, T. & Butterfield, D. 2004b. A simple model for predicting soil temperature in snow-covered and seasonally frozen soil: model description and testing. Hydrology And Earth System Sciences 8(4): 706–716.

Rankinen, K., Granlund, K. & Bärlund, I. 2004c. Modelling of seasonal effects of soil processes on N leaching in northern latitudes. Nordic Hydrology 35: 347–357.

Sarvala, J., Helminen, H., Saarikari, V., Salonen, S. & Vuorio, K. 1998. Relations between planktivorous fish abundance, zooplankton and phytoplankton in three lakes of differing productivity. Hydrobiologia 363: 81–95.

Sarvala, J., Helminen, H. & Karjalainen, J. 2000. Restoration of Finnish lakes using fish removal: changes in the chlorophyll-phosphorus relationship indicate multiple controlling mechanisms. Verhandlungen der Internationalen Vereinigung für theoretische und angewandte Limnologie 27: 1473–1479.

Schiller, H. & Doerffer, R. 1999. Neural network for emulation of an inverse model – operational derivation of Case II water properties from MERIS data. International Journal of Remote Sensing 9: 1735–1746.

Törmä, M., Rankinen, K. & Härmä, P. 2007. Using phenological information derived from MODIS-data to aid nutrient modeling. IEEE International Geoscience and Remote Sensing Symposium, 23-28 July 2007, Barcelona Spain, IGARSS 2007 Proceedings. Pp. 2298-2301.

Uusi-Kämppä, J. 2005. Phosphorus purification in buffer zones in cold climates. Ecological Engineering 24(5): 491–502.

Vehviläinen, B. 1994. The watershed simulation and forecasting system in the National Board of Waters and the Environment. Publications of the Water and Environment Research Institute 17: 3–16.

Vehviläinen, B. & Huttunen, M. 2002. The Finnish watershed simulation and forecasting system (WSFS). XXIst Conference of the Danubian countries on the hydrological forecasting and hydrological bases of water management. Bucharest-Romania. 2–6 September 2002.

Ventelä, A.-M., Tarvainen, M., Helminen, H. & Sarvala, J. 2007. Long-term management of Pyhäjärvi (southwest Finland): eutrophication, restoration - recovery? Lake And Reservoir Management 23: 428–438.

Wade, A.J., Durand, P., Beaujouan, V., Wessels, W., Raat, K., Whitehead, P.G., Butterfield, D., Rankinen, K. & Lepistö, A. 2002. A nitrogen model for European catchments: New model structure and equations. Hydrology And Earth System Sciences 6: 559–582. (See also Errata. Hydrology And Earth System Sciences 8: 858–859).

Whitehead, P.G., Wilson, E.J. & Butterfield, D. 1998. A semi-distributed Integrated Nitrogen model for multiple source assessment in Catchments (INCA): Part I – model structure and process equations. Science of The Total Environment 210/211: 547–558.

APPENDIX 1. Sensitivity analysis for the SWAT model

Table App1-1 shows the results of the sensitivity analyses for the SWAT model application. Every model run covered six years (1994-1999). The first year was used as "warm-up" period. In this study, the sensitivity analysis was performed on the daily average flow and on the daily average suspended solids concentration. The analysis was first performed without observed data and then using observed data. The general watershed parameters SURLAG (Surface runoff lag coefficient) and TIMP (Snow pack temperature lag factor) seemed to be the most sensitive parameters for flow in the case without observed data. However, with observed data the importance of groundwater (GWQMN), management (CN2) and soil parameters (SOL_AWC, SOL_Z and SOL_K) was increased.

In terms of sediment concentration, more parameters were in the sensitivity class of "very high" and "high" than in the case of flow (Table App1-1). The most sensitive parameters were general watershed parameters SPCON and SURLAG and main channel characteristics (CH_COV and CH_EROD).

Table App1-1. Sensitivity of the average daily flow and sediment concentration to input parameters with and without observed.

