NORTHERN HYDROLOGY AND ITS GLOBAL ROLE

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SIGURLAUG GUNNLAUGSDÓTTIR

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Northern Hydrology and its Global Role

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SESSION 5: ADVANCED METHODS AND TECHNOLOGIES IN HYDROLOGICAL PRACTICE

MONITORING SYSTEM FOR GROUNDWATER AND SOIL WATER BASED ON SIMULATIONS AND REAL-TIME OBSERVATIONS: THE NORWEGIAN EXPERIENCE

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ABSTRACT

The Norwegian Water Resources and Energy Directorate (NVE) is responsible for the administration of Norway's water and energy resources. NVE collects data characterising the quantitative aspect of the land phase of the water cycle. The national observation network for groundwater and soil moisture consists of 17 automated stations for soil moisture and temperature and 65 stations for groundwater. Due to the sparse station network and a relative short period with data, hydrological models are a requisite to describe the water and energy balances on a national scale. NVE is developing a new method to produce soil moisture and groundwater maps based on both daily model simulations and real-time observations. A spatially distributed version of the conceptual HBV-model and a physically-based 1-dimensional model (COUP) are applied. A Web- and GIS-based system developed for producing snow, water and climate maps is used to disseminate information on groundwater and soil water situation (seNorge.no). The usefulness and effectiveness of the system to forecast and follow extreme hydrological conditions are illustrated and discussed using examples from the period 1990-2007 (hydroelectricity and water shortage, floods and landslides).

Keywords: HBV, COUP, landslide, flood, drought, water shortage, soil water deficit, hydropower.

INTRODUCTION

The Norwegian landscape is characterised by fjords and mountains, glaciers, boreal and alpine forests and a large number of lakes and bogs. Aquifers in Norway consist mainly of small, highly permeable glaciofluvial deposits along streams and lakes located in typical U-shaped valleys, and small precipitation-fed tills in mountains, both overlying fractured bedrock without primary porosity (mainly crystalline and metamorphosed hard rocks).

The groundwater and soil water conditions are controlled by the physiographic and climatic conditions (temperature and precipitation). Snow and soil frost, together with evapotranspiration, affect the recharge, and thereby the fluctuation of the groundwater level and discharge quantity to rivers. Base flow analyses showed that in the Glomma catchment in the south-eastern Norway, 80 to 100 % of the total river discharge comes from groundwater in periods with low flow, typically in winter and late summer (Wong and Colleuille, 2005; Colleuille et al., 2006). Even in periods with snowmelt and flood, a considerable amount of groundwater contributes to the river flow. The percentage of groundwater contribution is considerably lower (35-70 %) in western Norway due to a sharp topography, the lack of porous media on the mountains and the maritime climate. Norwegian aquifers have generally a limited storage capacity and are thereby sensitive to extreme climatic variation, controlling hazardous events such as landslides, floods and droughts.

The Norwegian Water Resources and Energy Directorate (NVE) is responsible for the administration of Norway's water and energy resources. The Hydrology Department collects water-related data covering the quantitative aspects of the land phase of the water cycle, and is developing tools to manage national water resources (including flood and drought forecasting, inflow for hydropower production, snow, glacier, sedimentation, water temperature, soil water and groundwater).

The purpose of this article is to present our experience in developing a tool providing national daily information on groundwater and soil water conditions. Analysis of extreme hydrological conditions is illustrated and discussed in this article using examples in the period 1990-2007 (hydroelectricity and water shortage, floods and landslides).

MATERIAL AND METHODS

Monitoring network

Currently NVE operates about 65 groundwater-monitoring areas using 80 observation wells and has 17 stations for soil moisture and temperature measurements in Norway (including Svalbard). These stations are monitored in cooperation with the Norwegian Geological Survey (NGU), Norwegian Institute for Agricultural and Environmental Research (Bioforsk), the University of Life Science (UMB) and hydropower companies. This observation network is designed to capture the effects of climate on soil water and groundwater levels in key topographic settings in all major physiographic and geological units in Norway. At soil water stations, measurements of soil moisture content are performed at 8–10 different depths, with profile Probes Delta-T (TDR technology), along with soil water potential by Watermark sensors and tensiometers, soil temperature (thermistors) and groundwater levels (pressure transducer). All the soil water stations and over 2/3 of the groundwater stations are automated with hourly measurement and are equipped with real-time capability. Automatic data transmission uses mobile phone technology and, in remote locations, stations are powered by solar panels. All the data are automatically stored in the national hydrological database operated by NVE.

The first groundwater-level observations were recorded in 1949, but the majority of the groundwater stations were established in the 1970s and 1980s, while the soil water stations where first set up in the beginning of the 1990s.

Modelling tools

Two independent models simulating land surface hydrological and thermal conditions are used. The physically-based COUP-model (Jansson and Karlberg, 2004) simulates one dimensional water and heat dynamics in a layered soil column covered by vegetation by solving the relevant differential equations numerically. The model is run with a daily time step, using precipitation, air temperature, wind speed, relative humidity and sun radiation data as input. In addition, plant growth characteristics (e.g. Leaf Area Index, canopy height and root depth) and soil characteristics (e.g. soil water retention curve, hydraulic conductivity) are necessary inputs to the model. Simulations with the COUP-model are for the time being only carried out for 10 representative soil-water stations where observations were used for parameterisation and validation of the model (Colleuille et al. 2007; Colleuille and Haugen, 2007; Øverlie et al., 2007).

A spatially distributed version of the conceptual HBV-model (Beldring et al., 2003) is also used in this project. The model performs water balance calculations for square grid-cell landscape elements. The model is calibrated with a constraint such that model discretisation units with an identical landscape classification are assigned the same parameter values. For each grid cell the percentage of lake, glacier and land-use classes (sparse vegetation, subalpine forest, forest, agricultural land) is determined based on nationwide GIS-information. The input data are spatially distributed, and water balance computations are performed separately for every model element. The model is run with a daily time step, using precipitation and air temperature data as input. An overview of some important differences between the COUP- and HBV-models, and the result of a preliminary validation exercise is given in Colleuille et al. (2007).

RESULTS AND DISCUSSION

Operational procedure

About 25 % of the operative groundwater stations have over 30 years of observations. All the soil water stations have shorter than 10 years of daily observations. Due to the limited observation length and the sparse station network, which cannot cover all river basins in Norway, hydrological models are needed to describe the water and energy balances on a national scale. The Groundwater and Soil Water System is therefore based on two totally independent sources of information: observations and simulations. Observations are obtained from the monitoring network, and simulations from the distributed HBV-model and COUP-model.

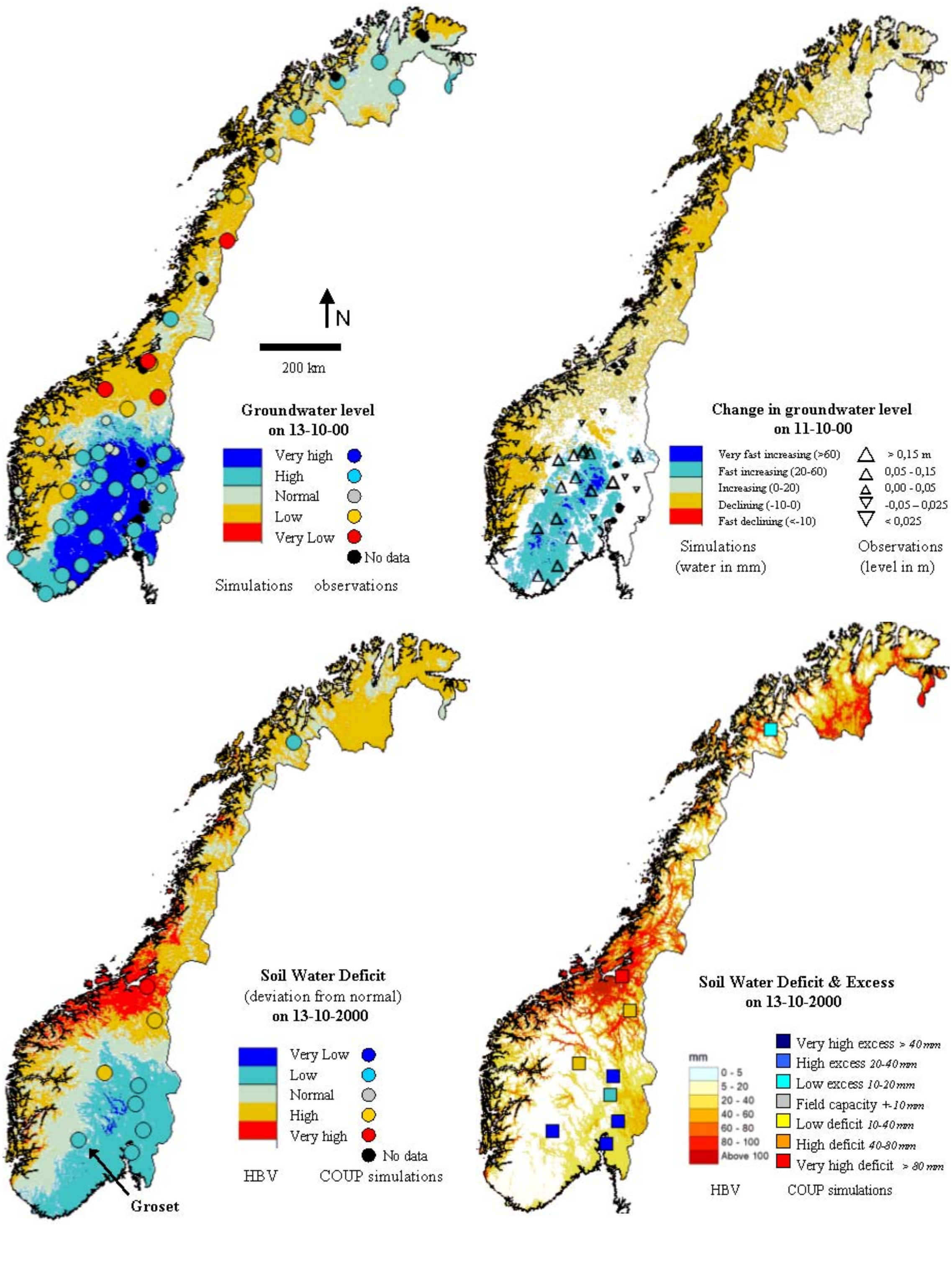


Figure 1. Groundwater and Soil Water Conditions on 13-10-2000. Deviation from average groundwater level (top left); daily change in groundwater level (top right); deviation from average soil water deficit (bottom left) and water deficit/excess values in mm (bottom right).

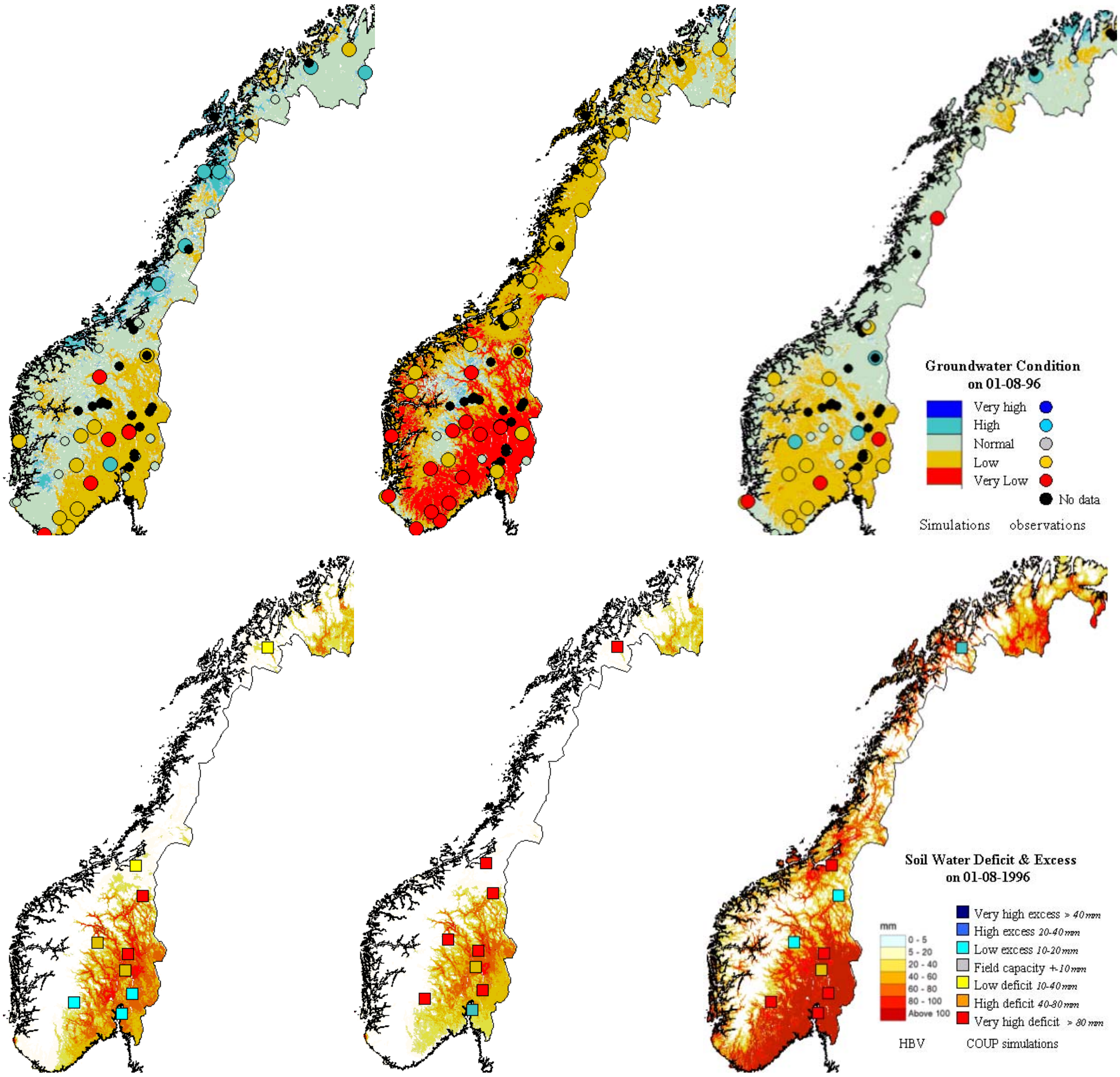
The data processing of the HBV-modelling involves automatic collection of meteorological observations and simulations of daily snow, runoff, groundwater and soil-water conditions. The simulations presented in this article are based on precipitation and temperature grids at a spatial resolution of 1 km^2 provided by the Norwegian Meteorological Institute (Engeset et al. 2004). The model is updated every day with the last-day temperatures and precipitation observations. Forecasts are made for 6 days based on meteorological forecasts. Hydrological maps are automatically produced based on the gridded output data. A Web- and GIS-based system (www.seNorge.no) is used to distribute the information of water and snow conditions (i.e. precipitation, air temperature, evapotranspiration, snow-water equivalent, groundwater, soil water deficit and stream flow).

The data processing of the COUP-modelling is not automated and is very time consuming. COUP-simulations are therefore for the time being used first of all for generating historical data. COUP-model is used in this work to get a better estimation of soil water conditions (wetness degree). Observations are, for the time being, only used in the parameterisation and validation work.

The data processing of the groundwater-level observations consists of collecting all available data in the national hydrological database for the current day. Time series are interpolated on a daily resolution, in order to fit the temporal resolution of the models.

Groundwater and soil water maps

GIS-map combining HBV-simulations with coloured dots representing observed groundwater or COUP-simulated soil water conditions is produced on daily basis. Statistics are compiled based on available data in the reference period from 1990 to 2006. The coloured dots represent groundwater and soil water conditions as a percentile for the current day of the year (Fig. 1). Water conditions are classified by comparing the current observation with the reference period. For observation values falling between the 25 and 75 percentile limits, the groundwater and soil water is considered to be at normal conditions. For values greater than the 75 the situation is classified as high and for higher values (or equal) to 100 percentiles very high. A black dot represents a station which does not have sufficient data to produce statistics or where data are not available (e.g. logger not transmitting). Another set of coloured squares is used to represent absolute value of simulated soil water deficit with COUP. Triangles are also used to indicate change in the observed groundwater levels in comparison with observations the day before (see Fig. 1).



Figur 2. Top: Groundwater conditions (deviation from average) on 01-12-1995, 01-04-1996 and 01-08-1996 (left to right). Bottom: Soil water conditions (deficit and excess soil water in mm) for the same dates.

Flood and landslide

The maps presented in Fig. 1 depict groundwater and soil water conditions on 13-10-2000. The climate conditions in Norway are divided between a wet South-East (very high groundwater level) and a dry West and Middle Norway. Soils in South-East Norway are wetter than average (1990-2006) and according to COUP-simulations are close to saturation (excess of water from field capacity over 40 mm). No water storage capacity combined with heavy rainfall and abnormal mild weather lead to very high groundwater level and cause several landslides and severe and prolonged floods (100-200 years floods) from the middle of October to the middle of December. Information on groundwater and soil water conditions together with precipitation and snowmelt forecast may be considered as determining factors in regard to flood and landslide hazards warning.

Hydroelectricity and water shortage

Southern Norway has experienced 3 major drought events since 1990: two winter droughts: 1995-96 and 2002-03 and one summer drought: 2006. Figur 2 shows groundwater and soil water conditions for three days during the winter drought 1995-96: December 1995, April and August 1996. The groundwater levels in the South eastern Norway in December are already lower than normal due to a dry and warm autumn. In April the groundwater level of the majority of the stations in Southern Norway reaches the lowest level observed in the period 1990-2006 and often since the beginning of the measurement in the 70s. At the same time the hydrological situation is characterised by small snowpack and very deep soil frost in the mountain areas. Deep frost and groundwater levels lead to frost damages (freezing of pipes), very low base flow, and water shortage both for electricity production and water supply (dry wells) during the winter. The drought continues in some parts of Southern Norway during the summer 1996 (Fig. 2), partly due to the small quantity of snow which is too little to replenish the soil water deficit created during the winter (Fig. 3).

The second drought event starts earlier in autumn 2002 due to a dry and warm autumn. This drought is characterised by a higher soil water deficit in the mountain areas than in 1996. Cold winter and low water inflow to power plants lead to very high electricity price in Norway during this winter. However normal snowpack contributes to refill groundwater and surface water reservoirs during spring.

The summer 2006 is also characterised by a short drought that lasts from July to November. This summer drought is caused by lesser snow than normal the previous winter, warmer and drier weather than normal during the summer causing high evapotranspiration. At some places in Southern Norway it is registered the lowest groundwater level ever. The inflow to power plants is reduced and NVE is worried about possible hydroelectricity and water shortage for the coming winter. However mild weather and extreme heavy rainfall lead to the end of drought at the end of November.

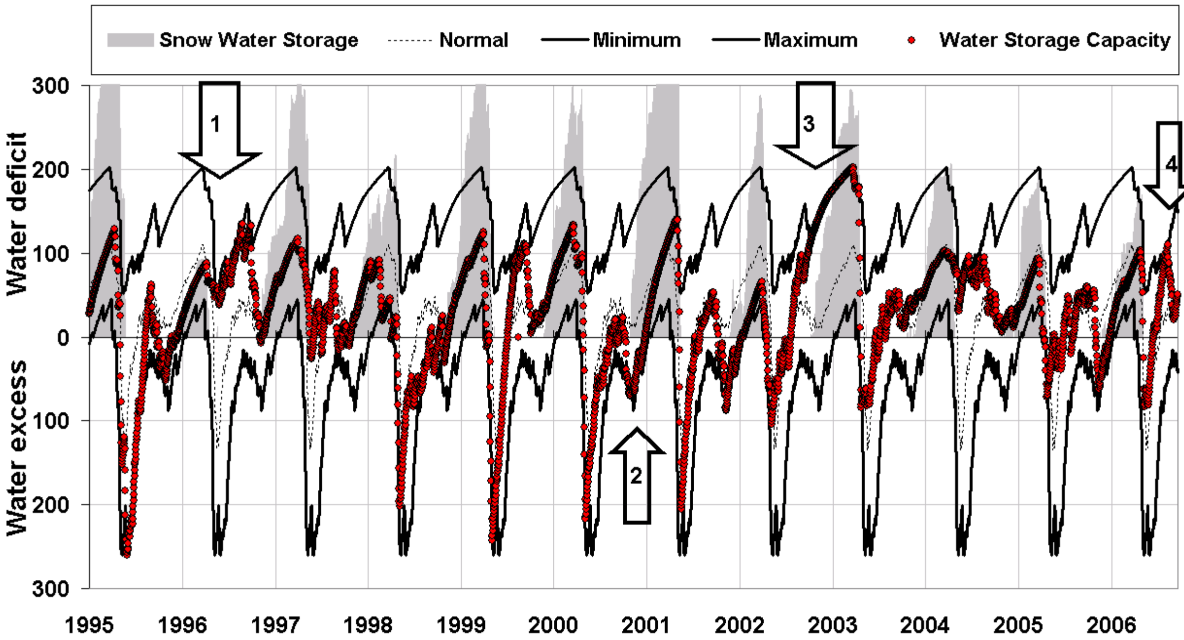


Figure 3. Simulated soil water deficit and excess in mm water (0 is equal to field capacity) and snow water storage from January 1995 to October 2006 for Groset station (950 m o. h., see location on Fig. 1). The arrows indicate extreme hydrological events described in this article: (1) winter drought 1995-96; (2) Floods and landslides autumn 2000; (3) winter drought 2002-03; (4) summer drought 2006.