FLOW, no observed data			FLOW, with observed data			SED.CONC., no observed data			SED.CONC., with obs. data		
Rank	Mean	Parname	Rank	Mean	Parname	Rank	Mean	Parname	Rank	Mean	Parname
🟧 1	0,41	SURLAG	🟧 1	0,71	GWQMN	🟥 1	8,23	SPCON	🟥 1	4,35	SPCON
🟧 2	0,30	TIMP	🟧 2	0,38	SOL_Z	🟥 2	2,49	CH_COV	🟥 2	2,61	CH_COV
🟦 3	0,16	SMFMX	🟧 3	0,37	TIMP	🟥 3	1,90	CH_EROD	🟥 3	1,80	CH_EROD
🟦 4	0,13	SMFMN	🟧 4	0,36	ESCO	🟥 4	1,15	SURLAG	🟥 4	1,04	SURLAG
🟦 5	0,10	SOL_AWC	🟧 5	0,33	SOL_AWC	🟥 5	1,06	CN2	🟧 5	0,77	GWQMN
🟦 6	0,09	GWQMN	🟧 6	0,30	CN2	🟧 6	0,98	CH_N	🟧 6	0,76	TIMP
🟦 7	0,08	CH_K2	🟧 7	0,20	SOL_K	🟧 7	0,70	SPEXP	🟧 7	0,53	CH_K2
🟦 8	0,07	SMTMP	🟦 8	0,19	REVAPMN	🟧 8	0,64	GWQMN	🟧 8	0,49	CH_N
🟦 9	0,06	ESCO	🟦 9	0,09	RCHRG_DP	🟧 9	0,63	ESCO	🟧 9	0,45	CN2
🟩 10	0,05	CN2	🟦 10	0,08	SMTMP	🟧 10	0,57	SOL_K	🟧 10	0,34	ESCO
🟩 11	0,04	SOL_K	🟦 11	0,06	SFTMP	🟧 11	0,52	SMFMN	🟧 11	0,24	SOL_AWC
🟩 12	0,04	SOL_Z	🟦 12	0,06	SMFMX	🟧 12	0,49	TIMP	🟦 12	0,17	REVAPMN
🟩 13	0,02	SFTMP	🟦 13	0,06	SMFMN	🟧 13	0,48	SOL_AWC	🟦 13	0,15	SPEXP
🟩 14	0,01	CH_N	🟦 14	0,06	SURLAG	🟧 14	0,43	SMFMX	🟦 14	0,14	SOL_Z
🟩 15	0,01	RCHRG_DP	🟩 15	0,01	SLOPE	🟧 15	0,42	SMTMP	🟦 15	0,13	SMTMP
🟩 16	0,01	ALPHA_BF	🟩 16	0,01	GW_REVAP	🟧 16	0,37	CH_K2	🟦 16	0,12	SMFMX
🟩 17	0,01	REVAPMN	🟩 17	0,01	GW_DELAY	🟧 17	0,30	SOL_Z	🟦 17	0,11	RCHRG_DP
🟩 18	0,00	SLSUBBSN	🟩 18	0,01	CH_K2	🟧 18	0,29	REVAPMN	🟦 18	0,08	SOL_K
🟩 19	0,00	SOL_ALB	🟩 19	0,01	CANMX	🟦 19	0,20	RCHRG_DP	🟦 19	0,07	SMFMN
🟩 20	0,00	SLOPE	🟩 20	0,01	SOL_ALB	🟦 20	0,17	ALPHA_BF	🟦 20	0,06	SLOPE
🟩 21	0,00	GW_REVAP	🟩 21	0,00	CH_N	🟦 21	0,12	GW_DELAY	🟦 21	0,05	SFTMP
🟩 22	0,00	GW_DELAY	🟩 22	0,00	ALPHA_BF	🟦 22	0,12	SLOPE	🟦 22	0,05	ALPHA_BF
🟩 23	0,00	CANMX	🟩 23	0,00	SLSUBBSN	🟦 23	0,06	SFTMP	🟦 23	0,05	GW_DELAY
🟩 24	0,00	EPCO	🟩 24	0,00	EPCO	🟦 24	0,05	USLE_C	🟩 24	0,04	USLE_C
			🟩 25	0,00	USLE_C	🟩 25	0,04	SLSUBBSN	🟩 25	0,02	SLSUBBSN
						🟩 26	0,02	GW_REVAP	🟩 26	0,02	CANMX
						🟩 27	0,02	CANMX	🟩 27	0,00	GW_REVAP
						🟩 28	0,01	SOL_ALB	🟩 28	0,00	SOL_ALB
						🟩 29	0,00	USLE_P	🟩 29	0,00	USLE_P
						🟩 30	0,00	EPCO	🟩 30	0,00	EPCO
						🟩 31	0,00	BIOMIX			