HBV vs. COUP-simulations

Soil-water deficits simulated by HBV and COUP are quite different (Beldring et al., 2005; Colleuille et al., 2007). According to observations, HBV may overestimate the soil water deficit in summer and underestimate it in winter. HBV-model uses a simple empirical parameterisation of evaporation based on temperature, while the COUP-model has a better physical description of the evaporation process (Penman-Monteith approach). In addition, soil water reduction in HBV is only due to evapotranspiration. Moreover, when soil water content is higher than the field capacity, excess water in HBV is transported to groundwater zone immediately. Soil water reduction in HBV is only due to evapotranspiration, but in reality soil may store as much as 300 mm water over field capacity (figure 3) and this is correctly simulated with COUP. This soil water contributes, several days after infiltration, to groundwater recharge. In headwater catchment with tills, the lack of recharge in winter (snow and frost) combined with groundwater discharge to streams and lakes lead to an fall of groundwater levels resulting in soil water depletion (soil water deficit up to 100-300 mm). The correct simulation of these processes is decisive to get a proper analysis of the water conditions in regard to f. ex. landslide and water shortage warning. It is generally a good agreement between HBV-simulated and observed groundwater conditions (Colleuille et al., 2007). The agreement between HBV and COUP simulation of summer soil water conditions is also relatively good (figures 1 and 2). However the observed match between HBV and COUP simulations of soil water deficit during winter is often due to an incorrect reason: HBV overestimates the deficit during autumn.

CONCLUSIONS

This system is considered as a satisfactory tool for providing a nationwide daily picture of the groundwater and soil water conditions. The system may be used to assess the past, current and forecasted groundwater and soil water conditions. It promotes the use of this information in regard to water management and hazard warning such as flood, landslide, drought and hydroelectricity shortage.

A historical archive of daily grid data (only HBV-simulations) from 1990 to present day is available on internet (seNorge.no). This archive will be extended to include both data from 1960 and climatic scenario. Another type of map as soil frost map is also under development. The generation of daily grid-maps is however both time (about 1 week for a year simulation) consuming, and computational demanding which restrict for the time being our ambition.

The system is still under construction. Only the HBV-grid maps system for groundwater and soil water, both historical and forecasted conditions is completely operative. The combined HBV-COUP-observations water conditions maps are expected to be automated in 2008. The use of COUP-model for daily update and forecast purpose (more realistic simulation of soil water conditions) is not yet feasible. The number of available parameterised COUP-model is also very limited for the time being, but hopefully there are representative for the dominating soil and climatic conditions in Norway. The programming of a simpler version of COUP-model or the implementation of more physically-based routine in the distributed HBV-model will therefore be assessed.

ACKNOWLEDGEMENT

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THE SWEDISH HYDROLOGICAL SERVICE DURING 100 YEARS

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ABSTRACT

This year, 2008, the hydrologists at SMHI are celebrating their 100 year anniversary. In 1908 the Hydrographical Bureau was established. Earlier some measurements of water level and discharge were performed by engineers for agricultural or land survey activities. In this presentation the development of the hydrological service during the century will be followed. The story begins with just a couple of engineers performing measurements and designing a network to support hydropower development. Today it is a modern hydrological service with about 70 hydrologists working with measuring technology and hydrological models to meet the new needs of society. One of the most important factors for this evolution was, and still is, the combination of hydrology, meteorology and oceanography in the same organisation.

INTRODUCTION

SMHI, the Swedish Meteorological and Hydrological Institute, is today a government agency under the Ministry of the Environment. It uses meteorological, hydrological, climatological and oceanographic expertise to promote efficiency, safety and a better environment in various sectors of society.

For the hydrological part, a government agency had been proposed already in 1902 and the Hydrographical Bureau was established in 1908 in Stockholm. During the 19th century hydrology had been mainly an agricultural question. Drainage and lowering of lakes were important issues to improve agricultural output. Sweden needed more productive agricultural land to be able to feed its growing population. Most of the measurements were performed by land surveyors. Around 1900 the potential for hydropower was recognised, which gave rise to a new need for hydrological information, often in remote areas with poorly developed infrastructure.

In the first instructions for the Hydrographical Bureau we can read that staff in 1908 should consist of one director, two engineers and a messenger. The object was to map the Swedish fresh water, both scientifically and practically. Axel Wallén became the first director of the Hydrographical Bureau, which immediately started to organise a hydrological network (Fig. 1). Eleven years later the hydrological service was merged with the State Meteorological Central Institute, established in 1873 under the Academy of Sciences. Much later, the oceanographers were merged as well. The joint localisation of these three sciences in one organisation has proved to be a very wise decision and has been a great advantage for SMHI ever since.

SMHI received its present name, the Swedish Meteorological and Hydrological Institute in 1945. Today SMHI has approximately 550 employees of which about 70 work in hydrology. More about SMHI´s early history can be found in SMHI (1973).

Figure 1. A new hydrological station is installed in the River Torneälven at Juoksengi in 1908.

MEASUREMENTS AND OBSERVATIONS

The Swedish hydrological service was born at a time when society had great plans for large scale hydropower developments and very fundamental hydrological knowledge was lacking. It is therefore natural that, in the beginning, focus was on basic hydrological conditions, such as mapping of the area statistics of the river basins, their hydraulic heads and river flow, see for example Melin (1979). The development of methods for discharge measurement was also of great importance. For the early questions on the water balance it was a great advantage that the meteorological and hydrological services were merged as soon as in 1919.

The measurement techniques developed over time. For a major part of the century traditional current meters, combined with water level recording and discharge rating curves, remained standard. Towards the end of the 20th century hydro-acoustic instruments came into use. These were to show their potential during some major floods in the 1990s and have now become standard. It has meant a revolution in terms of accuracy and operative possibilities. Hydro-acoustic methods were, among others, used to measure the entire flow in Öresund between Copenhagen and Malmö, when the bridge was constructed.

Hydrological records reflect the times we live in. In Sweden this is well illustrated by the water levels of Lake Hjälmaren and the flow of the River Göta älv, shown in Fig. 2 and Fig. 3. Lake Hjälmaren was lowered in the 1880s to increase agricultural production. The hydropower development and the regulation of Lake Vänern, according to the decree for regulation of 1937, were carried out to control water levels and enhance hydropower production. Similar features can be observed for the records of Lake Mälaren and its outlet in Stockholm after its regulation in 1943. The man-made impacts on the hydrological system were dramatic in all these cases. With the full scale development of hydropower, which ended in the 1970s, many large rivers in the north experienced changes of similar magnitudes in their flow patterns.

Today the network for water levels and runoff consists of about 330 stations, 200 of which are owned by SMHI. Both observations and calculated runoff values are stored in the hydrological databases SVAR and WISKI.

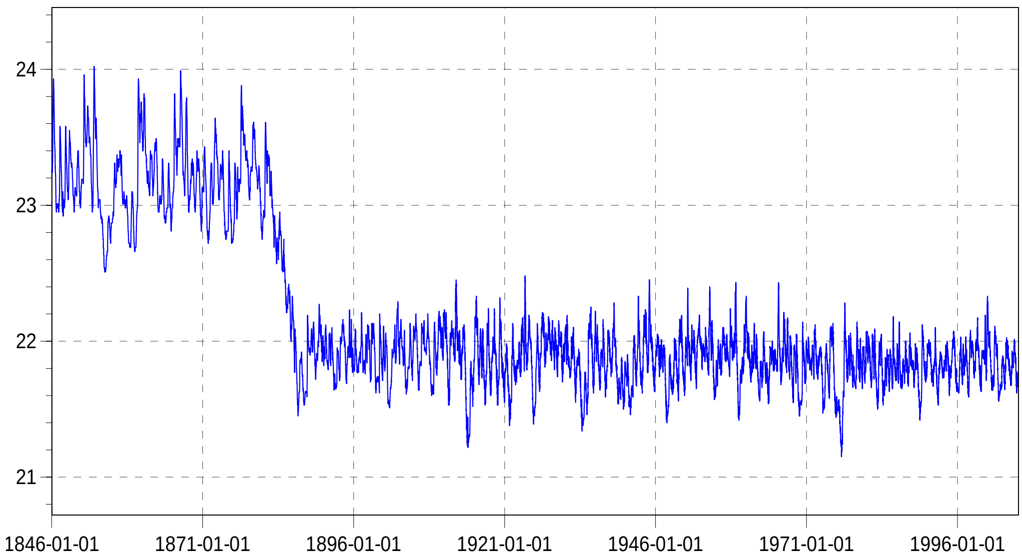

Figure 2. The record of water levels (m above sea level) from Lake Hjälmaren shows the strong impacts of its lowering in the 1880s, to improve agricultural production in the area.

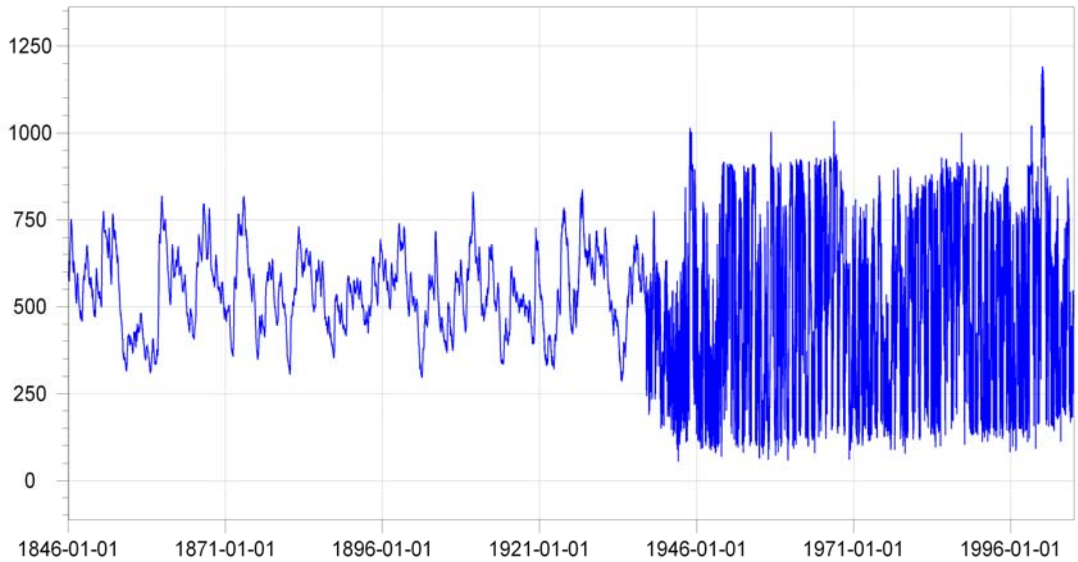

Figure 3. The runoff record (m^3/s) from Sweden's largest river, the Göta älv, at the outlet of Lake Vänern, shows that hydropower development and decree for regulation of 1937 had an impact on the river flow that can hardly be matched by that of climate change. Note the extreme peak of 2001!

HYDROPOWER, ICE AND RIVER REGULATION

The impact of the hydropower development on the environment soon came into focus. A unique competence concerning ice conditions in rivers and lakes was developed at SMHI. The problem was that hydropower plants and the regulations affected the winter roads on the frozen lakes and rivers and also hampered the storage of timber for floating in spring. SMHI investigated the impact as a basis for compensation of losses. In 1954 the Ice division had a staff of 52, 20 of whom were living and working in the north of Sweden. Research and tests of the strength of ice were also carried out. Today ice observations are made mostly in the interests of climatology.

Power plants are required to operate in accordance with the decrees of the water courts. Supervision of these has been a major task of hydrologists for a long time and continues to represent an essential part of the activities of the hydrological service. The hydrologists of SMHI also participated in the extensive studies that preceded the regulation of the big Lake Vänern (1937) and Lake Mälaren (1943), with profound impact on society ever since.

In 1967 a network of stations for measurement of suspended matter in rivers was established by the University of Uppsala. SMHI operated it from 1975 to 1994, and several studies on the transport of sediments were carried out.

HYDROLOGICAL MODELLING STARTED IN THE 1970s

All the time river runoff had been in focus. The dream was to be able to estimate river flow in any river at any time. With the advent of computers, mainly serving the weather service, the hydrologists of SMHI had a golden opportunity to start developing hydrological models in the 1970s. The work was carried out at the water balance department, HBV, which gave its name to the hydrological model which is still widely used. The first successful run of the HBV model took place in the spring of 1972. The Swedish hydropower industry soon saw its potential for the forecasting of inflows to the reservoirs and supported its further development for many years. Close research co-operation between the hydrologists at SMHI and the hydropower industry has been a tradition since then. This co-operation expanded to also cover air borne snow-mapping, remote sensing by satellites and flow statistics among others.

The HBV model proved to be very versatile and came into use for many purposes and in many countries. In the 1980s the first steps were taken to use the model as an alternative to traditional measurements. The question asked was: “Measure or model?” Today a balance has been established in which information from both sources is used on a routine basis. So, the answer is “Both!”.

Nowadays different national versions of the HBV model are available nationwide in Sweden, Norway and Finland.

INTERNATIONAL OUTLOOK

Model development was one component of the research programme, titled International Hydrological Decade, IHD (1965-1974). IHD also inspired the installation of a number of research basins in the Nordic countries. The work in these basins contributed greatly to better measurement techniques and better understanding of hydrological processes. It was also a basis for increased national and Nordic co-operation in the field of hydrology. IHD was a significant step forward in the internationalisation of hydrological research and promoted Nordic co-operation.

The first Nordic hydrological conference was held in Stockholm in 1955 and later on it became a tradition among Nordic hydrologists to meet regularly. The Nordic Hydrological Association, the Nordic Hydrological Programme, KOHYNO (COordination of HYdrology in the NOrdic countries) and the CHIN-group (the Chiefs of the Hydrological services In the Nordic countries) have been instrumental in this respect. The present Nordic Hydrological Conference is the twenty-fifth such!

The HBV model became one of the survivors of the international flora of hydrological models, which were developed in the 1970s. It became an important tool for the international consultancy activities that started in the 1980s. Its application to the countries in Central America was a first main achievement. This begun a closer co-operation with the Swedish International Development Agency, which remains ongoing.

The increasing interest in the Baltic Sea and the collapse of the Soviet Union opened new possibilities for international co-operation in the 1990s.

Hydrologists at SMHI engaged in the international BALTEX research program and the HBV model was applied to the entire Baltic basin. Close contacts were established with colleagues from Estonia, Latvia and Lithuania, and these countries subsequently became members of the Nordic Hydrological Association.

MOVING TO NORRKÖPING IN 1975

1975 will for ever stand out as water divide between the old and the new SMHI. SMHI moved from Kungsholmen in Stockholm to the outskirts of Norrköping and a new era started. The entire staff was now in the same situation in a new city and all working in the same modern buildings. Many of us found new friends from neighbouring departments and disciplines. No activity has made so much for the integration of SMHIs three disciplines, meteorology, hydrology and oceanography as the location to new premises in Norrköping, in the hot summer of 1975.

DRAMATIC HYDROLOGICAL EVENTS IN THE 1980s TRIGGER DEVELOPMENT

Dramatic hydrological events in the 1980s led to a new interest in hydrological design, flood forecasting and flood protection. The collapse of the Noppikoski dam in September1985 became the symbol of this. A modelling technique was developed at SMHI to meet new requirements from dam designers and physical planners, and a nation-wide re-evaluation of Swedish hydrological dam safety was begun. Much of this work was carried out by SMHI on contract from the power industry. A debate about physical planning and exploration of flood prone areas soon emerged and a comprehensive mapping of flood risks along rivers and lakes was carried out, on commission from the Swedish Rescue Services Agency.

To support the rescue services and local authorities a modern hydrological forecasting service was established. This group was to become very busy. The two most spectacular floods occurred in 1995 (well remembered in Norway!) and in 2000, representing 100 years return periods or longer. Since then more or less severe floods have occurred almost every year. These are not the only dramatic events during the century. You may ask yourselves how we will be able to handle floods like the ones in the River Dalälven and in the River Klarälven in 1916, or the one in southern Sweden in 1924, when they occur the next time!

OCEANOGRAPHY ENTERS THE SCENE

What hydropower did for hydrology, the development of nuclear power did for the development of the oceanographic service. It became an official part of SMHI in 1982, but activities had already begun in 1964, with tracer experiments on the Swedish west-coast. In late 1950s investigations concerning the reactor's cooling water started and in the 1970s extensive studies were carried out for Lake Vänern. Even though it is not represented in SMHIs logo, oceanography constitutes a significant part of its activities, in particular at the office and laboratory facilities in Gothenburg. The oceanographic research also meant a lot to the hydrologists and meteorologists. Oceanographers and hydrologists have common interests concerning large water bodies, measuring techniques, remote sensing, ice conditions and biogeophysical processes. They have found synergies in model development. Meteorologists and oceanographers also have a lot in common, especially when it comes to the planetary boundary layer, remote sensing and three dimensional hydrodynamical modelling.

In the 1990s the construction of the bridge between Sweden and Denmark, Öresundsbron, called for substantial investigations by SMHI staff, both as to measurement and numerical simulation of the impacts of the bridge on water exchange through the Öresund. The research vessel Sensor was used extensively in these activities. The bridge opened in 2000 and brought Sweden and Denmark much closer to each other.

MORE ENVIRONMENTAL CONCERNS

The 1980s also brought a new awareness of the environment as acidification and eutrophication of rivers, lakes and coastal areas showed that emissions are harmful to our water resources. It was found important to couple the discharge of the rivers to the hydrochemistry of the water. SMHI co-operated with the county administrations in the design of the hydrological network and began to run the HBV model at several hundreds of sites where runoff observations were not available.

Severe algae blooms became an increasing nuisance in summer in the Baltic Sea and its bottom oxygen conditions worsened. The hydrological service started to focus more on these problems, and the first steps were taken to model more than just runoff – the water quality as well. The HBV model was developed further to include concentrations and transport of nitrogen and phosphorous. A nation-wide estimation of the retention of nutrients from their source to the sea was carried out. This led to efforts towards a more complete integration of hydrology, oceanography and meteorology with an environmental touch, the HOME concept.

MERGING OF THE DISCIPLINES IN 1992

In 1992 an important reorganisation of SMHI was performed. All departments became customer oriented (e. g. Environment, Safety, Core, Business, Media) and the merging of the three branches was completed. This also meant that a new research department was established, comprising meteorological, hydrological and oceanographic research in one unit. This was very timely, as problems became more interdisciplinary.

DEVELOPMENT OF THE NEW RESEARCH DEPARTMENT

In the 1990s, the environmental problems of the Baltic Sea became a major concern, the understanding of which required input from the three disciplines. A new question of a new dimension also came into focus – climate change or global warming. After some years with the new research organisation, a regional climate modelling research group was formed, the Rossby Centre. Its task was primarily to model the future climate in Sweden and northern Europe. The hydrological research was soon heavily involved in the climate issue as well. The anticipated change in water resources was perhaps the most important foreseeable impact of global warming.