🟥 Very high sensitivity
🟧 High sensitivity
🟦 Medium sensitivity
🟩 Low sensitivity

Table App1-2. Autocalibration results of 6 simulations made for a selected set of parameters with SWAT.

Parameter	Initial, best guess	Best parameter	Good range
SMTMP	-0,1	1,28	0,92-1,63
SMFMX	2,6	4,56	3,6-6
SMFMN	1,3	0,096	0-0,46
TIMP	0,9	0,983	0,8-1
ESCO	0,95	0,891	0,79-1
EPCO	1	0,889	0,79-1
SURLAG	4	0,424	0,25-0,52
GWQMN	0,4	158	0-206
SOL_AWC	0,22	0,94	0,78-1
CN2	82	81	77-90

APPENDIX 2. Atmospheric correction of MERIS data - in spatial water quality and remote sensing

Fig. App2-1 shows the MERIS turbidity result for the three campaign dates in 2006 with and without atmospheric correction. The correction was based on the SMAC method and uses daily atmospheric parameters. As can be seen, the correction improved the estimation by removing differences between dates. In Fig. App2- 2 this improvement is shown in a scatter-plot format. When the correction is used the data points move closer to each other. Fig. App2-3 shows scatter plots for $a_{cdom}(400)$. With the channel-ratio algorithm the atmospheric correction did not change the results significantly.

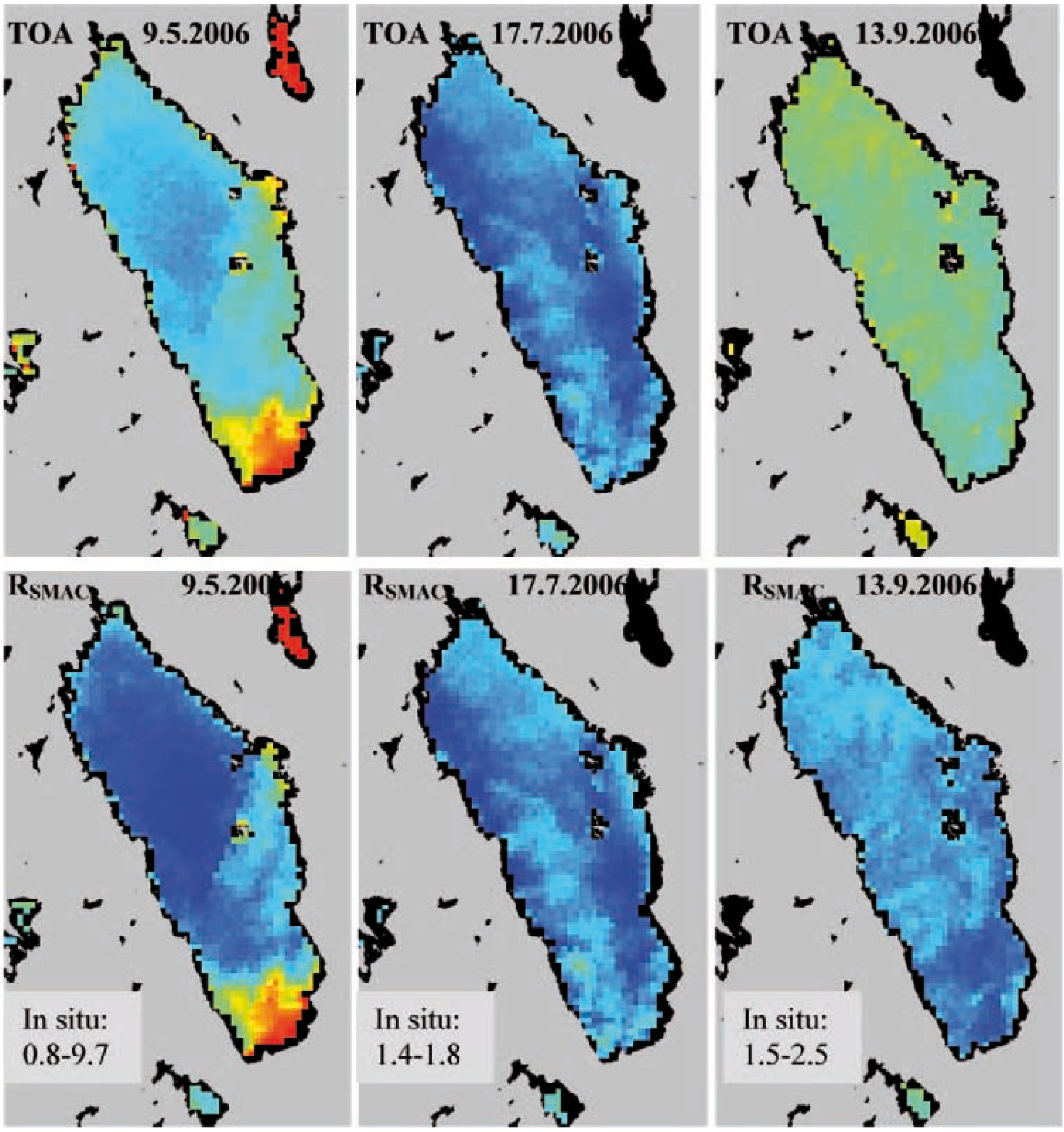


Fig. App2-1. The effect of the atmospheric correction (SMAC) on the estimation of turbidity from MERIS data on 9.5.2006, 17.7.2006 and 13.9.2006. The top row shows the top-of-atmosphere (TOA) reflectance values of MERIS channel 9 (708 nm). The bottom row shows the result after atmospheric correction (RSMAC). The *in situ* values shown in the images indicate the turbidity range of water sample data.

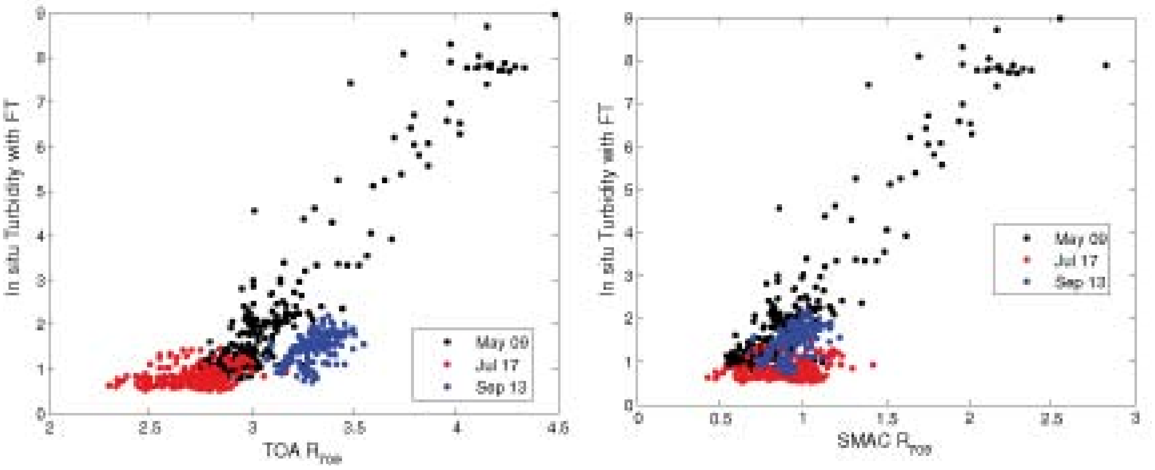


Fig. App2-2. Estimation of turbidity using MERIS data with and without SMAC during 2006. TOA R709 and SMAC R709 are the top-of-atmosphere and SMAC corrected reflectances, respectively. FT = transect data.