Climate change will affect river flow, water supply, urban systems, natural hazards, dam safety and hydropower production. It will also affect the inflow from rivers to the Baltic Sea and transportation of nutrients. Experience from hydrological modelling was also used to help improving the land surface processes in the climate models, with particular emphasis on runoff. This work was, and still is, carried out in close co-operation with meteorologists but also together with our fellow hydrologists from the other Nordic countries and the Baltic States in the *Climate and Energy* and *Climate and Energy Systems* projects.

The new research department expanded rapidly and its staff has increased from about 30 people in 1992 to some 70 people today. The researchers come from many countries and are involved in a great number of national and international projects. They have also developed an extensive international scientific network.

COMPUTERS AND INFORMATION TECHNOLOGY

The advent of computers meant a revolution for all of us, even if it took some time to make use of its full potential. It takes time to adapt. Today hydrological models can be run on a laptop. And today nation-wide hydrological simulations are natural tools for our daily work. Data are also more easily available and we can get statistics of almost anything whenever needed. We also have most of the land use statistics available in GIS. With this in mind it is fascinating to look back at the early days of hydrology. How could our predecessors carry out such enormous and impressive projects without any computer support and with such limited data? And we also have to give them our sincere thanks. Where would we stand today, for example in the climate debate, without their devoted and patient field work, often carried out under hardship and dangerous conditions?

Internet and web-based products meant another revolution. We are already addicted to this, but we are probably only in the beginning of this process.

THE EUROPEAN UNION

Sweden joined the European Union in 1995. This meant new opportunities for, and demands upon, the hydrological service. The Water Framework Directive led to the establishment of five regional water authorities in Sweden. An important task of the Swedish hydrological service is to supply these new authorities with adequate and detailed hydrological information. At SMHI a new model, called HYPE, has been developed during the last three years for environmental use. This model, and new measurement technology, will be further developed to provide daily high resolution data on runoff, nitrogen and phosphorus in altogether 17 000 Swedish water bodies which are reported to the European Union.

THE FUTURE

To understand the future it is sometimes useful to look back. When in 1908 the hydrological services were formed in Sweden and in Finland conditions were drastically different from today. Norway had been a fully independent nation for three years, but its hydrological service had already existed since 1895. Finland still had almost ten years to go before it obtained full independence. Globally the world was about to enter one of its darkest and most difficult eras, with two world wars during the century to come. The Soviet Union would come and go and there would be scientific achievements hardly expected or even thought of. The first airplane flew in 1903 and in 1969 man landed on the moon. And who could foresee the development of global environmental problems, computers, information technology and the Internet?

Looking back at this development, how can we ever think of forecasting the future? But still, a few things are obvious. We are globalised now, and we have realised that there are limits to the Earth’s resources. Thus, it is not difficult to foresee that problems related to emissions in the atmosphere, global warming and its impacts on water resources will follow us for decades to come, probably longer. This will require both mitigation efforts and adaptation strategies. It might very well be so that problems related to global warming will overshadow some of the more traditional environmental problems in our area. For hydrology this means opportunities and challenges. Hydropower, the most important renewable source of energy in the Nordic area, will become even more valuable. Concern about water resources is number one among possible impacts of global warming.

Long time series are invaluable and will be so in the future. They give us perspective on today’s extreme events and help us design with proper safety margins. As shown in Fig. 2 and Fig. 3, man-made activities have strong impacts on the hydrological records, impacts that sometimes are greater than those expected from climate change. It is therefore important to realise that not only is climate changing, but also that societal changes may have an impact that is equally great or even greater.

The new times to come will make data still more valuable. We need to carry on with data collection and deliver long, unbroken and homogeneous records of high quality to coming generations, as prior generations provided us.

Hydrology is at its best in combination with other sciences. And the complex future problems will require interdisciplinary approaches. Hydrologists have by tradition been good at interacting with, and supporting, other parts of the society. This is the main reason for the successful development of the Nordic hydrological services. The future will require more of that.

THE ROLE OF KNOWLEDGE

The development of the Swedish hydrological service would not have been possible without the skill and high scientific level of its staff. It is worth noticing that in the first year-book from the Hydrographical Bureau, for 1908-1909, the first 100 pages are devoted to a scientific exposé on "The knowledge about Sweden's hydrography before the time around 1870" (Hydrografiska byrån, 1911). The hydrological service of SMHI has delivered a great number of year-books and scientific reports since then, some of them representing breakthroughs in hydrology. Highlights are the two volumes of the Swedish national atlas devoted to Sea and Coast (SNA 1992) and Climate, Lakes and Rivers (SNA, 1995). Today Internet offers completely new possibilities for exchange and dissemination of real time data, products and scientific results, a potential which we have just begun to explore.

Higher education is important. A number of doctors and professors have their scientific background in the hydrological research at SMHI. It is of utmost importance that this positive attitude to knowledge is maintained. It is needed if we want to stay abreast with the rest of the world and benefit from international research. It is also a prerequisite for coping with the hydrological problems to come.

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INTEGRATION OF RADAR PRECIPITATION IN DISTRIBUTED HYDROLOGICAL MODELLING

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ABSTRACT

Spatially distributed precipitation is one of the most critical inputs required for successful distributed hydrological modelling. In the past, precipitation distributions have been estimated by spatial interpolation from point observations in rain gauges. The spatial distribution inferred by this approach introduces errors due to the imprecise knowledge of precipitation distribution in space and requires a dense network of rain gauges, which is available only for a few catchments. In recent years, the implementation of weather radars in Norway by the Meteorological Institute has made radar a potential tool to improve estimation of precipitation between the gages. In view of this, the Gaula catchment with a sparse rain gauge network is modelled using grid square weather radar data. Automated procedures for processing the radar images are implemented, and the LANDPINE hydrological model is configured to share the same grid used by the weather radar, integrating the distributed precipitation fully. The ability to use radar-based precipitation estimates is assessed through a comparison study between precipitation estimates from the Rissa radar and interpolated precipitation from the rain gage network using Inverse Distance Weighting method. LANDPINE is calibrated with precipitation inputs from the two sources and the simulated runoff is evaluated.

Keywords: weather radar, precipitation, GIS, distributed modelling

INTRODUCTION

In many hydrological applications a crucial factor is the availability of accurate precipitation estimates for input to hydrological models. Traditionally, point measurements at rain gauges have been used with hydrological models, and a network of gauges is used to determine the precipitation distribution over a catchment or other area of interest. Even if rain gauges could provide good quality data by physically measuring the depth of precipitation, rain gauge networks are usually too sparse to capture the spatial variability of precipitation over the catchment and therefore result in inaccurate areal precipitation estimates. In addition to this, different interpolation methods result in different precipitation surfaces. Weather radars offer an advantage over rain gauges in that they provide coverage over a wide area with high temporal and spatial resolution. With resolutions on rectilinear grids down to 1km x 1km, it is possible to estimate the precipitation distribution at a greater spatial detail. Hydrologists have been applying and testing radar precipitation estimates in hydrological models for many years (Anderl et al., 1976, Bell and Moore, 1998, Cluckie and Owens, 1987). Presently most practical applications of hydrologic modelling employ lumped models precluding the efficient use of precipitation estimates from radar. Distributed models, however, allow the incorporation of spatial variability of precipitation inputs and can lead to an improvement of runoff simulations. The performance of some distributed hydrological models when utilizing spatially distributed precipitation from radar has been evaluated in some studies (Carpenter et al., 2001).

Hydrologic modelling efforts currently in Norway usually involve hourly or daily precipitation data obtained from a network of rain gauges. Weather radar data are available from the Norwegian Meteorological Institute (Met.no). Comparison of radar data with rain gauge-derived data is necessary to evaluate the impact of the two precipitation data sources on model output. In this study, we compare the Rissa radar estimates over the Gaula catchment with areal precipitation interpolated from daily precipitation data from a network of 28 gauges for a two-year period. The interpolation method considered here is the Inverse Distance Weighting (IDW) coupled with a precipitation gradient. The main focus of this study is to evaluate the radar data as they are available from Met.no for hydrologic modelling purposes. LANDPINE is calibrated with precipitation inputs from the two sources and the simulated runoff is evaluated. The operational implementation of radar-rain gauge comparisons to improve radar precipitation estimates is not considered. This study may serve as a benchmark for the evaluation and application of Met.no radar data.

STUDY AREA AND DATASETS

The area considered for this study is the Gaula Catchment located in central Norway, centred at approximately 10°45'E and 62°52'N (Fig. 1). The total area of this catchment is 3092km2 with an average altitude of 732m.a.s.l. (range: 59 - 1278). The Digital Elevation Model (DEM) is available for this area with a pixel resolution of 25 x 25m. An area of 115x138km (15870km2), covering the catchment was selected as the extent from within which a network of 28 rain gauges was used for the study (Fig.

1). The radar data used in this study are from the Rissa radar located on the coast, and the Gaula catchment is located at 72-135km from this radar.

Hourly data from the Rissa radar is available starting from January 2006. These data are stored and supplied by Met.no in Hierarchical Data Format (HDF5) and contain quantitative precipitation estimates which have been calibrated by using rain gauge data (Gjertsen, 2002). The resolution of the grid for the radar is 1km x 1km. The period considered for this study runs from January 1 2006 till January 15 2008. Daily precipitation data from the 28 weather stations located in and around the catchment were extracted from Met.no's database for this two year period along with rain gauge location coordinates and elevations. As observed in the figure, most of the rain gauges lie outside the catchment boundary.

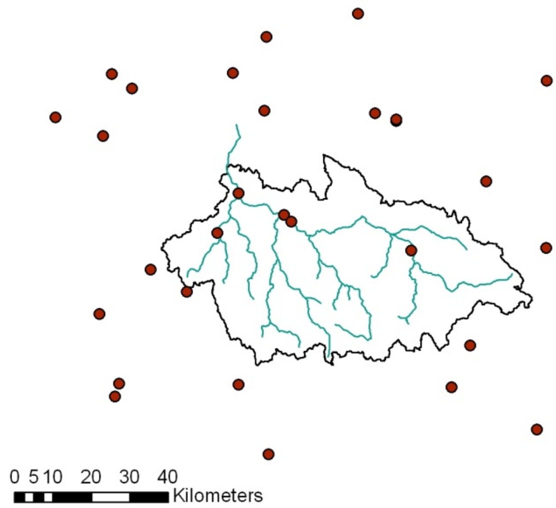


Figure 1. Raingauge sites in and around the Gaula catchment

DATA PROCESSING

The format in which the hourly radar precipitation files are available is not readily compatible with common GIS softwares. This poses a limitation in directly analysing the radar data in the GIS software for the purpose of geo-referencing and extracting suitable data ready to be used as an input to hydrological models. In addition to this, the large number of hourly files to be handled makes it unviable to carry out data processing manually. This led to the implementation of an automated procedure for processing the HDF5 hourly files. Most of the automation was done within the ArcGIS 9.2 system (http://www.esri.com/).

The hourly HDF5 radar files were converted to ASCII Grid files by using a utility program distributed with the Geospatial Data Abstraction Library (GDAL), which is a translator library for raster geospatial data formats (http://www.gdal.org/). The ASCII files were then converted to ESRI Grid files and their original projection, which is Polar Stereographic Projection, was defined. In order to overlap the precipitation data on other distributed grids to be used as an input to the hydrological model, the files were projected into the UTM system. The above geoprocessing was automated through a Python script for handling large number of files.

The hourly UTM grid files were aggregated to 24 hour accumulations in order to make comparisons with data derived from the daily rain gauge observations and produce distributed daily precipitation to be used for hydrological simulations with a daily time step. Simple consecutive summation of the grid files is not an option because of two reasons. The first is due to several missing hourly files and the need to define different 24hour summations due to the different daily precipitation observation times used at climate stations (08:00 A.M. local time). A Python script was therefore developed which uses date and time strings to generate daily sums accumulated to any time of the day or monthly sums by accounting for missing files.

Automation was also required to extract data for a specific catchment and a specific rain gauge from the entire radar coverage. Again a Python script was prepared for this process which takes the coordinates of the outlet of a catchment and the coordinates of rain gauges. The script automatically delineates the catchment boundary for the outlet provided and extracts part of the radar grid which corresponds to the catchment extent. The rain gauge coordinates are used to extract the data from all the radar pixels which overlap with the gauge locations. This extracted data can be used to carry out the comparison study but has not been used in this study.

Using the above automated procedure a series of 24h accumulation radar grids were created for each day and clipped for the Gaula catchment. In order to create a similar data series of interpolated precipitation grid, another program was used. Gridded precipitation was created with this program using the rain gauge network over and around the catchment as an input. Hereafter, we use the word datasets to refer to these two data series.

HYDROLOGIC MODEL

LANDPINE is a distributed hydrological model developed at the department of hydraulic and environmental engineering to study the impacts of land use changes on runoff generation (Rinde, 2000). The model explicitly accounts for interception in high and low vegetation, storage of water on the ground surface, evapotranspiration, accumulation and melting of snow, infiltration, retention of water in the soil, and generation of surface runoff and outflow from the soil in a distributed manner. The modelling concept on which the representation of these hydrological processes is based on is a gridded partitioning of the catchment area. But water movement in rivers and outflows from water reservoirs are described by the use of an aggregated linear tank response function. The computational grids for the model are configured to overlap with the grid used by the radar data (1km x 1km).

METHODS

Intercomparison of precipitation datasets

The fist objective of this study is to analyze the differences between radar derived data and data interpolated from gauges using the IDW method. This analysis is carried out through the computation of mean areal precipitation over the catchment using both data sources and by looking at the cumulative grid sums for both datasets. Cumulative and monthly sums of areal mean precipitation are also computed to assess the presence of any definite seasonal trend. We also prepare a series of spatial maximum cell precipitation values for both data sets and present the differences. The two year period from January 1 2006 till January 15 2008 is considered for this analysis.

Another relevant analysis is to compare the daily point observations from the rain gauges with the corresponding pixels from the radar grid (Jayakrishnan et al., 2004 and Kitchen et al., 1992). This dataset had been generated using the automated procedure described above but has not been considered in this study since the radar data adjustment process at Met.no involves calibration of the data using rain gauge observations (Gjertsen, 2002). The point measurements alone cannot be therefore used for an independent comparison or verification of the radar data.

Runoff simulation

The hydrological model, LANDPINE, is calibrated against observed runoff series at the catchment outlet. The model is calibrated first using the IDW interpolated precipitation as an input and then another independent calibration is carried out with the radar data as an input. The calibration process is done using a combination of automatic and manual calibration procedures. A model-independent parameter optimizer, PEST, was used for the automatic calibration with runoff as the evaluated variable for testing performance (Watermark Computing, 2002). The statistical performance criteria used is the Nash/Sutcliffe efficiency criterion (R^2). The runoff simulations from the two calibrations are compared. This can reveal the effect of differences in spatial precipitation distribution on the model output.

Even though both datasets are available from January 1 2006, the period considered for calibration of the model begins from September 1 2006. This was done to follow the hydrologic year and begin the simulation at a date when all the snow in the catchment has melted. This step was necessary because there is no distributed snow accumulation data over the catchment which would be required as an input for the model if the calibration was started on the 1st of January. There was not enough radar data available for carrying out verification of the model calibration.

RESULTS

Long-Term cumulative sum

Plot of the accumulated areal precipitation values over the entire period for both datasets is given in Fig. 2. The Gaula catchment had cumulative radar derived areal precipitation value that is higher than the one for the rain gauge derived cumulative areal precipitation value. The areal precipitation values from the radar are higher for 61% of the total number of days considered in the analysis.

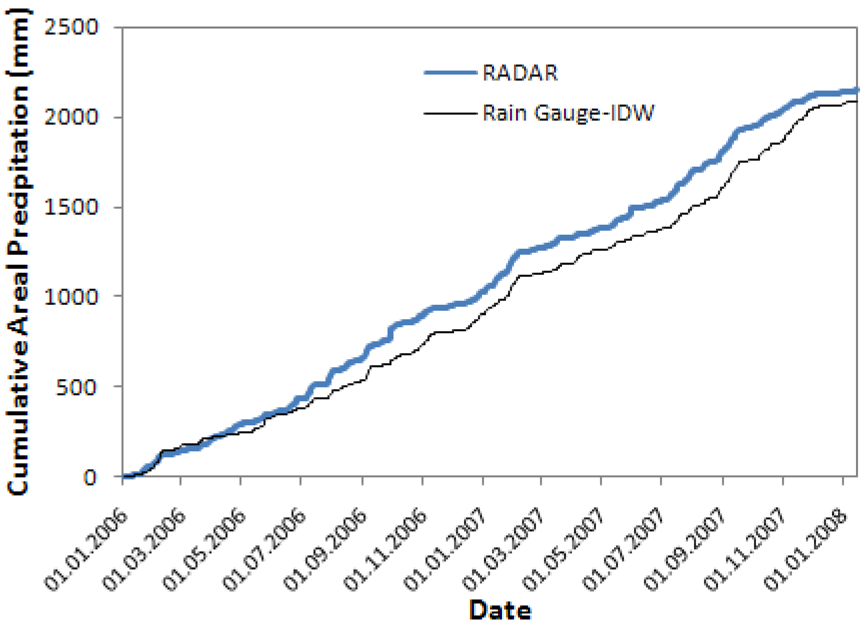
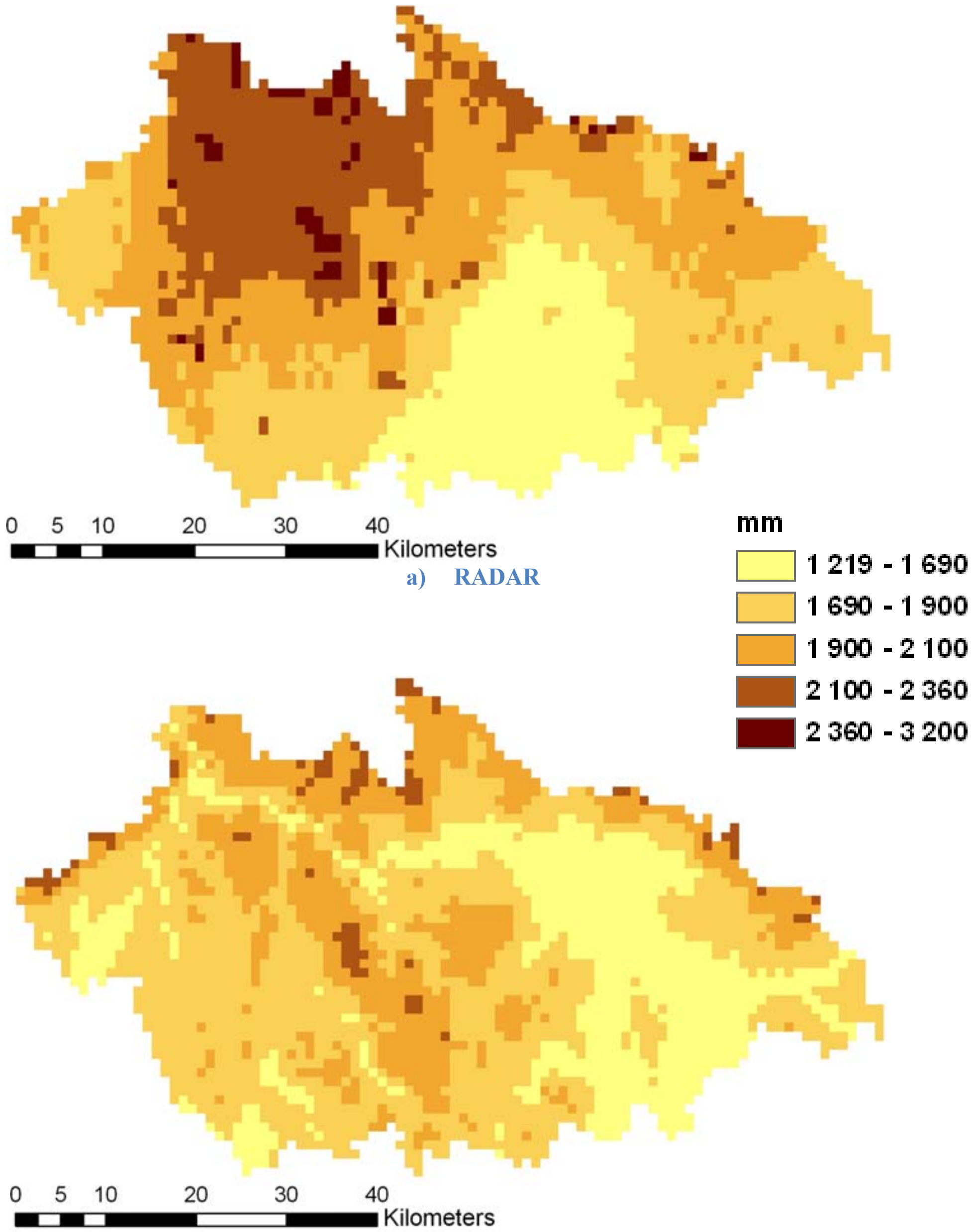


Figure 2. Plot of cumulative areal precipitation

Even though the difference between the cumulative areal precipitation has a realatively low value of about 70mm, the spatial distributions of the total precipitation show significant variations (Fig. 3). The summation of the radar grids shows higher precipitation in areas around the north-western part of the catchment. Unlike the trend in the summation of the IDW grids (Fig. 3b), clear precipitation bands are observed for the total radar precipitation (Fig. 3a). The cumulative grid for the IDW data set reveals that the precicpitation distribution is significantly influenced by the topography due to the inclusion of a precipitation gradient in the interpolation procedure. This influence is pronounced due to the sparseness of rain gauges inside the catchment. A strong effect of the rain gauge location due to the distance weighting method is also indicated in the IDW grid where the cells of lower total precipitation are concentrated at the eastern part of the catchment. This is due to the rain gauge located in this area with a lower annual precipitation than the neighbouring stations.



b) IDW

Figure 3. Areal distributions of total precipitation for the two year period

Monthly Precipitation

Comparison of the monthly total precipitation amounts (Fig. 4) for the catchment does not demonstrate a clear seasonal trend in the available data. But the annual variability of the monthly precipitation sums seems to be similar for both datasets except for a few months. Moreover, the overestimated radar values seem to be concentrated within the summer months. It can also be observed that the radar derived total areal means are considerably higher for the months of April, July and September of 2006 and

May and July of 2007. On the other hand, the gauge derived total areal means are much higher for the months of February 2006 and November 2007. The higher sum for the radar means for November 2006 is mainly due to a considerable overestimation of the radar during a single day, November 29.

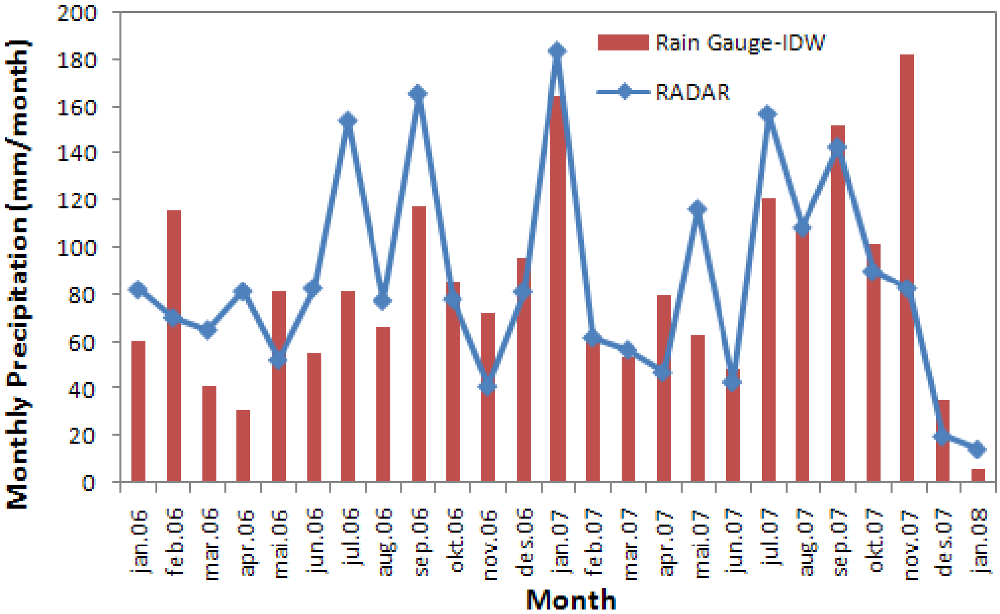


Figure 4. Total monthly precipitation

Spatial Maximum Precipitation

Comparison of maximum precipitation amounts is carried out by selecting the cell with the highest daily precipitation for each daily grid of both datasets. The plot of the resulting pairs is given in Fig. 5. This plot indicates that maximum cell values of the radar grid are higher than the ones for the IDW grid for much of the time. For 80% of the days during the analysis period of two years, the radar estimates maximum precipitation cells which are higher than those for the IDW interpolated grids.

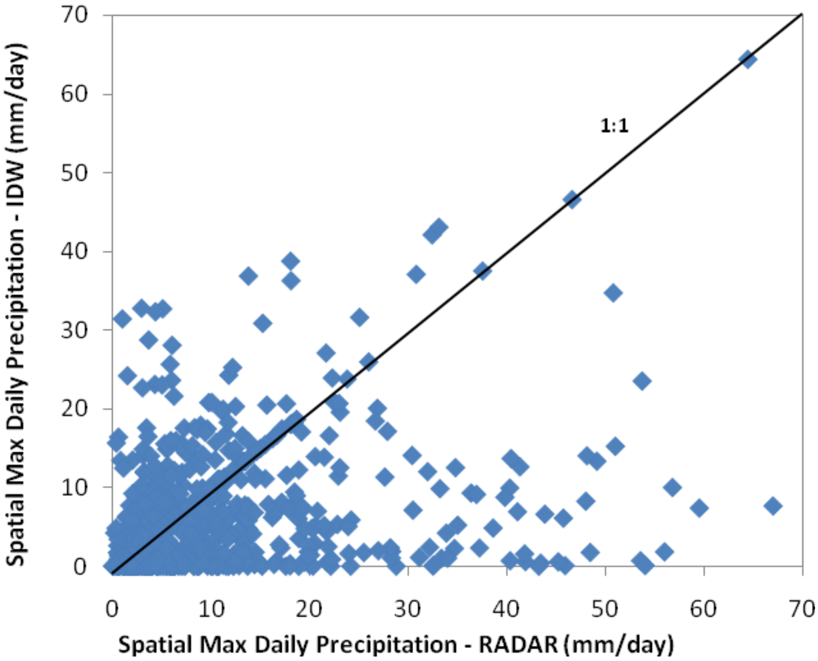


Figure 5. Plot of spatial maximum daily precipitation

Model calibration

Model simulated flows driven by the radar and IDW precipitation data for the calibration period are plotted in Fig. 6 together with the observed flows. The R^2 value for both calibrations was 0.80. The plot also reveals the similar resemblance of the generated hydrographs to the observed with few exceptions. The most noticeable event where a significant deviation can be observed is the peak flow in November. The simulation with IDW data underestimates the peak while the simulation with radar data results in a significant overestimation. The overestimation was due to an overestimated precipitation estimate by the radar on November 29. Another event with relatively higher deviation is observed during the beginning of the simulation period where both simulations underestimate the flow. Comparison of the optimum parameter sets for the two calibrations showed that the differences in the precipitation grids of the two datasets did not lead to a significantly different model parameterization. But it is emphasised that these results are conditioned on the calibration procedure.

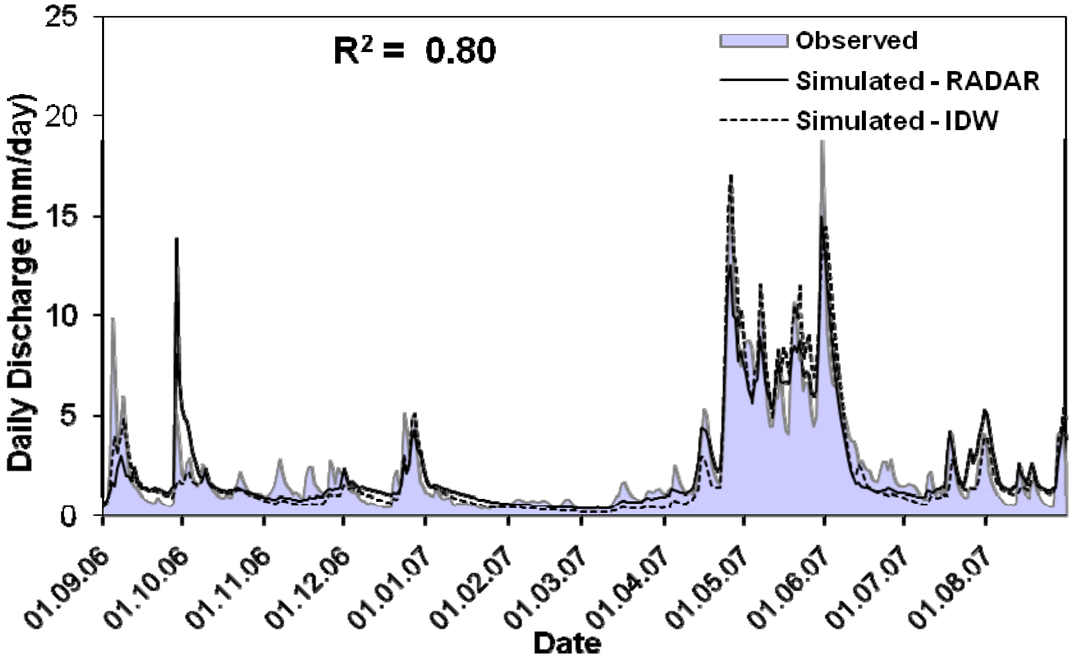


Figure 6. Plot of observed and simulated runoff

CONCLUSIONS AND FUTURE RESEARCH

Although much of this work continues, some conclusions can be made at the present time. An automated procedure for processing the radar data files from Met.no has been developed in this study. This implementation facilitates the analysis of the radar precipitation and creates flexibility with respect to the extraction of necessary sub-data. The efficiency of such automation is evident when considering that radar data for a single year consists of nearly 9000 files.

The other objective of this study was to compare the precipitation data derived from the Rissa radar and from interpolation of rain gauge observations using IDW. With regard to overall performance, the data from the Rissa Radar produce viable mean areal precipitation. However, the validity of the radar estimates cannot be fully assessed due to the lower density of rain gauges within the catchment. The differences computed during the comparison study indicate that there are variations in the spatial distribution of precipitation produced from the two sources. The comparison with respect to cells with maximum precipitation has particular implications for flood simulations where the representations of localized storm events are of greater importance. Though it is not possible to conclude with certainty that the radar performs better, the fact that higher precipitation cells are estimated in between the gauge using the radar indicate its superiority with respect to spatial detail. This is especially true when it comes to catchments where a dense rain gauge network is not available, as is the case with Gaula.

The simulated flow series using radar derived data and gauge interpolated data were both able to reproduce the main features of the observed series.

When using the radar data, calibration of the model parameters did not improve the model performance. However, the results indicate that the processed radar precipitation estimates from Met.no have the potential to be used for modelling. The fact that similar calibration results were obtained with precipitation inputs of different temporal and spatial variation justifies a more comprehensive testing with more variables and not only discharge at the outlet. Even if the calibrations against the observed discharge have resulted in similar performances, this may not be the case if other distributed model outputs are used for the evaluation. Inaccurate spatial precipitation distribution can result in seemingly acceptable runoff simulations if underestimations in some part of the catchment are compensated by similar overestimations in other parts. Considering LANDPINE in particular, the aggregated flow response function after the soil routine (Rinde, 2000) may have masked spatial differences in runoff generation that would result from a spatially variable precipitation input. Therefore, a continuation of this study is already underway where a catchment with a number of snow measurement sites is going to be used for testing the radar data capabilities. The distributed snow data, in addition to observed discharge, will be used to evaluate simulation results with radar data and some routines of the model are being upgraded to increase its sensitivity to non-uniformity of spatial generation of runoff. The inclusion of distributed snow data for testing different precipitation inputs is vital because runoff is not an adequate measure for the validity of precipitation distribution during periods when snow melt-generated runoff dominates.

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IDENTIFICATION OF AREAS EXPOSED TO FLOODING IN NORWAY AT A NATIONAL LEVEL

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ABSTRACT

NVE are the responsible public authority concerning river related hazards. In order to meet the demands from the municipalities in their area planning process and their need for mapping of areas with potential risk for water related hazards, a project group have been established. The main focus of the project group is to map and identify areas at risk related to hazards in rivers. Three different hazard types have been identified:

- Flooding
- Debris flows
- Quick-clay slides

In addition one part of the project group is focussing on the implementation of a national flood information system.
Areas prone to flooding have been mapped at two different levels of detail. One national scale (covering the whole country), and another detailed scale for selected river reaches. This paper will focus on the development of methodology for mapping of areas prone to flooding at a national level. Hopefully, the mapping at a national level will be a first step to meet the requirements given in the EU flood directive.

Keywords: flooding, areas at risk for flooding, GIS analysis

INTRODUCTION

The importance of having an instrument as flood maps was recognised in Norway after the damaging spring floods in 1995. Municipalities can use flood maps in the spatial planning process to avoid building in potential dangerous areas and so avoid damages and loss of life. Since the start of the project about 1500 km of river stretches have been mapped.

NVE being the responsible public authority concerning river related hazards, is now, in the light of the implementation of EU Directive on the assessment and management of flood risks, in the process of revising the guidelines for land use in areas with risk for flooding. One of the recommendations in the revised guidelines is that all areas exposed to certain types of natural hazards should be mapped. This kind of information is crucial for the municipalities in their area planning process.

This recommendation is in accordance with the first step of implementation the EU flood directive stipulating the assessment of flood risk by performing a small scale analysis using available data both hydrological and topographical in order to determine where to do more detailed mapping and assessing of flood risks.

A project group was established to develop a cost effective method based on available data and knowledge, easy to understand for both municipalities and the public.

AVAILABLE DATASETS

Although there is a lot of experience in floodplain mapping in Norway, doing a national small scale flood mapping covering the whole country of Norway provides us with a whole new set of challenges

Norway is a big country when different phenomena are to be mapped at a national scale. The total area of Norway is 324,220 km^2 and consists of a vast amount of rivers and lakes:

Lakes: - Total number 968444, approx. 250 000 > 2500m^2
- Covers 17869 km^2

Rivers: - Approx. 410 000 km of rivers and streams

Rivers – river network

The numbers for rivers are based on our national river network. In the river network all river reaches have been classified according to Strahler river order (appendix 1). NVE has established a national river network derived from base map data in scale 1:50000. In the river network all rivers, streams and lakes are interconnected. A river network is often a preferred data structure when making GIS-analysis compared to rivers represented as lines and polygons. A network gives opportunities to perform upstream and downstream analysis, which is impossible when rivers are represented as lines and polygons.

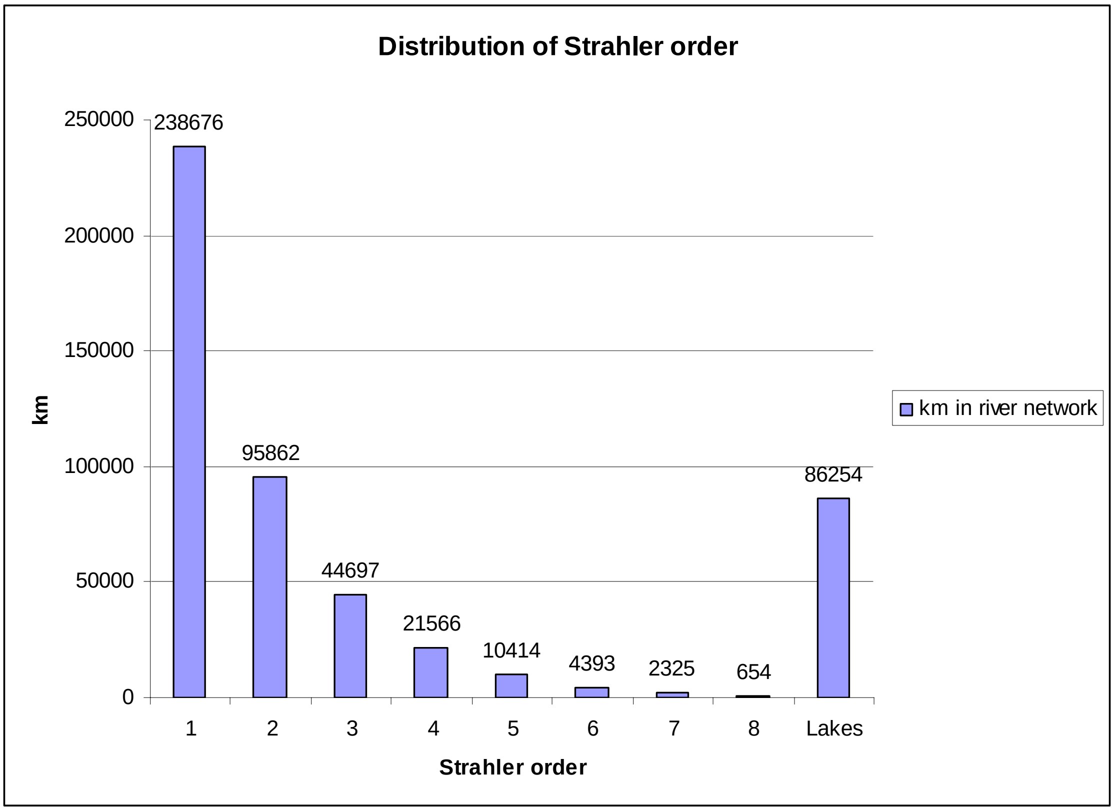


Figure 1: Distribution of rivers according to Strahler order.

Elevation

When mapping of areas prone to flooding is performed at a national level there is a limitation in the availability of accurate base map data. Several sources are available for information about elevation, but only one DEM is available with national coverage. Together with the fact that the mapping should be cost effective is this an important issue. It was therefore decided at an early stage in this project that the national 25x25m digital elevation model (DEM) from the Norwegian Mapping Authorities should be the preferred source for information about elevation.

The Norwegian Mapping Authorities have developed a national DEM with a spatial resolution of 25 x 25 m. The DEM is made from contours with 10m and 20m equidistance from base maps in scale 1:50000. Approximately 60 % of the country has contours with 5m equidistance. More detailed elevation data are available along some of the main roads and in urban areas. The national DEM has it limitations in terms of accuracy, and for future use it must be noted that the Norwegian Mapping Authorities have started to develop a new national digital elevation model (DEM). The mapping methodology of areas prone to flooding will need to be revised when the new elevation model is available.

Hydrological data

NVE has a network which consists of 600 gauging stations. The measurements are kept in NVE's hydrological database HYDRA 2.

METHODOLOGY

The main focus has been to investigate the possibility to derive areas prone to flooding based on our national DEM. Two different approaches have been evaluated:

- Geormorphological, slope analysis and use of the river network
- Hydrological ,deriving the flood extent from the DEM based on a hydrological analysis of expected rise in flood level at a given location along a river reach

Common for the different approaches is the use of the 25 x 25 m DEM.
The main challenge is the coarse resolution of the DEM. Another challenge is to develop a product which is recognisable for the public and easy to communicate to the local authorities and the public.

Geomorphology, slope analysis and river network

The main hypothesis in this approach is that flat areas in the vicinity of rivers were created in a process of sedimentation and thus prone to flooding. Flat areas can be identified by the use of a dataset representing slope. A national dataset representing slope have been calculated based on the DEM. Slope calculation is a predefined tool in most GIS software. In order the find a representative threshold value for slope, representing flat areas, the slope dataset were compared with the flood extent from our existing detailed flood inundation maps. Based on the comparative study between flood inundation maps and the slope dataset, a representative threshold value ≤ 3 degrees were chosen. Based on the threshold value of 3 degrees, all areas in the slope dataset ≤ 3 degrees were identified as flat areas or prone to flooding.