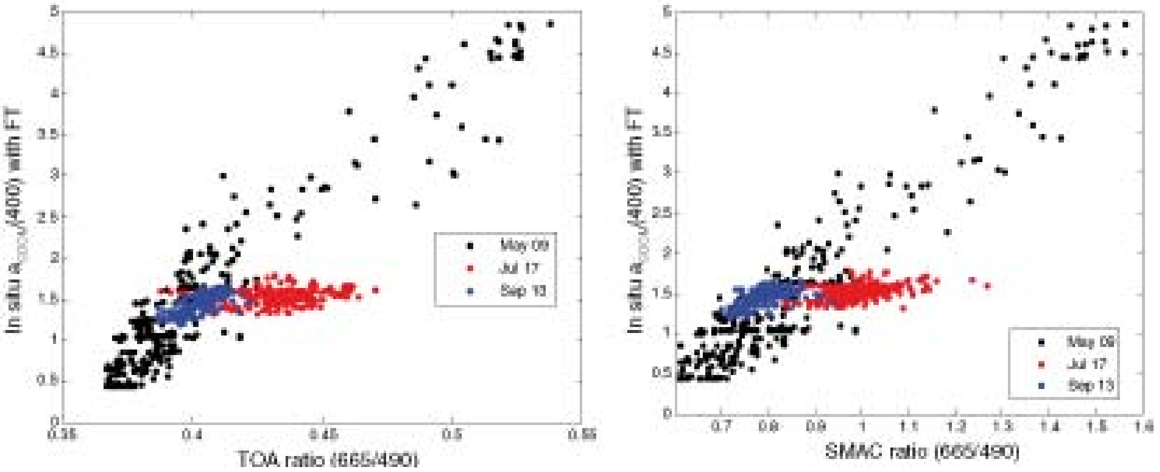


Fig. App2-3. Estimation of $a_{cdom}(400)$ using a MERIS channel ratio with and without SMAC during 2006. TOA ratio (665/490) is the ration of the top-of-atmosphere reflectances of channels centered at 665 and 490 nm. SMAC ratio (665/490) is the same atmospherically corrected reflectances. FT = transect data.

DOCUMENTATION PAGE

Publisher	Finnish Environment Institute SYKE			*Date* May 2008
Author(s)	Ahti Lepistö, Timo Huttula, Ilona Bärlund, Kirsti Granlund, Pekka Härmä, Kari Kallio, Mikko Kiirikki, Teija Kirkkala Sampsa Koponen, Jari Koskiaho, Niina Kotamäki, Antti Lindfors, Olli Malve, Timo Pyhälahti, Sirkka Tattari and Markus Törmä			
Title of publication	**New measurement technology, modelling, and remote sensing in the Säkylän Pyhäjärvi area – CatchLake**			
Publication series and number	Reports of Finnish Environment Institute 15/2008			
Theme of publication				
Parts of publication/ other project publications	http://www.ymparisto.fi/syke/catchlake			
Abstract	New environment technologies, such as the use of high resolution measurements together with advanced mathematical models, are increasingly required in monitoring and environmental research for water protection. Sensors, wireless techniques, remote sensing and models are continually progressing. Climate change -induced mild winters challenge the traditional measures to reduce diffuse loading, and suggest a need for further development of environmental monitoring schemes. Innovative measuring technologies offer new possibilities for this work. Lake Pyhäjärvi (154 km^2) is of great importance both regionally and nationally. A large number of management measures have been applied both in the catchment and in the lake itself, but more real-time, detailed data and model-based scenarios are required for water protection studies. CatchLake1 project (2006-2007) was divided into three parts: modelling, lake and catchment measurements, and remote sensing. Integrated catchment models (SWAT and INCA-N) were applied at the Yläneenjoki catchment to simulate suspended solids, phosphorous and nitrogen loading to the lake. Intensive measurements from measuring campaigns over the whole river catchment were utilized in modelling. A custom-made flow-through method was used to collect high resolution transect datasets of water quality information from Lake Pyhäjärvi in six campaigns. Remote sensing methods were applied to retrieve spatial water quality information from Lake Pyhäjärvi, which was consistent with surface measurements from a boat. In the ongoing CatchLake2 project (2008-2009), the 3-d model Coherens will be applied to Lake Pyhäjärvi to simulate the spatial heterogeneity of water quality. In addition, measuring techniques, remote sensing time series and linking of catchment and lake models will be developed.			
Keywords	water quality, nutrient loading, measuring technology, modelling, remote sensing, water protection			
Financier/ commissioner	Tekes (Finnish Funding Agency for Technology and Innovation), Finnish Environment Institute SYKE			
	ISBN (pbk.)	ISBN 987-952-11-3125-7 (PDF)	ISSN (print)	ISSN 1796-1726 (online)
	No. of pages 73	*Language* English	*Restrictions* Public	*Price (incl. tax 8 %)*
For sale at/ distributor	Finnish Environment Institute SYKE, Custom service, P.O.Box 140, FI-00251 Helsinki, Finland Email: neuvonta.syke@ymparisto.fi			
Financier of publication	Finnish Environment Institute SYKE, P.O.Box 140, FI-00251 Helsinki, Finland Email: neuvonta.syke@ymparisto.fi, www.environment.fi/syke			