Figure 2. Extent of calculated 500-year flood (shaded area) with areas prone to flooding based on slope only

In order to reduce the extent of flat areas two different approached were tested. First, a 500m buffer was applied along the rivers. All defined flat areas outside the buffer were removed from the dataset. This approach was later rejected because it had some unwanted side-effects in areas with a wide floodplain. The second approach was to identify all flat areas, but only keep flat areas that were interconnected with the river.

As it appears in fig.2, there is a very good correlation between the calculated 500-year flood and the identified areas prone to flooding based on this approach. The result of this simplification makes the final product much easier to read. Fig.3 and fig.4 shows the results from two other locations.

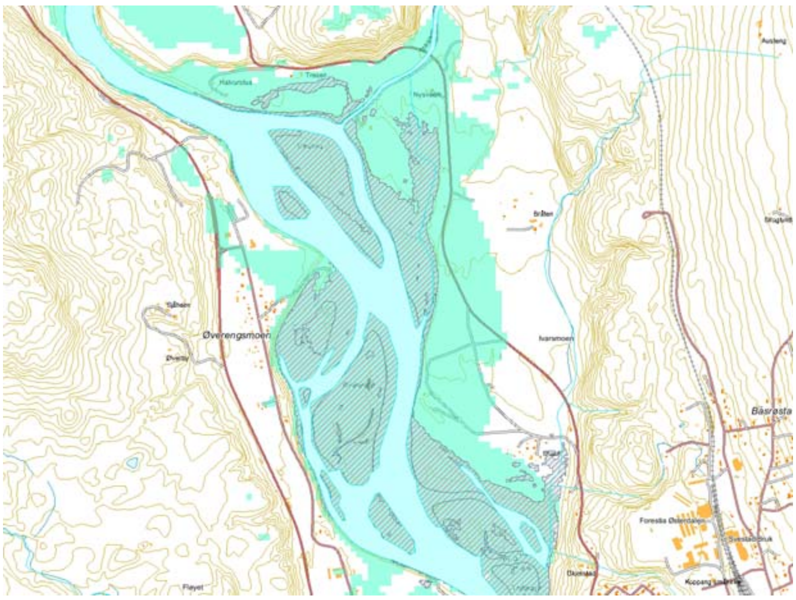


Figure 3. The figure shows the extent of the calculated 500-year flood (shaded area) at Koppang from our flood inundation maps together with the areas which are identified as prone to flooding based on slope

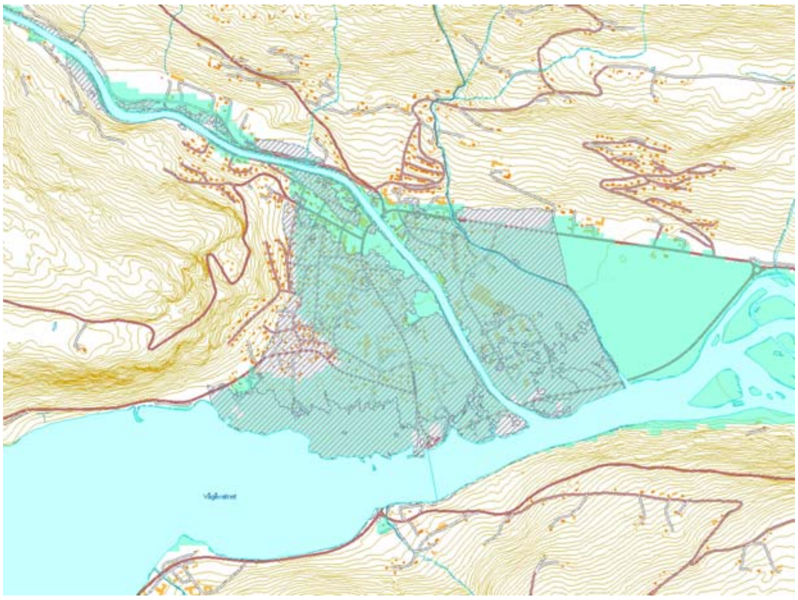


Figure 4. The figure shows the extent of the calculated 500-year flood (shaded area) at Vågåmo from our flood inundation maps together with the areas which are identified as prone to flooding based on slope.

Hydrology – deriving flood levels

The basic idea is to develop a simple method to calculate the potential rise of water level in various kinds of rivers. The method is based on the assumption that the water level can be derived without the use of detailed hydrological or hydraulic calculations.
Basicaly 4 different approaches were used depending on the availability of data.

- Data from gauging stations (discharge, waterlevels)
- Catchment characteristics (catchment area, lake percentage, specific runoff)
- Catchment area
- Comparable rivers in the same area.

For ca 150 riverstreches in Norway hydraulic calculations were made to make detailed flood inundation maps. Rise in water level from these rivers were correlated with discharge and catchment characteristics.

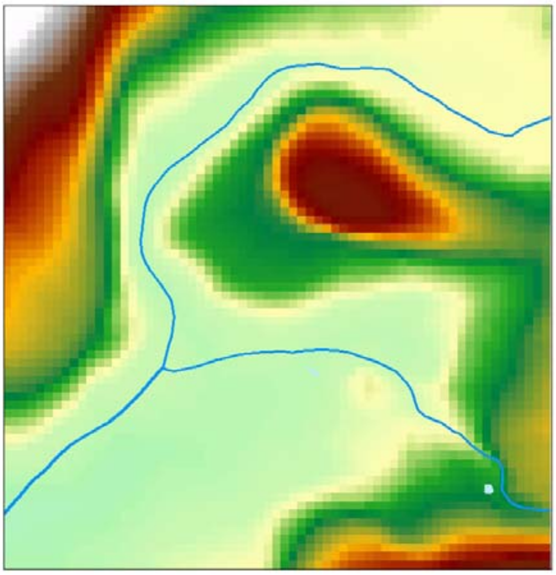
For gauging stations outside of the flood inundation map areas, rise in water level can be established based on flood frequency analysis and the discharge rating curve.

In ungauged river basins, catchment characteristics were used to estimate rise in water level. A precondition was to use relative simple parameters that can be used for different kind of rivers, both small and big, steep and flat, different strahler etc. Regresion analysis were done with rise in water level for a 500 year flood, both at gauging stations and river stretches with flood inundation maps. The results show a moderate relation with a R2 value between 0,3 and 0,5. The regression residual is between 2 and 4 m, depending on catchment area. About the same values were found when using the rise in water level from both gauging stations and flood inundation maps.

In ungauged catchments, using only area gives a slightly worse result. Alternatively, values were taken from comparable catchments (based on expert judgement).

None of the methods take special hydraulic situations into account.

In regular floodplain analysis the rise in water level has been established through detailed hydraulic analysis using measured cross sections. By placing these values on the cross sections a floodplain can be calculated. By overlaying the floodplain with a digital elevation model (DEM) the inundated area can be calculated.



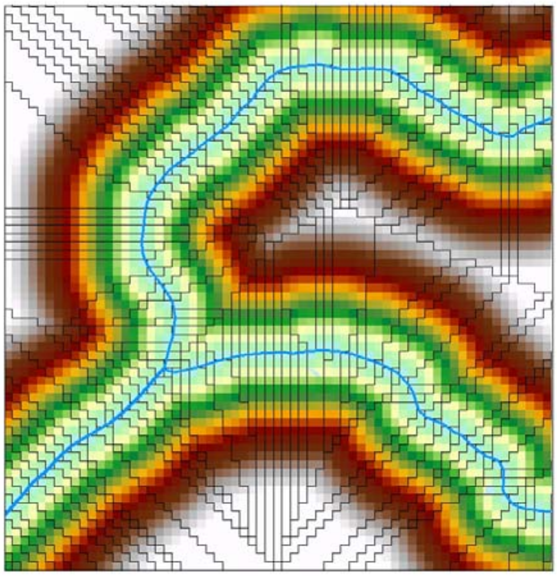


*Figure 5. The 25*25 m DEM.*
Figure 6. The virtual DEM based on buffers and the "cross section" strokes.

A method had to be developed where a floodplain could be calculated without using cross sections. See figure 6. In Order to do this a set of 25 m buffers is calculated around the rivers. The buffer number is then used as a height value (first buffer is 1 m , second buffer is 2 m etc) in a virtual elevation model. With standard GIS functionality the drainage pattern is calculated for this "elevation" model using the individual river grid cells as pour points. The result is a set of narrow strokes perpendicular to the river. These strokes can be given the value of the highest water level along the river crossing the stroke. This value is simply derived from the digital elevation model. Adding the maximum rise of water level gives a calculated flood level. By comparing this height with the height in the original elevation model the floodplain can be easily extracted.

DISCUSSION

The geormorphological method

The geormorphological method is a simple approach to assess areas prone to flooding. The method disregards the use of any hydrological information. The method is purely based on the topography of the terrain. In the comparative studies with the detailed flood inundation maps, the identified areas prone to flooding are overestimated compared to the extent of the calculated 500-years flood. This is of course a disadvantage when the product are to be used in area planning – potential build-up areas get restrictions because they are identified as prone to flooding. These overestimations are largest upstream. At the moment we are in the process of investigating further development of the geormorphological method. One option is to investigate the possibility to remove areas close to the watershed divide because of the size of upstream area.
On the other hand, considering it is a small scale analysis, it is better to overestimate the danger than to underestimate.

Discussions about the product within NVE showed that it is a challenge to communicate the results. It is difficult for people to comprehend flood plain analysis without using any hydrological measures.

Hydrological method

All parameters that are used in the hydrological method have their own inaccuracy. In sum, this leads to a significant uncertainty in the results. Some of the uncertainties and inaccuracies are mentioned below.

- Accuracy of the used elevation model
- Use of elevation model to obtain water levels
- Uncertainty in maximum rise of water level
- Implementation of regional different values
- Disregarding local hydraulic conditions (underestimation)

Considering all the uncertainties it is important to use a safety margin to insure that the results are an overestimation instead of and underestimation of flood level.

The first results are promising, but they also raise some new issues to be solved. One of the major problems is to differentiate automatically between the main river in an area, the one the water level rise is estimated, and the tributaries. We need to conclude if it is possible or not to assign the rise in water level in the tributaries.

The Norwegian mapping authorities are in the process of establishing a new digital elevation model (DEM). The new DEM will have a better accuracy in elevation and probably a more detailed geometric resolution. When the new DEM is ready the methodology for defining areas exposed to flooding will be revised.

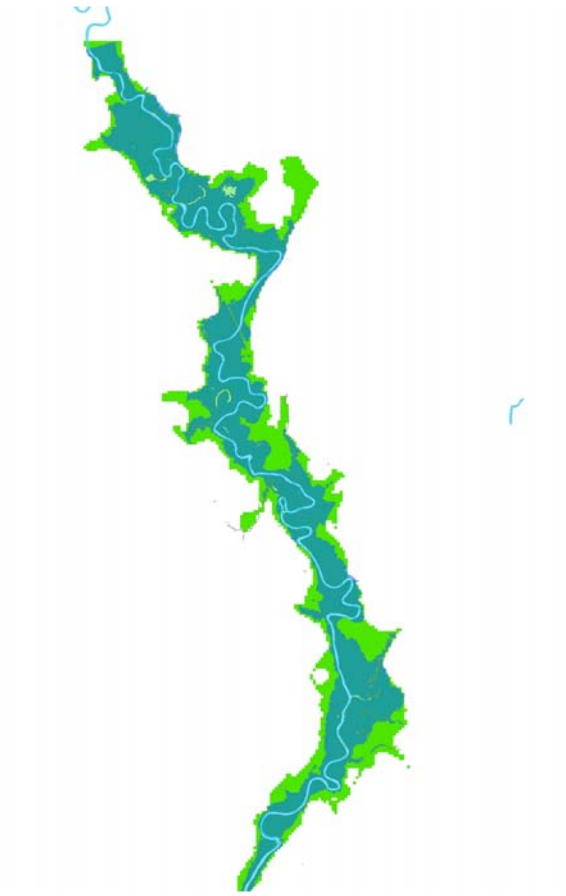


Figure 7. Results of the hydrological method compared with the calculated 500-year flood showing the over-estimation of the inundated area.

CONCLUSION

Two different methods to identify areas prone to flooding have been evaluated. Both methods have their advantages and disadvantages. The geormorphological method is simple and straightforward to implement, but it lacks support. It is difficult for people to comprehend the results. The hydrological method with its uncertainties and issues to be solved apparently has more support and is easier to understand.

In the end, the best approach to assess flood risk might be a combination of the results from the two described methods.

Appendix 1 - Strahler Stream Order

The **Strahler Stream Order** is a simple hydrology algorithm used to define stream size based on a hierarchy of its tributaries.

The streams range from one at the headwaters (which is a "1") to the most powerful which is the Amazon River which is a "12." The Ohio River is an "8" and the Mississippi River is a "10." 80 percent of the streams and rivers on the planet are first or second order.

To qualify as a stream it must be perennial. When two **first-order** streams come together, they form a **second-order** stream. When two second-order streams come together, they form a **third-order** stream. Streams of lower order joining a higher order stream do not change the order of the higher stream. Thus, if a first-order stream joins a second-order stream, it remains a second-order stream. It is not until a second-order stream combines with another second-order stream that it becomes a third-order stream.

It is important to appreciate that stream order is dependent upon map scale. As scale decreases and more detail is added to the river network (i.e. new tributaries) then a river may increase its stream order.

Arthur Newell Strahler first proposed the hierarchy in 1952 in an article “Dynamic basis of geomorphology,” in the Geological Society of America Bulletin. It is often referenced in professional descriptions of rivers as *Strahler 1952*.

Figure 14-4 Stream ordering by the rules proposed by Strahler (1964).

EMPLOYMENT OF REGIONAL CLIMATE MODELS AS DATA SOURCE FOR HYDROLOGICAL MODELLING

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ABSTRACT

A set of 21 regional climate models (RCM) from PRUDENCE framework was considered. The method for the evaluation and ranking of RCMs was developed comparing modelling results with observations. The RCM output was used for forcing of a calibrated hydrological model of a pilot river basin. An amplification of the discrepancy of the meteorological data was found comparing modelled and observed river runoff. A statistical method for RCM data correction was proposed and employed for the reference period and climate change scenarios. Non-obvious conclusions regarding expected change of river run-off were drawn after applying corrected RCM data in the hydrological model.

INTRODUCTION

The paper addresses an issue of prediction the impact of the climate change on the river run-off. The study is a part of Latvian national research programme "Impact of climate change on Latvian water environment" (www.daba.kalme.lv). The obvious steps for evaluation of future runoff are (1) selection of the most appropriate regional climate model, (2) calibration of reasonable run-off model for some reference period, (3) application of p.(2) model with p.(1) model data for climate change scenarious. The issue and similar studies may be regarded as rather actual, see for example Bergström et al (2001), Jha et al (2004), and Graham et al (2007).

We followed the approach described in the further Chapters:

(1) Selection of RCM. The set of 21 RCM was considered. The RCM calculations for the reference period (1961-1990) were compared with temperature and precipitation observations in hydrometeorological stations in Eastern Baltic region. The discrepancy between the RCM and observations were quantified.

(2) Application of RCM data to hydrological modelling. A hydrological model of pilot river basin in Latvia was calibrated for 3 years period. The run-off calculations for the reference period were performed by this model

with input data from (a) meteorological observations, (b) RCM calculations. Hydrological modelling indicated the non-linear amplification of seemingly minor statistical differences between the RCM outputs and meteorological observations.

(3) Correction of RCM data. The method of the RCM data correction was proposed. It is based on the shifting of the event occurence graphs, and it ensures that the statistical properties of the RCM data are the same as of the meteorological observations. The correction method was applied to RCM calculation results for the reference period (1961-1990) and of B2 and A2 climate change scenarious (2071-2100).

(4) The hydrological modelling of the pilot basin was done for reference, B2 and A2 scenarious revealing the expected response of the basin hydrology on the climate change. It was shown that the direct use of (non-corrected) RCM data for the forcing of the hydrological models may yield inadequate (and even opposite) conclusions regarding the impact of climate change on the river runoff.

SELECTION OF RCM

We considered the collection of the RCM calculations organised in a web-accessible database at Danish Meteorological Institute under EC 5th FP research project "PRUDENCE" EVK2-CT2001-00132 (prudence.dmi.dk). The considered models (abbreviations from PRUDENCE project) were CHRM HC_CTL, CLM CTL, CLM CTLsn, HadRM3P adeha, HadRM3P adehb, HadRM3P adehc, HIRHAM HC1, HIRHAM HC2, HIRHAM HC3, HIRHAM ecctrl, HIRHAM ECC, HIRHAM Xtra hi res. F12, HIRHAM high res. F25, HIRHAM HADCN, PROMES control, RACMO HC1, RCAO HCCTL, RCAO hi res, HCCTL_22, RCAO MPICTL, RegCM ref, REMO 3003.

The observations of air temperature and precipitation by Soviet Hydrometeorlogical Agency (www.meteo.ru) in Eastern Baltic area (i.e. in and near the territory of Latvia, see Fig.1) were used; 14 stations were Tallinn, Pärnu, Valga (Estonia), Pskov, Kaliningrad (Russia), Minsk (Belarus), Vilnius, Kaunas, Šiauliai (Lithuania), Liepāja, Rīga, Kolka, Daugavpils, and Gulbene (Latvia). The daily values of all 21 model and 14 observation stations were used.

The penalty function K_i describing the deviation of each i-th RCM from the meteorological observations was constructed. We aimed in evaluation of model accuracy in terms of temperature, precipitation, their monthly and interannual variation, and spatial distribution. Therefore we used four parameters for construction of penalty function: monthly mean temperatures T, monthly net precipitation p, and standard deviation of T, p during the reference 30-year period at all stations. All parameters were normalised to equal their weights.

$$K_i = \Delta T_i + \Delta p_i + \left(\Delta D_T\right)_i + \left(\Delta D_p\right)_i$$

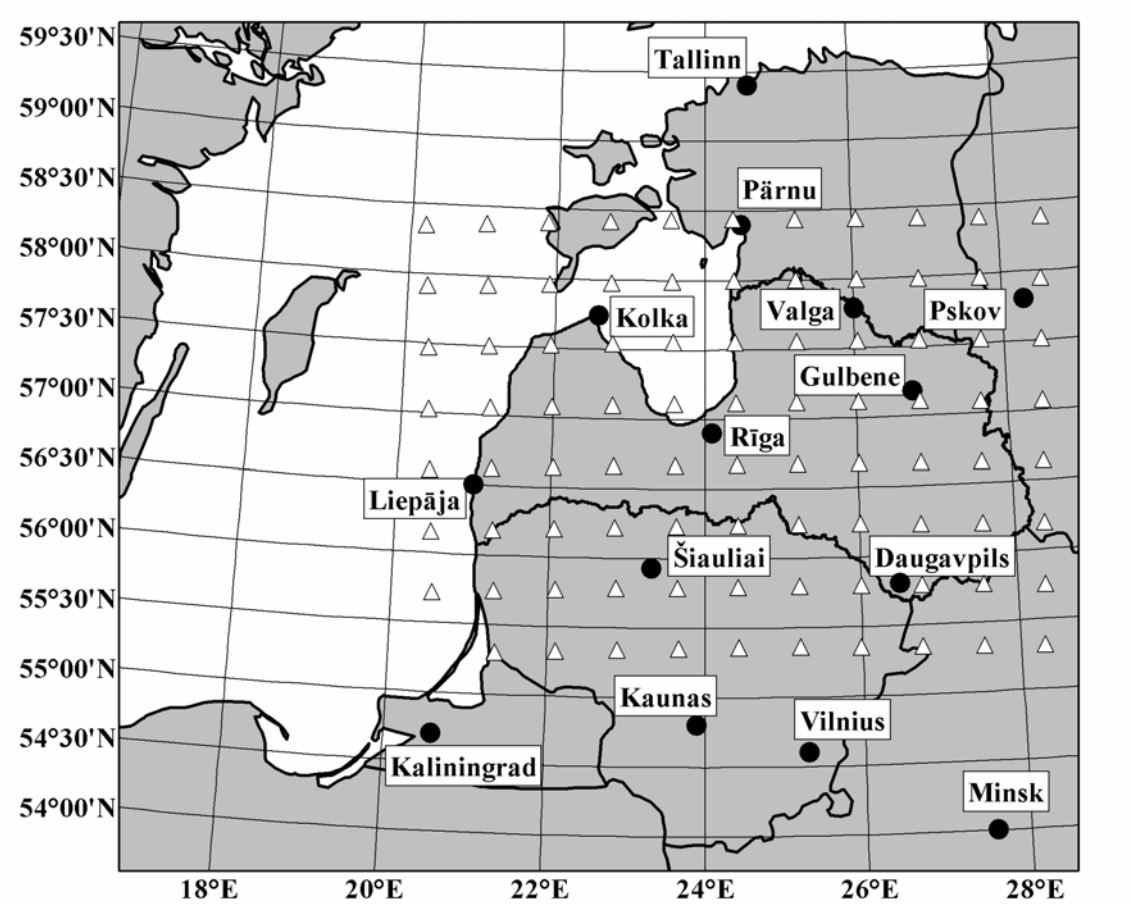


Figure 1. The observation stations and selected nodes of RCM (SMHI HCCTL) calculation grid over the territory of Latvia.

The calculation of each of 4 components of the penalty function (say, for temperature T) was performed as

$$\Delta T_i = \sum_{s,m} \frac{\left(\overline{T}_{i,s,m} - \overline{T}^*_{s,m}\right)^2}{T_{\max}}, \quad T_{\max} = \max_{i,s,m}\left(\left(\overline{T}_{i,s,m} - \overline{T}^*_{s,m}\right)^2\right)$$

Here indices denote model (i=1..21), station (s=1..14), month of a year (m=1..12), modelled parameter is T, whilst observed parameter is T^*.

Normalising penalty function to its maximum value (maximum K=1) yields the best evaluation of the agreement of RCM and observations data over the study area for SMHI HCCTL model (K=0.41). This model will be considered further throughout the paper. Generally, all models reasonably represent the seasonal cycle of temperature, overestimate winter precipitation and underestimate summer precipitation in the study area. The comparison of the observations and RCM, as well as climate change predictions by RCM for Riga is illustrated in Fig. 2. The difference between the model and observations (0.8 degC and 164 mm) is not critical, however one must be careful interpreting the estimated climate change scenarious by RCM, i.e. direct comparison of observations with B2 and A2 calculations may yield to overestimation of expected T and p changes.

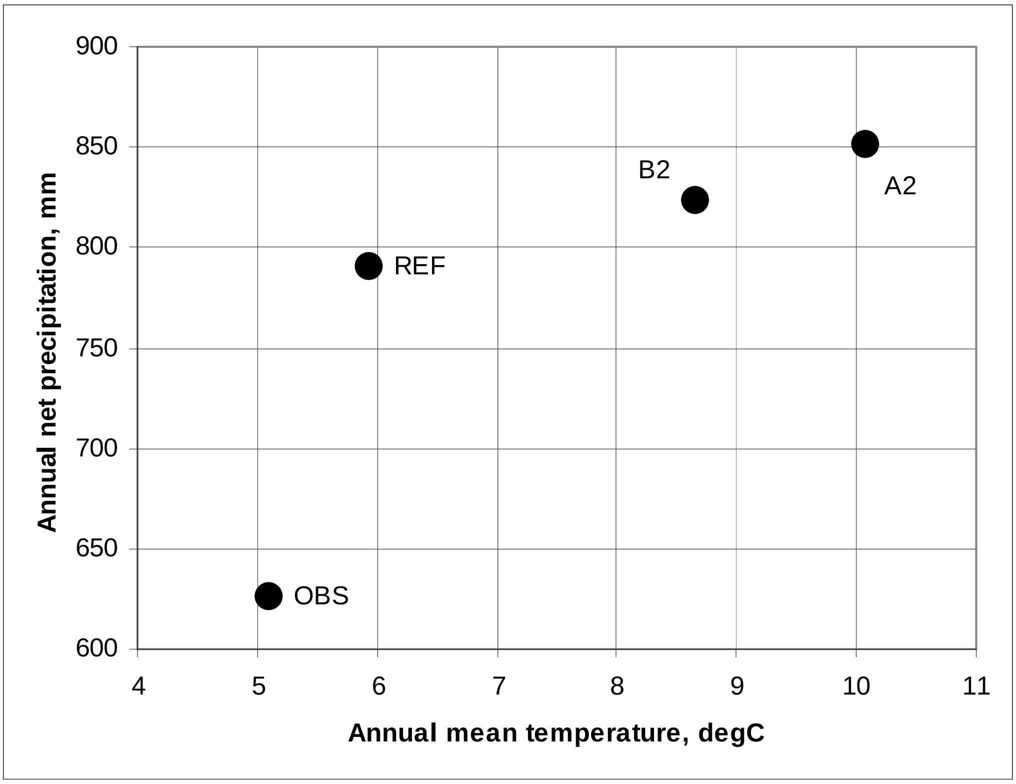


Figure 2. Annual mean temperature and net precipitation in Riga: observed (OBS) and calculated by the best RCM (REF) for 1961-1990, and predicted by the best RCM (B2, A2) for the climate change scenarious.

APPLICATION OF RCM DATA IN HYDROLOGICAL MODEL

The basin of Aiviekste river in the central Latvia was chosen as pilot basin. The in-house hydrological model was used, see Bethers & Seņņikovs (2007). It is temporally and spatially distributed model, based on finite volumes. Model includes physically based surface flow, snow, subsurface flow, and lake modules as well as dynamic flow routing through the stream channel system. The location of the pilot basin (area 9300 km^2) and the upper level of hierarchical river network is shown in Fig. 3. The selection of the pilot basin was determined by well balanced presence of forest and agricultural subbasins, slow and fast-flowing tributaries, as well as several lakes.

The hydrological model was calibrated on daily discharge observations in seven observation stations for three year (Jul/1976 to Jun/1979) period using input data – daily observations of temperature and precipitation – from three meteorological observation stations closest to the river basin.

The calibration time period was chosen to include three different consecutive years: dry, average and wet. The time-plot of calculated and observed discharges for the calibration period is shown in Fig.4. The good agreement can be characterised by model efficiency coefficient E=0.921 according to Nash & Sutcliffe (1970).

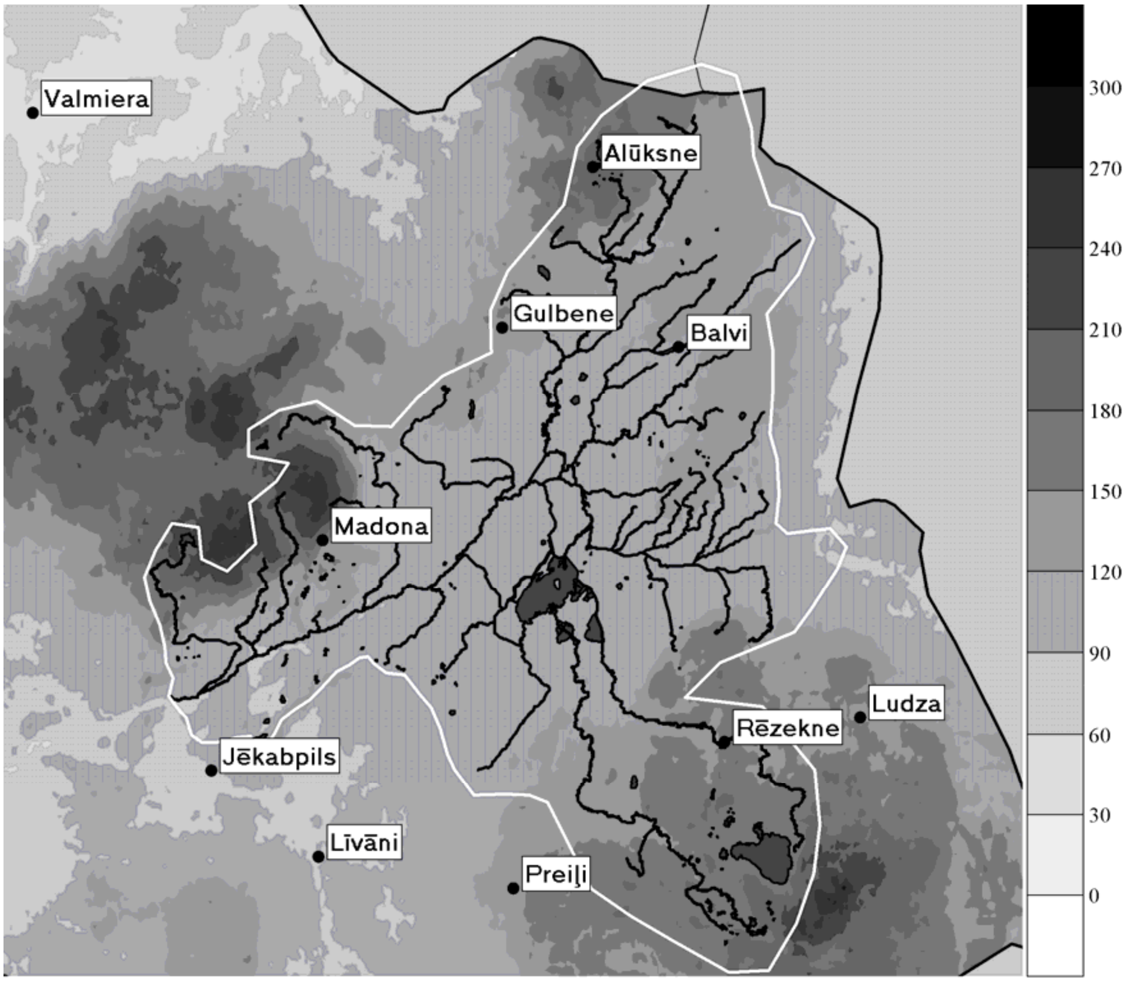


Figure 3. Elevation distribution and stream network in river Aiviekste basin.

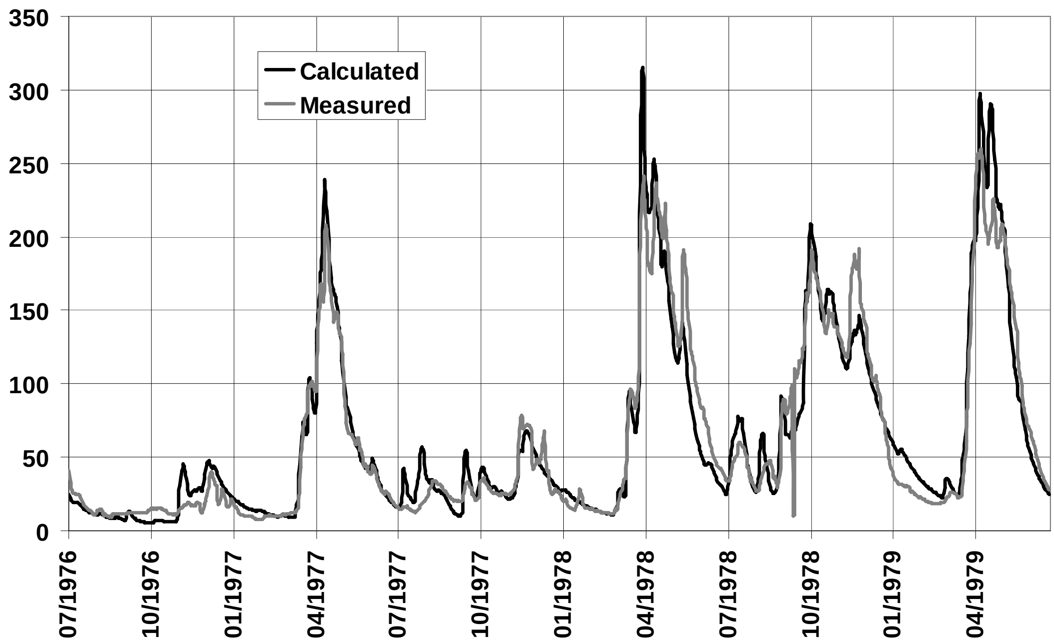


Figure 4. Calculated and measured Aiviekste discharges (m^3/s) for 1976-1979.

The calibrated model was further employed for the run-off calculations of reference period (1961-1990), using as input data T and p from observations and RCM calculations, and for future period (1971-2000) using input data from respective RCM scenarious. The results of calculations are summarised in Fig. 5. One may consider (a) excellent agreement between the observed run-off and run-off calculated from the meteorological observations, (b) distinct disagreement of the run-off calculated from the best possible RCM data. The differences between the observed and modelled climate (see Fig. 2) have been significantly amplified by hydrological model. Even more, considering possible climate change one cannot make even qualitative judgement whether run-off of river Aiviekste will increase (correct, comparing run-off observations with scenario modelling) or decrease (correct, comparing run-off modelling from reference and scenario data).

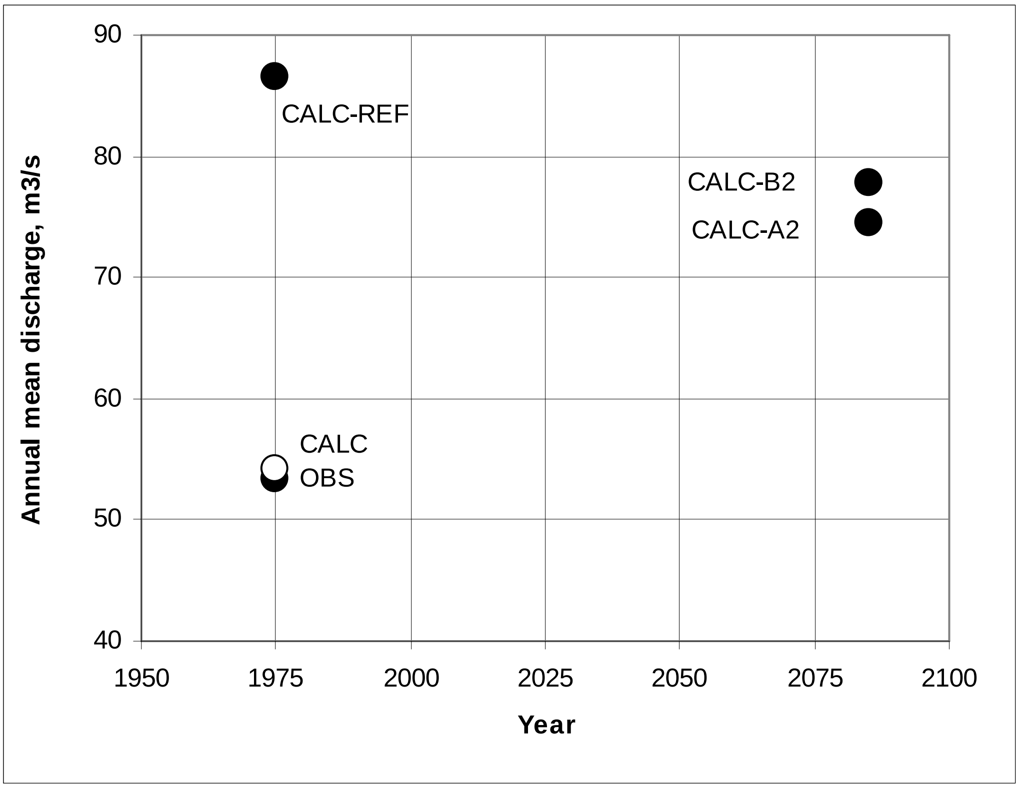


Figure 5. Annual mean discharge of Aiviekste river: observed (OBS) and calculated by hydrological model from observed (CALC) and RCM (CALC-REF) data for 1961-1990, and from RCM data (CALC-B2, CALC-A2) for the climate change scenarious.

RCM DATA CORRECTION

We propose a method of RCM data correction, based on the shifting the occurrence distribution of particular daily parameter (temperature or precipitation).

(1) Two cumulative probability curves – one of the observed data, and one of RCM data – were constructed for each day-of-the-year, for each parameter in each observation station. The data within moving slot of time (+/- 5 days) were used to increase the number of events to 330 (30 years times 11 days) for each curve. Data was randomly perturbed to ensure smoothness of probability curves.

(2) For each value of model data (say T) we found the probability f(T). We then find the observed temperature T^* for which $f(T^*)=f(T)$, and assume that model temperature correction for T is equal to T^*-T. Thus, the temperature correction is a function of model temperature, and is given by

$$\Delta T(T) = (T - T^*)\Big|_{f(T)=f(T^*)}$$

See the example of the temperature correction for typical winter day in Fig. 6. Correction ensures that the model daily temperatures in the range [-

17;+2] degC are decreased to match occurrence of cold events, whilst the higher daily temperatures are increased.

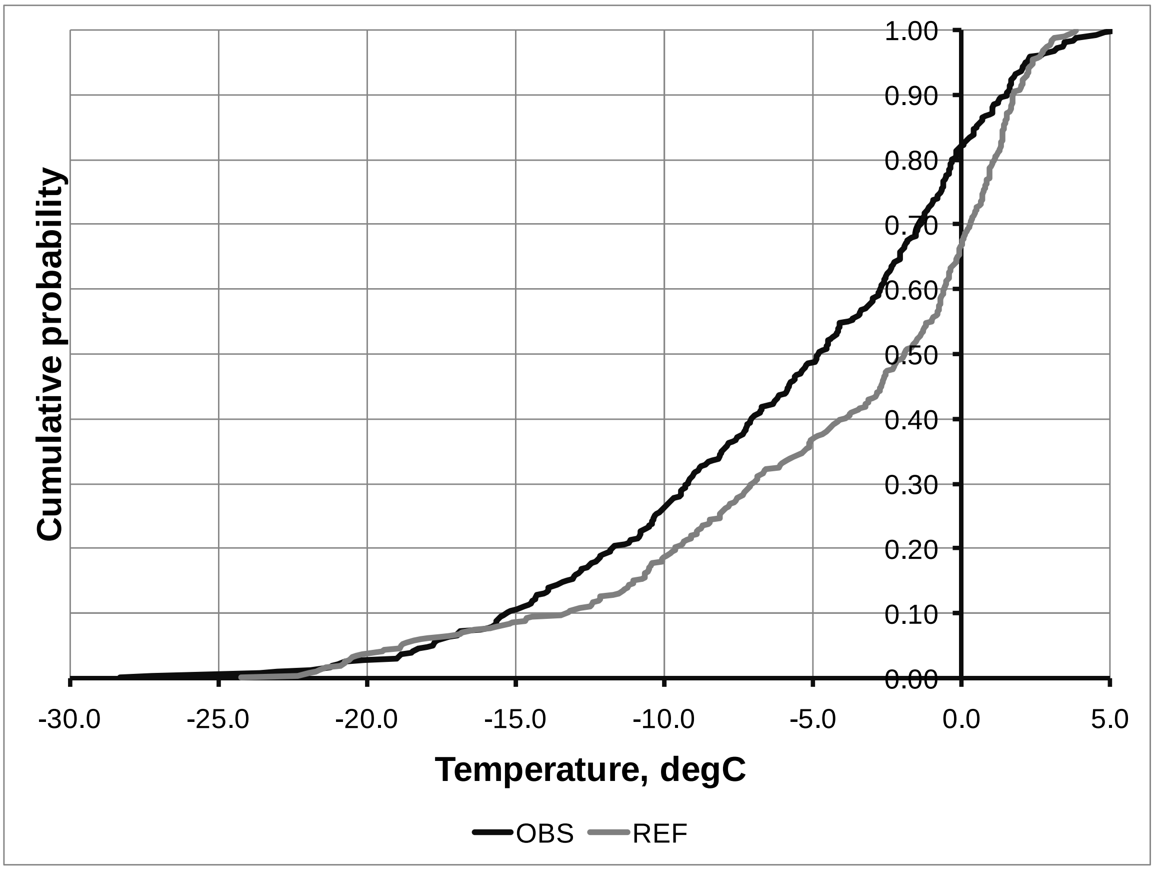


Figure 6. Cumulative probability of temperature (i.e. percentage of occurrence of temperatures below given temperature) for 15-Jan at Riga. Observations and RCM data for reference period.

(3) The correction functions of p.(2) are found for each day, for each parameter, and at each observation station. They are spatially interpolated to cover the model domain and applied for the correction of the RCM data. Thus, the datasets “modified RCM data for reference period” is created; it contains the climate signal characteristics from RCM, and in the same time has the statistical properties of the observed data.

(4) The same correction functions of p.(2) were applied for the RCM scenario results, yielding datasets “modified RCM data for climate change scenarious”. However, authors at this stage cannot provide arguments defending the validity of this approach.