Printing place and year				

KUVAILULEHTI

Julkaisija	Suomen ympäristökeskus SYKE			*Julkaisuaika* Toukokuu 2008
Tekijä(t)	Ahti Lepistö, Timo Huttula, Ilona Bärlund, Kirsti Granlund, Pekka Härmä, Kari Kallio, Mikko Kiirikki, Teija Kirkkala Sampsa Koponen, Jari Koskiaho, Niina Kotamäki, Antti Lindfors, Olli Malve, Timo Pyhälahti, Sirkka Tattari ja Markus Törmä			
Julkaisun nimi	**New measurement technology, modelling, and remote sensing in the Säkylän Pyhäjärvi area – CatchLake** (Uusi mittaustekniikka, mallinnus ja kaukokartoitus Säkylän Pyhäjärven alueella – CatchLake -hanke)			
Julkaisusarjan nimi ja numero	Suomen ympäristökeskuksen raportteja 15/2008			
Julkaisun teema				
Julkaisun osat/ muut saman projektin tuottamat julkaisut	http://www.ymparisto.fi/syke/catchlake			
Tiivistelmä	Ympäristömittausten, mallintamisen ja -monitoroinnin markkinoiden uskotaan kasvavan merkittävästi tulevaisuudessa: uusia antureita, ajantasaista tiedonsiirtoa ja kaukokartoitus-tekniikoita kehitetään jatkuvasti. Ilmastonmuutoksen myötä lisääntyvät leudot talvet aiheuttavat haasteita sekä hajakuormituksen vähentämistavoitteille että ympäristön monitoroinnille. Tässä työssä kehittyneet mittaustekniikat ja mallit tarjoavat uusia mahdollisuuksia. Säkylän Pyhäjärvi (154 km^2) on merkittävä sekä alueellisesti että valtakunnallisesti. Sen valuma-alueella ja itse järvessä on toteutettu lukuisia vesiensuojelutoimia, joilla kuormitusta on saatu vähenemään. Vesiensuojelun vauhdittamiseksi tarvitaan kuitenkin entistä reaaliaikaisempaa täsmätietoa ja ennusteita. CatchLake1 -hanke (2006-2007) koostui kolmesta osasta: mallinnuksesta, mittauksista valuma-alueella ja järvellä, sekä kaukokartoituksesta. Ravinne- ja kiintoainekuormitus Yläneenjoen valuma-alueella mallinnettiin integroiduilla SWAT- ja INCA-N malleilla. Mallisovellusten vertailuaineistoksi mitattiin vedenlaadun vaihtelua jokiuomista automaattisilla mittausasemilla. Pyhäjärvellä toteutettiin kuusi mittauskampanjaa, joissa kartoitettiin vedenlaadun alueellista vaihtelua läpivirtauslaitteistolla liikkuvasta veneestä. Järven alueellinen vedenlaatu tuotettiin myös tulkitsemalla satelliittihavaintojen aikasarjoja. Näillä riippumattomilla menetelmillä saadut tulokset olivat hyvin vertailukelpoisia keskenään. Alueellista järviaineistoa on tarkoitus jatkossa hyödyntää prosessipohjaisessa järvimallinnuksessa. Tekes on myöntänyt rahoituksen CatchLake2 –jatkohankkeeseen (2008-2009), joka painottuu enemmän järvitutkimukseen: aiheina kaukokartoitusaikasarjat, mittaustekniikan kehittäminen ja järven 3-d mallinnus.			
Asiasanat	Vedenlaatu, ravinnekuormitus, mittaustekniikka, mallintaminen, kaukokartoitus, vesiensuojelu			
Rahoittaja/ toimeksiantaja	TEKES, Suomen ympäristökeskus			
	ISBN (nid.)	ISBN 987-952-11-3125-7 (PDF)	ISSN (pain.)	ISSN 1796-1726 (verkkoj.)
	Sivuja 73	*Kieli* Englanti	*Luottamuksellisuus* Julkinen	*Hinta (sis.alv 8 %)*
Julkaisun myynti/ jakaja	Suomen ympäristökeskus (SYKE), PL 140, 00251 HELSINKI Sähköposti: neuvonta.syke@ymparisto.fi, www.ymparisto.fi/syke			
Julkaisun kustantaja	Suomen ympäristökeskus (SYKE), PL 140, 00251 HELSINKI Sähköposti: neuvonta.syke@ymparisto.fi, www.ymparisto.fi/syke			
Painopaikka ja -aika				

PRESENTATIONSBLAD

Utgivare	Finlands miljöcentral SYKE			*Datum* Maj 2008
Författare	Ahti Lepistö, Timo Huttula, Ilona Bärlund, Kirsti Granlund, Pekka Härmä, Kari Kallio, Mikko Kiirikki, Teija Kirkkala Sampsa Koponen, Jari Koskiaho, Niina Kotamäki, Antti Lindfors, Olli Malve, Timo Pyhälahti, Sirkka Tattari och Markus Törmä			
Publikationens titel	**New measurement technology, modelling, and remote sensing in the Säkylän Pyhäjärvi area – CatchLake** (Ny mätningsteknologi, modellering och fjärranalys i Säkylä Pyhäjärvi området - CatchLake)			
Publikationsserie och nummer	Finlands miljöcentrals rapporter 15/2008			
Publikationens tema				
Publikationens delar/ andra publikationer inom samma projekt	http://www.ymparisto.fi/syke/catchlake			
Sammandrag	Nya metoder för miljöanalys, som t.ex. intensiva mätningar tillsammans med avancerade matematiska modeller behövs allt mera i vattenskydd, uppföljning och miljöforskning. Sensorer, trådlös teknologi, fjärranalys och modeller gör fortlöpande framsteg. Mildare vintrar som följd av klimatförändringen utgör en utmaning för de traditionella metoderna som använts för att minska den diffusa belastningen. Därför krävs en vidare utveckling av miljöuppföljningsscheman. Sjön Pyhäjärvi (154 km^2) är av hög regional och nationell betydelse. Ett stort antal åtgärder för miljöskötsel har tillämpats både på avrinningsområdet och i själva sjön men mera realtida, detaljerade data och modell scenarier behövs för vattenskyddet. Projektet CatchLake1 (2006-2007) var tredelat i modellering, mätningar i avrinningsområdet och i sjön samt i fjärranalys. Integrerade modeller (SWAT och INCA-N) tillämpades för Yläneenjoki avrinningsområdet för att simulera belastningen av suspenderade ämnen, fosfor och kväve till sjön. Dessutom användes intensiva mätningar från mätningskampanjer från över hela avrinningsområdet i modelleringen. En specialutvecklad genomströmningsmetod tillämpades per båt för att samla vattenkvalitetsdata i tvärsnitt av hög resolution från sjön Pyhäjärvi vid sex mätningskampanjer. Samtida fjärranalysresultat analyserades för att återfå spatial information för vattenkvalitetet i sjön Pyhäjärvi som jämförelse med in situ mätningarna. I det pågående CatchLake2 projektet (2008-2009) används den tredimensionella sjömodellen Coherens för att simulera den spatiala heterogeniteten av vattenkvalitetet. Därtill utvecklas mätningstekniken och tidsserier från fjärranalys såsom anknytningen av modeller för avrinningområdet och sjön.			
Nyckelord	*vattenkvalitet, näringsbelastning, mätningsteknologi, modellering, fjärranalys, vattenskydd*			
Finansiär/ uppdragsgivare	Suomen ympäristökeskus SYKE			
	ISBN (hft.)	ISBN 987-952-11-3125-7 (PDF)	ISSN (print)	ISSN 1796-1726 (online)
	Sidantal 73	*Språk* Engelska	*Offentlighet* Offentlig	*Pris (inneh. moms 8 %)*
Beställningar/ distribution	Finlands miljöcentral (SYKE), kundservice, PB 140, 00251 Helsingfors Epost: neuvonta@ymparisto.fi			
Förläggare	Finlands miljöcentral (SYKE), PB 140, 00251 Helsingfors Epost: neuvonta@ymparisto.fi, www.miljo.fi/syke			
Tryckeri/tryckningsort och -år				

New environment technologies, such as the use of high resolution measurements together with advanced mathematical models, are increasingly required in monitoring and environmental research for water protection. Sensors, wireless techniques, remote sensing and models are continually progressing. Climate change -induced mild winters challenge the traditional measures to reduce diffuse loading, and suggest a need for further development of environmental monitoring schemes. Innovative measuring technologies offer new possibilities for this work.

Lake Pyhäjärvi (154 km2) is of great importance both regionally and nationally. A large number of management measures have been applied both in the catchment and in the lake itself, but more real-time, detailed data and model-based scenarios are required for water protection studies. CatchLake1 project (2006-2007) was divided into three parts: modelling, lake and catchment measurements, and remote sensing. Integrated catchment models (SWAT and INCA-N) were applied at the Yläneenjoki catchment to simulate suspended solids, phosphorous and nitrogen loading to the lake. Intensive measurements from measuring campaigns over the whole river catchment were utilized in modelling. A custom-made flow-through method was used to collect high resolution transect datasets of water quality information from Lake Pyhäjärvi in six campaigns. Remote sensing methods were applied to retrieve spatial water quality information from Lake Pyhäjärvi, which was consistent with surface measurements from a boat.

In the ongoing CatchLake2 project (2008-2009), the 3-d model Coherens will be applied to Lake Pyhäjärvi to simulate the spatial heterogeneity of water quality. In addition, measuring techniques, remote sensing time series and linking of catchment and lake models will be developed.

NEW MEASUREMENT TECHNOLOGY, MODELLING, AND REMOTE SENSING IN THE SÄKYLÄN PYHÄJÄRVI AREA – CATCHLAKE

SYKE

TEKNILLINEN KORKEAKOULU
TEKNISKA HÖGSKOLAN
HELSINKI UNIVERSITY OF TECHNOLOGY

PYHÄJÄRVI INSTITUUTTI

Tekes

ISBN 987-952-11-3125-7 (PDF)
ISSN 1796-1726 (verkkoj.)

FINNISH ENVIRONMENT INSTITUTE