The T-p plot, indicating the results of the RCM data correction is shown in Fig. 7.

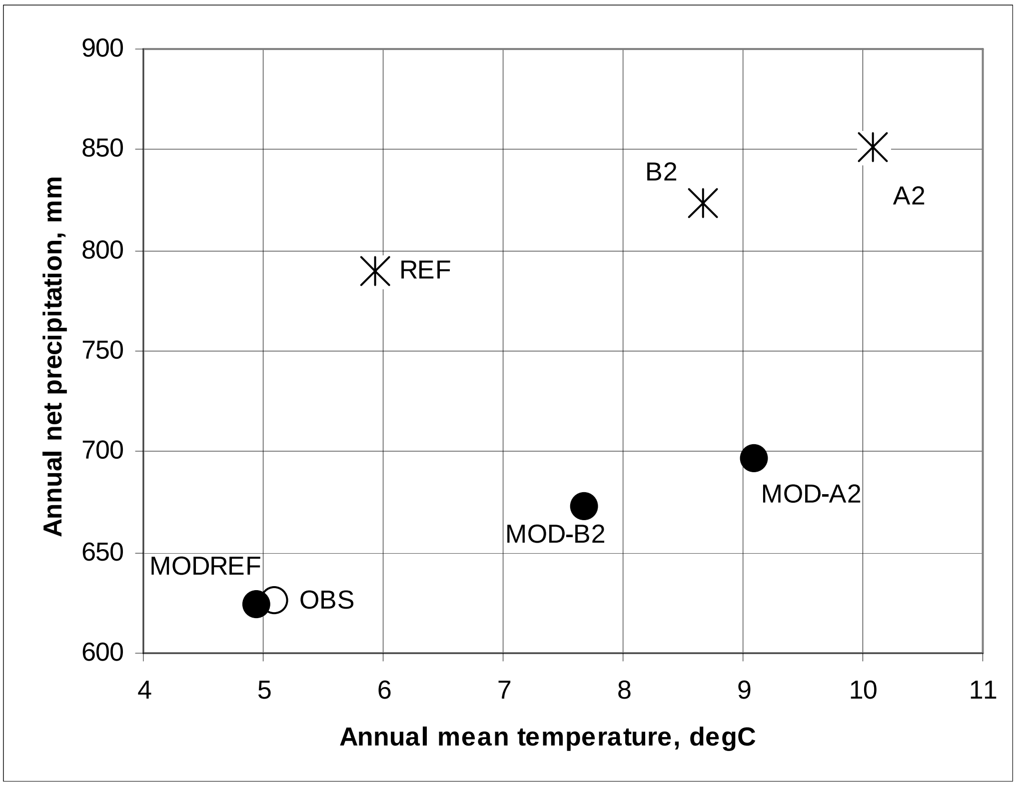
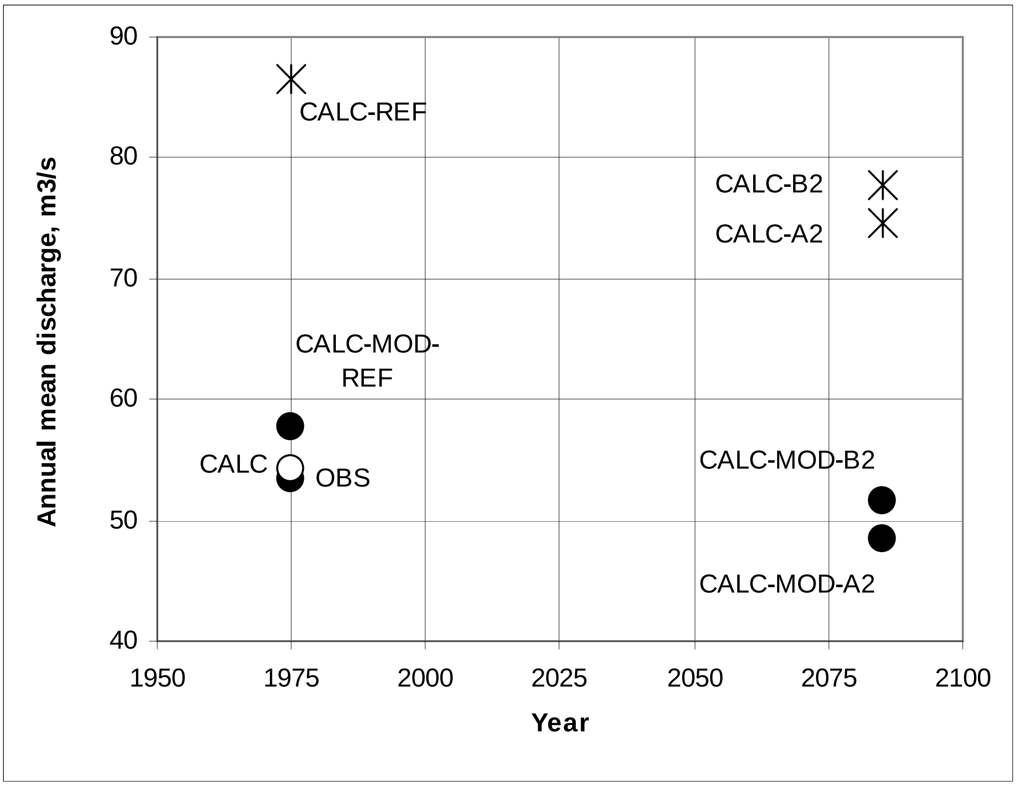


Figure 7. Annual mean temperature and net precipitation in Riga: observed (OBS), calculated by the best RCM (REF), and corrected (MODREF) for 1961-1990. Predicted by the best RCM (B2, A2) as well as corrected (MOD-B2, MOD-A2) for the climate change scenarious 2071-2100.

HYDROLOGICAL CALCULATIONS WITH CORRECTED RCM DATA

The calculation of the hydrological processes in the Aiviekste river basin were re-done using the corrected RCM datasets for the reference period, as well as for the climate change scenarious B2 and A2. The results of calculations are summarised in Fig. 8 (compare with Fig.5) for annual mean values (Fig. 8 above) and for the mean seasonal cycle – monthly mean values (Fig. 8 below).

The hydrological calculations from the corrected RCM data (CALC-MOD-REF) indicate reasonable agreement with discharge observations (OBS). One may consider that under the prescribed climate change scenarious the mean annual discharge will decrease.



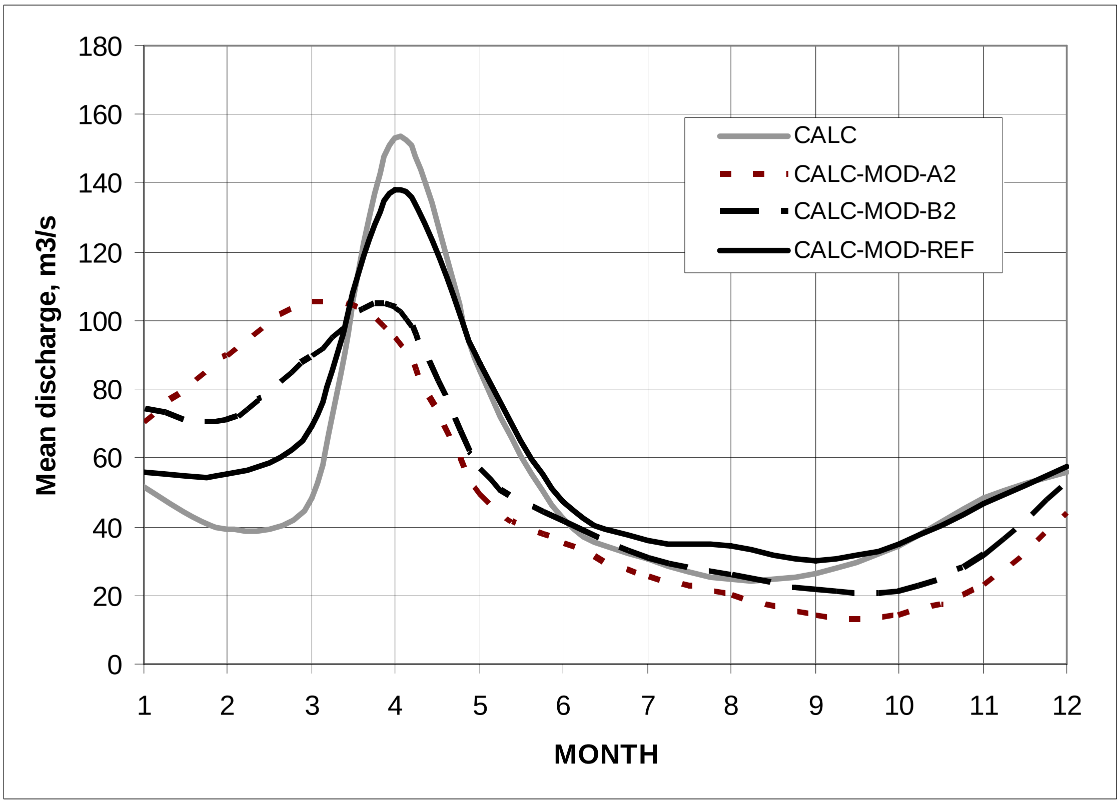


Figure 8. Annual mean (above) and monthly mean (below) discharge of Aiviekste river: observed (OBS) and calculated by hydrological model from observed (CALC), RCM (CALC-REF) and modified RCM (CALC-MOD-REF) data for 1961-1990, and from RCM / corrected RCM data (CALC-B2, CALC-A2, CALC-MOD-B2, CALC-MOD-A2) for the climate change scenarious.

The main seasonal alterations of river run-off due to climate change can be identified as (1) increase of winter run-off (JAN-MAR), (2) distinct decrease of spring snow-melt flood maximum (APR-MAY), (3) earlier spring snow-melt flood, and (4) decrease of autumn run-off (SEP-NOV).

CONCLUSIONS

The regional climate models provide sufficient information for the hydrological modelling of expected climate change on the river run-off. However, one must avoid direct usage of RCM data for the forcing of hydrological models before analysing RCM compliance with observations for the reference (and, if possible – reassessment) period. Even seemingly reasonable agreement of the meteorological RCM data with observations for the reference period may cause non-linear growth of discrepancies between the hydrological modelling results obtained from either observed or modelled meteorological data.

The proposed method of RCM data correction seems to provide means for avoiding confusion regarding the usage of RCM data for the input of hydrological models.

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DEVELOPMENT OF DYNAMIC FLOOD FORECASTING SERVICES

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ABSTRACT

The Norwegian Water Resources Directorate operates today's flood warning system (called the "National Flood Forecasting Service") for Norway. This system is based on forecasts of average daily discharge magnitudes. Expected discharge values are matched with distribution models from historical data and if exceeding magnitudes of given return periods, warnings are issued. Dynamic Flood Forecasting Services attempt to fulfil a need from the public and provide real time and forecasted information using the existing system, extending that with additional components and presenting outputs in non-traditional ways.

Hydraulic models of rivers are developed for selected locations in the country and are run automatically on daily basis parallel to and using data from the existing discharge forecasting system. These generate water level forecasts which are further employed in automated GIS analyses. The result is a series of animated and interactive maps and tables with points of interest showing actual and forecasted water levels and inundated areas on a dynamic web portal accessible to the public and the emergency services.

The article describes the details and the development of this system focusing on the overall concept and hydrological parts. The article titled Dynamic Flood Mapping by IO Peereboom focuses on the GIS analyses employed in the same system, therefore the two articles are complementary.

Keywords: Dynamic flood forecasting map, real time flood warning, forecast, automatic system, hydrological analysis, hydraulic modelling, GIS, hydroinformatics

INTRODUCTION

The Norwegian Water Resources Directorate (NVE) is in charge of operating the 24/7 flood forecasting service for Norway. The main objectives of this service are to provide information on and make initiatives against situations that may increase the probability of flood (long term warning), and issue of flood warnings in time, so that efforts can be made to reduce potential damage (short term warning).

The present short term warning system operates in three consecutive steps. Step 1 is the review of status which requires access to real time observations from gauging stations providing hydrological and meteorological data. Step 2 is the preparation of forecasts. Here data is used for forecast calculations giving expected discharge in the future. In Step 3 warnings are issued and broadcasted and measures initiated if necessary, based on the forecasted data.

BACKGROUND

Today information from the National Flood Forecasting Service is available to the public mostly through news agencies, TV channels and teletext. Emergency services and local authorities receive warning messages via email, telefax or telephone. With changes of media forms and needs of the public, internet plays a more important role in information broadcasting than before. According to the document Water Directors of EU et al. (2003), relevant and timely information should be made available to the public through the media, the Internet or other appropriate means. preparedness. The same source suggests that information about risk assessments should be easily understood, for example, clear flood maps and, where appropriate, information based on Geographic Information Systems (GIS) should be distributed. Everyone who may suffer from the consequences of flood events should be able to take – if possible – his/her own precautions and thus seriously limit flood damages. This requires adapting the existing services to the changing needs and increasing demands with new information content and presentation form.

The information, which is broadcasted today contains actual and forecasted, location specific precipitation, and flood magnitudes. Flood magnitudes are referred to in their “statistical form”, which is common in hydrology, and basically means flood return periods (e.g. “10 year flood”, drawn from statistics from historical measurements for regions). There is clearly an increasing need from the public and emergency services to receive forecasts in a more palpable form besides these, in form that are easier to understand in practise and are also possible to process and illustrate via modern media channels of the internet. A more meaningful way to present this information is by referring to water levels instead of flood return periods and to illustrate the information in various graphical and tabular forms as well as the former textual ways.

OBJECTIVE

For these reasons NVE have decided to develop the Dynamic Flood Forecasting System (DFFS), which extends the actual flood warning system to meet the new expectations. The DFFS uses internet as its main channel of information broadcast and presents water levels and related other data at specific locations instead of statistically classified flood magnitudes. Internet presentation provides new and modern means of publishing information, which include animation, spatial scaling of maps, showing maps generated for different times, interactivity and user-specific combination of contents.

METHODS AND MODELS

The complexity of the task requires using robust but simple methods. The tasks are divided into two main groups: development of the general and reusable framework for the system, and solving the periodic regeneration of the changing contents of the services. The result of the first task is basically a web portal interface combining the constantly regenerated tabular and map data, which allows interactivity and scaling of the maps. The second task includes the full automation of periodic regeneration of data, and solving the seamless flow of data from one subsystem to the other. The subsystems are the following:

1. Hydrological subsystem. This covers reading and calculating flood magnitudes (both observed and forecasted) and making those available as input for the hydraulic subsystem.
2. Hydraulic subsystem. This includes calculating flow levels and extracting water level data to be accessible for map generation services
3. GIS subsystem. Here base maps are generated from digital terrain data and forecasted water levels.
4. Data communication subsystem. This part is responsible for internal data flow. Results from one subsystem need to be filtered, reformatted and made available to the next subsystem, final results need to be published automatically.

HYDROLOGICAL SUBSYSTEM

This modelling system is in fact a HBV-type model used in today's operational flood warning system. It is an altered version of the original HBV model developed by Bergström (1976). Alterations are described by Sælthun (1996). This altered model system has been used for flood warning purposes for over a decade and proved to be reliable and useful for that purpose.

The system is based on modelling results from reference catchments, which (in principle) represent the hydrological and meteorological variations within Norway. Real-time observations from these locations (temperature, precipitation and discharge) are used as input parameters for HBV model simulations. In each catchment the cover and the distribution of the elevation are considered. ***Figure 1*** shows an overview of the locations of model catchments used for flood forecasting in Norway.

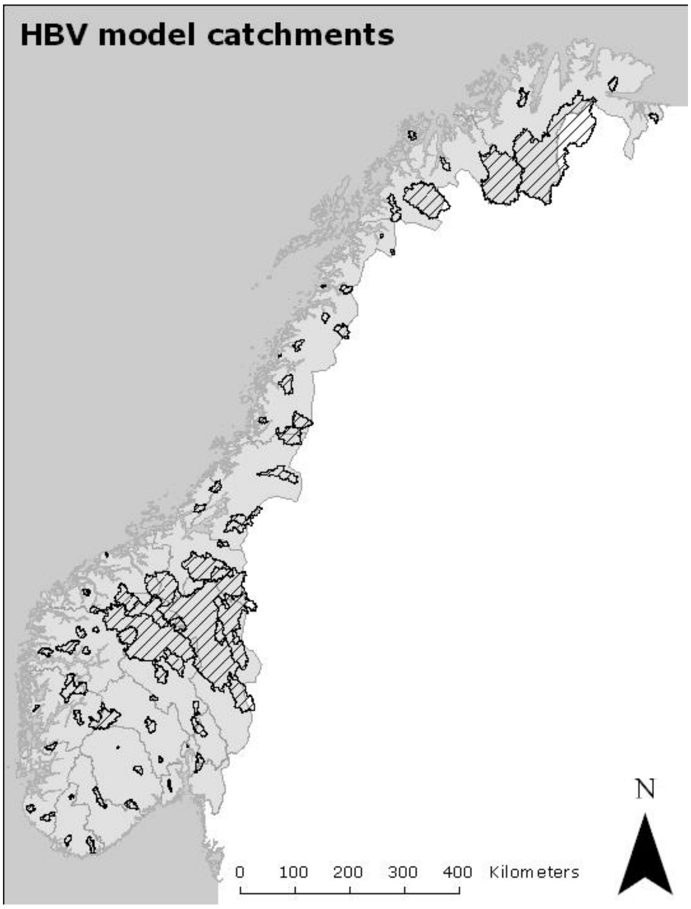


Figure 1. Map of the HBV model catchments which are used in operational flood forecasting in Norway. The catchments are meant to represent the hydrological and meteorological variations in Norway.

The system is run daily, and provides 7 days of forecasts of discharges, for 79 model catchments in Norway. Uncertainty of the discharge forecasts is also modelled, and the simulated discharges are corrected for pure model errors, with regret to the actually observed discharge through an autoregressive correction method. However these are not used directly in the DFFS project. Results for the present purpose are the discharge values for each HBV model catchment, which are used further on in the procedure.

It has to be noted that the (hydrological) modelling method is under revision. Changes will mainly include the use and generation of grid-type input and results instead of the lumped HBV model catchment related values.

HYDRAULIC SUBSYSTEM

In order to be able to forecast water levels (stages), the river hydraulics has to be considered. NVE has developed Flood Inundation Maps (FIMs) including inundation maps, reports and hydraulic models for selected locations all over Norway. NVE (2008) gives an overview of the project. These Flood Warning Maps are based on a combination of model calculations, which include interpolation of a digital elevation model (DEM), flood calculation with given return periods (5, 10, 20, 50, 100, 200 and 500 year floods) at the upstream sections of the selected locations, development of a hydraulic model for the possibly flooded areas and analysis of results. ***Figure 2*** shows locations all over Norway for which such reports were developed.

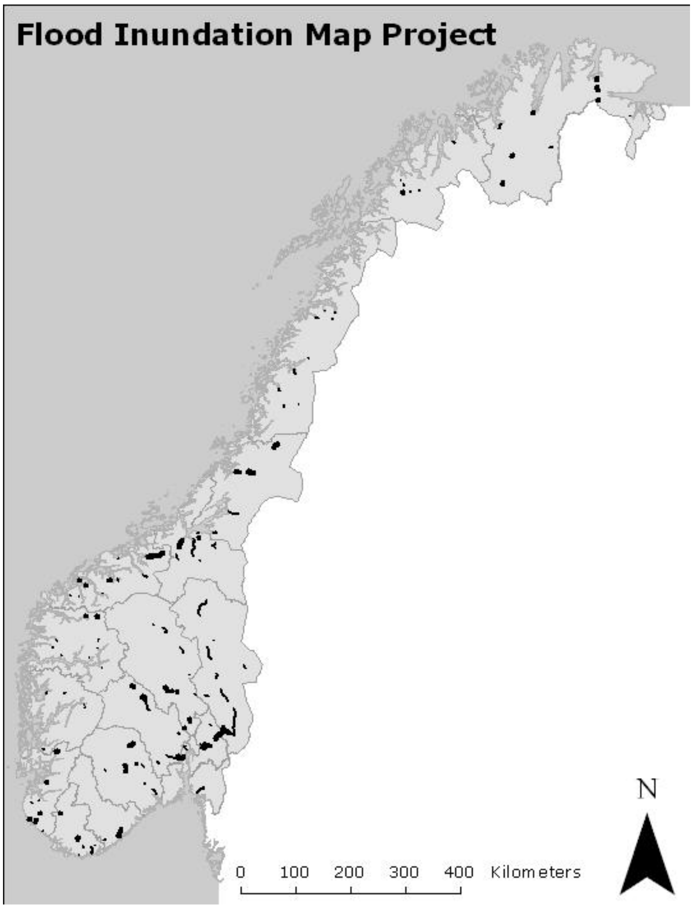


Figure 2. Locations for which Flood Warning Maps are developed.

The DEMs are constructed from 1 m contour lines (laser scanning). Various interpolation routines are then employed to construct a grid-type (raster) elevation model with 5 m resolution in each horizontal direction. In addition, cross section measurements crossing the entire flood channel and individual elevation points provide further information for modelling the hydraulic channel.

The hydraulic models in each case are calibrated for flood discharges based on historical observations and local research. The modelling method up till now was always one-dimensional (1D) calculation. For methodological details regarding hydraulic simulation of river flow see Olsen (2002). The hydraulic models are implemented in either the HEC-RAS system or in Mike 11. HEC-RAS is described in HEC-USACE (2002) and Mike 11 in Havnø et al. (1995). Both systems provide a solver for the fully dynamic Saint-Venant equations, and differ in the numerical solvers. There is no important difference between them from the modelling point of view for the present study.

The models developed for the Flood Inundation Map Project (FIMP) are reusable for the DFFS project after modifications. Most importantly the calibration needs to be revised, because while the FIMP features static models with relatively high discharges (floods), the DFFS needs to run on a daily basis, dynamically and for a wide range of discharges, in cases low flows. Alterations in the channel must also be checked, embankments, bridges and other constructions may alter the hydraulic features, and cause that some FIMs may become outdated.

A further difference is the determination of the boundary conditions, which are calculated as static values for the FIMs, while need to be updated for each simulation for the DFFS, this way these are dynamic values in the DFFS. The static simulation method is likely to be changed to dynamic as well, for example flooding in different parts of the catchment may occur at different times, thus modelling such a system requires dynamic capabilities. The boundary conditions required include discharge(s) fed into the system (at the most upstream section and occasionally along the model stretch) and downstream water levels. The discharges are taken from the daily HBV model results (see section about the hydrological subsystem above), while water levels are either related to naturally available features (like critical flow), to water regulation rules (predefined gate-operations, etc.) or to tide level predictions (in case the model stretch reaches tide-influenced area).

Output of this subsystem is a series of geo-referenced water level values for each forecasted time (in cases 12 or 24 hours), that are used further in the next subsystem.

GIS SUBSYSTEM

In principle once simulated water levels are available and a reasonably good DEM is in place, static flood inundation maps can be generated by simple subtraction of values and a combination of these two. In reality however, the process of flooding is rarely a static phenomenon, and various features of both the terrain and the flood dynamics must be considered, as well as the direct or indirect exposure of terrain parts to flood levels. NVE has developed automated scripts considering these for the FIMP cases, and therefore the scripts can here be reused.

The original scripts were developed in the AML language historically often used in UNIX-based GIS solutions, like in ArcINFO. Today's GIS-oriented aspects made it necessary to change the GIS solutions employed in NVE, and therefore the scripts had to be transcoded into Python language, which are used for example in the modern ArcGIS package. More details about desktop GIS can be found in ESRI (1996). Peereboom (2008) describes the challenges and solutions used in the updated script for the particular purpose of this project.

Results of the map generation are a series of geo-referenced water surface images for the modelling stretch. These are further used in a Web Mapping Service (WMS), which visualizes the data and puts it in the context of other static map elements, like roads, buildings and railway. Other results are calculated in tabular form, and these are a set of strategically important topographical features, for example low points of roads in the close neighbourhood of the possibly flood prone area, road and railway crossings, bridges and tunnels or buildings directly exposed to inundation.

Figure 3 shows a cut-out of the pure results of map generation. This water surface map is used further in the WMS in combination with other map features. The additional features may be collected from various internet sources, from practically any source offering WMS. This way each user may prepare a special map by combining various layers including the one provided by NVE's DFFS.

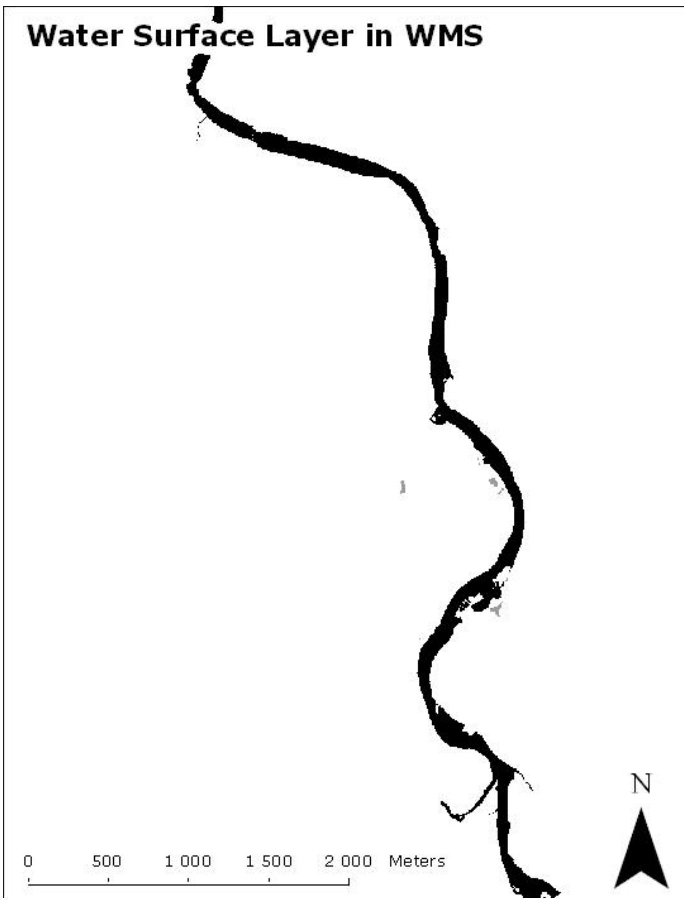
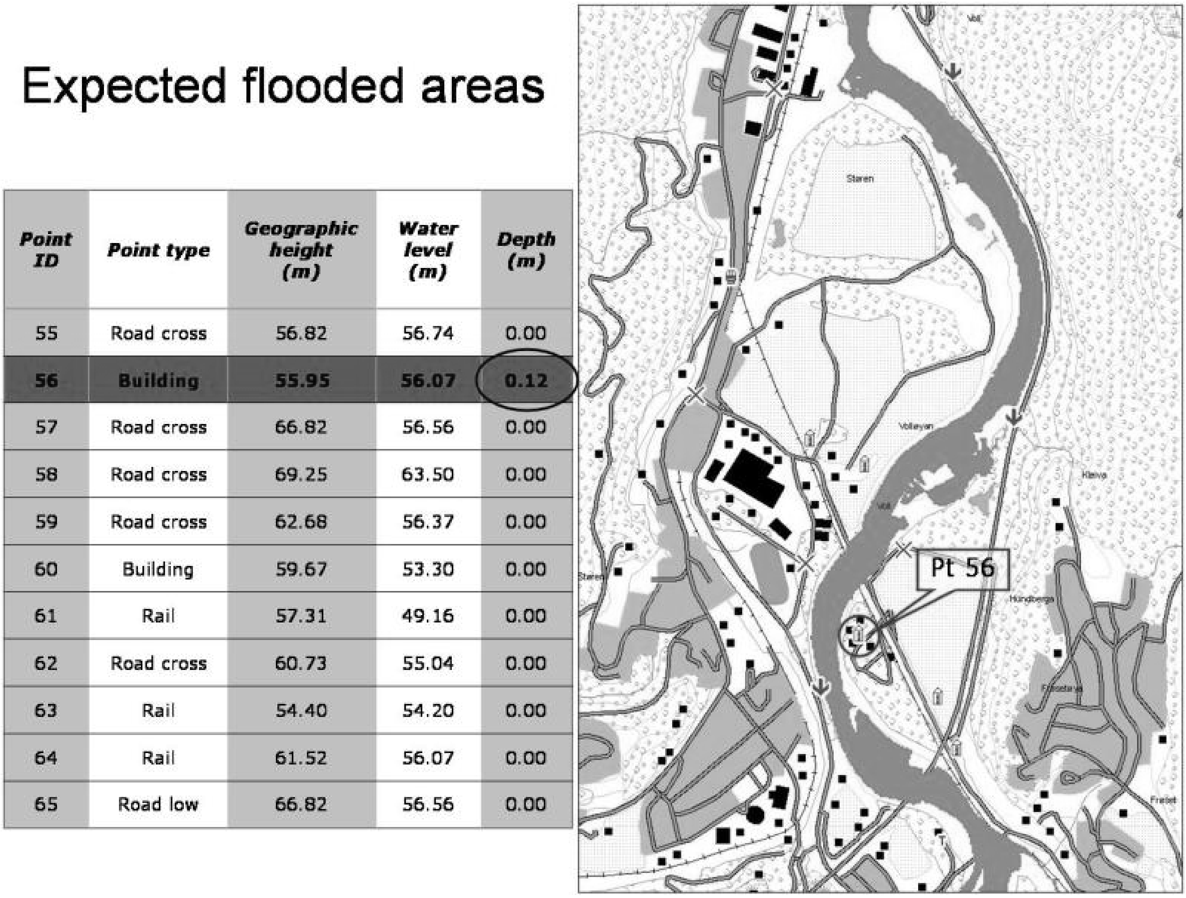


Figure 3. "Pure" water surface map as output of the GIS subsystem. Different grey shades indicate the grade of flood exposure (in 2 classes).



Point ID	Point type	Geographic height (m)	Water level (m)	Depth (m)
55	Road cross	56.82	56.74	0.00
56	Building	55.95	56.07	0.12
57	Road cross	66.82	56.56	0.00
58	Road cross	69.25	63.50	0.00
59	Road cross	62.68	56.37	0.00
60	Building	59.67	53.30	0.00
61	Rail	57.31	49.16	0.00
62	Road cross	60.73	55.04	0.00
63	Rail	54.40	54.20	0.00
64	Rail	61.52	56.07	0.00
65	Road low	66.82	56.56	0.00

Figure 4. Final DFFS as shown on via WMS with added layers and strategic location-table.

Putting the generated image in context, a more usable map is generated, which is made available in the final presentation interface of the system. ***Figure 4*** shows the added map features as well as the tabular results showing possibly flooded locations and structures.

DATA COMMUNICATION SUBSYSTEM

Data communication covers all necessary reformatting, filtering, internal data generating and shuffling, result file reading and input file writing procedures. Visual Basic for Applications in Microsoft Excel was used for this purpose. Microsoft (2008) provides details of this programming language.

The tasks in detail included the following:

1. Filtering HBV model results (extracting the relevant discharge values)
2. Interpolating daily forecasts to 12 hour resolution where necessary (cubic spline calculation was implemented)
3. Updating the input files for the hydraulic models (different mechanisms for HEC-RAS and Mike 11)
4. Running the hydraulic models
5. Filtering results of the hydraulic simulations and making it available for map generation

6. Generating and republishing the water surface maps for WMS portals with the new forecasted series of results

Completing these tasks required some hundred lines of coding and error handling. The system is run on a regular PC with Windows XP operating system, Microsoft Excel 2002 and ArcGIS 9.2.

RESULTS

As a consequence of the system construction, application of DFFSs is limited by its inputs. Only locations where existing FIMs are prepared can be considered (limitation of DEM and hydraulic features) and only rivers which are included in the operational flood warning services (limitation of input data). Keeping these in mind, so far three locations has been selected for developing DFFS. These are the Flisa area on river Glomma, the reach between Støren and Melhus on river Gaula, and the Lillestrøm bay area on river Glomma and lake Øyeren.

The locations (and projects) are different in terms of modelling methods, systems employed and boundary conditions, and therefore each case provided some special challenges. The Flisa stretch is short with a relatively complex geometry, the Gaula stretch on the other hand is several kilometres long with an internal boundary and tidal influence, while water regime in the Lillestrøm is influenced by many uncertain factors and heavy regulation both upstream and downstream from the modelling stretch. These cases served as tests to overcome the various difficulties and allowed a gradual development of the overall DFFS framework.

Presently not all three locations are shown in a uniform form, as early development steps were not yet readjusted to the later changed presentation system. However all three locations provide basically the same type of results, in different ways though. An important feature of the DFFS service is that its users can compare a number of forecasts in time, and call up different forms of data interactively. By default the forecasts are animated, showing each simulated map after each other, following simulation time steps. The user has the possibility to stop the animation, and go back or advance between the generated steps. Tabular data is also called up interactively, flooded features are automatically identified and highlighted.

CONCLUSIONS

The DFFS developed by NVE is a promising and new methodology that extends the use of classical flood and early warning systems. The development is over its childhood and is ready to be employed as part of the regular operational services. By means of these services a wider range of people in danger can be reached, and the public is provided with easy to understand information about possible flood risks that meet demands of modern communication requirements. Limitations related to its application must not be neglected, and therefore the services must always be understood as a supplementary for warnings at selected and somewhat special locations due to its data-intensive features.

ACKNOWLEDGEMENTS

The authors like to thank all colleagues that have provided help for this work over the past years. NVE financed the development for several years from internal R&D resources.

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DISCHARGE COMPARISON MEASUREMENTS, ICE COVERED RIVERS

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EXTENDED ABSTRACT

Introduction

The purpose of this study is to document any differences between discharges measured by different stream gauging instruments, and to make recommendations for which instruments to use. We compare two different acoustic instruments with a mechanical current meter. The instruments involved are

- Ott C31 with Vinge software, a mechanical current meter
- Nortek QLiner, an Acoustic Doppler Profiler
- RD Instruments StreamPro Section by Section, an Acoustic Doppler Profiler

Instruments

Ott C31 is a propeller type horizontal axis mechanical current meter. Velocity is calculated from the propellers revolutions per unit time. The propeller is designed to measure oblique currents within 15 degrees correctly. Depth is measured using a wading rod. NVE uses a waterproof PDA and the software Vinge to collect and process data from the current meter. Vinge calculates vertical mean velocity, area and discharge in accordance with the reduced points method and the mid section method in ISO 748 and ISO 9196.

Acoustic Doppler profilers transmit acoustic pulses through the water column. They calculate water velocity from the Doppler shift in the return signal and water depth from the pulses' travel time. None of the instruments can measure the entire vertical profile and they use different methods to extrapolate for the un-measured regions. Both instruments use the ISO 748 mid-section method to calculate area and discharge.

QLiner calculates vertical mean velocity by fitting a power-curve velocity profile to the measured velocities. QLiner uses both positive and negative velocities, and due to the beam configuration it can measure close to the surface. The software is flexible and gives a large range of measurable depths for a cross section.

For under-ice-measurements StreamPro uses a non-slip velocity profile in which the velocity profile goes to zero at the top and the bottom. StreamPro's signal processing gives less noisy data than the QLiner. For discharge measurements it uses only the magnitude of the measured velocity to calculate velocity profiles. The instrument itself can measure shallower verticals than the QLiner, but the software does not allow the user to measure shallow and deep verticals in the same cross section.

The table below lists which instruments and setups we have used. An *instrument* in this text means instrument + setup + averaging interval.

	"Instrument"	Setup	Avg. interval [s]
QLiner	QL-beam123-short	Using beam 3	60
	QL-beam123-long	Using beam 3	120
StreamPro SxS	SP-noslip-short	No-slip top and bottom (ice)	60
	SP-noslip-long	No-slip top and bottom (ice)	120
Current meter	CM-2p-short	ISO 2 points	45 or 60
	CM-6p-short	ISO 6 points	45 or 60

Data collection
All measurements were conducted as close as practically possible to simultaneously, and all instruments measure the same verticals, except where it was not possible to measure with one or more instrument. We measured approximately 20 verticals in each cross section. We did not use all instruments at all sites.

Processing
All data in this study are ASCII-files output from the different instruments' software, and plots and tables are generated by reading these files into Matlab. Values for different setups are generated in post-processing. The values we study are:

- Vertical mean velocity
- Vertical depth
- Discharge
- Area

To compare the instruments we calculate the *percent difference* between the instruments and the reference value. The reference value is chosen to be current meter measurements using two points per vertical. (*CM-2p-short*)

$$Percent\ difference = 100 \times \left(\frac{\text{Value} - \text{Ref}}{\text{Ref}} \right)$$

Value: Velocity, depth, area, discharge.
Ref: Corresponding value for current meter 2 points per vertical

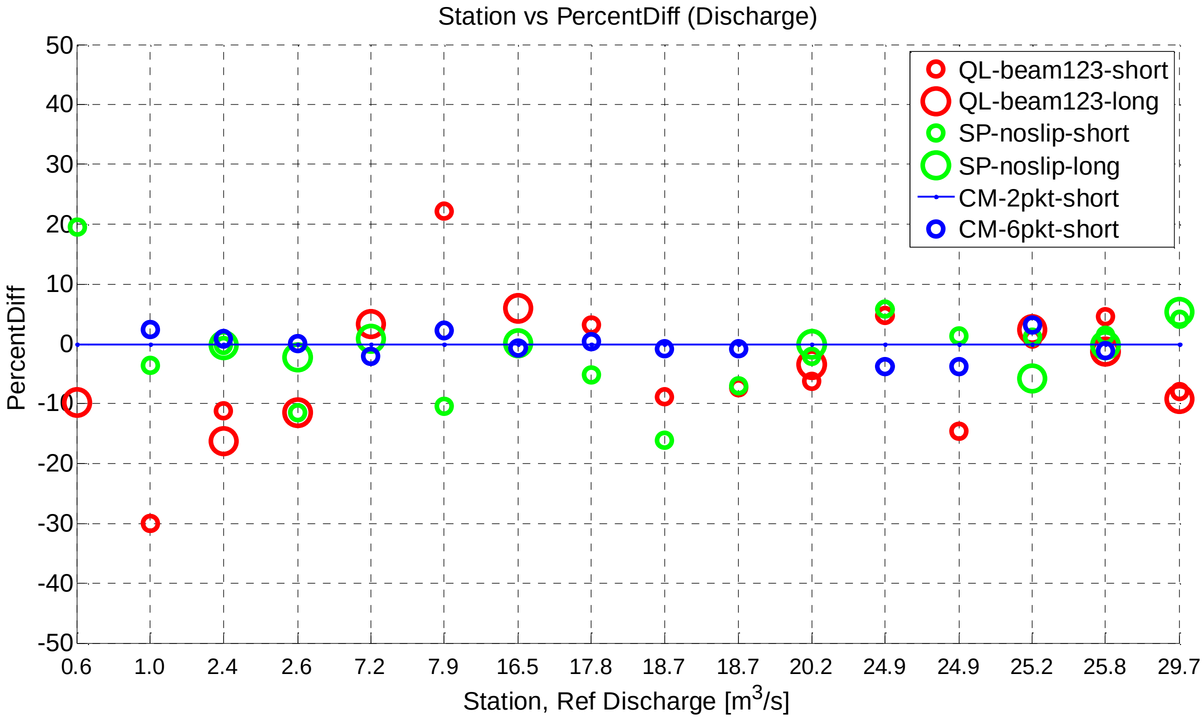
If *percent difference* is greater than zero, it means that the *value* is greater than the *reference value* and opposite if it is smaller.

Percent difference for velocity and depth was calculated for each instrument and each vertical, and each vertical is treated as an independent measurement.
Percent difference for discharge and area was calculated for each instrument and each cross section, and each cross section is treated as an independent measurement.

The absolute value of *percent difference* tells how many percent the deviation is from the reference, and for the remaining text it is referred to as the *deviation*. To rate the instruments we look at the mean and the median values of the *percent difference* and the mean and median values of the *deviation.*

Results

The plot below shows each instrument's discharge *percent difference* for each station, with the stations sorted by the stations reference discharge. The largest deviation from the reference value is 30%, and the deviations are slightly smaller for larger discharges.

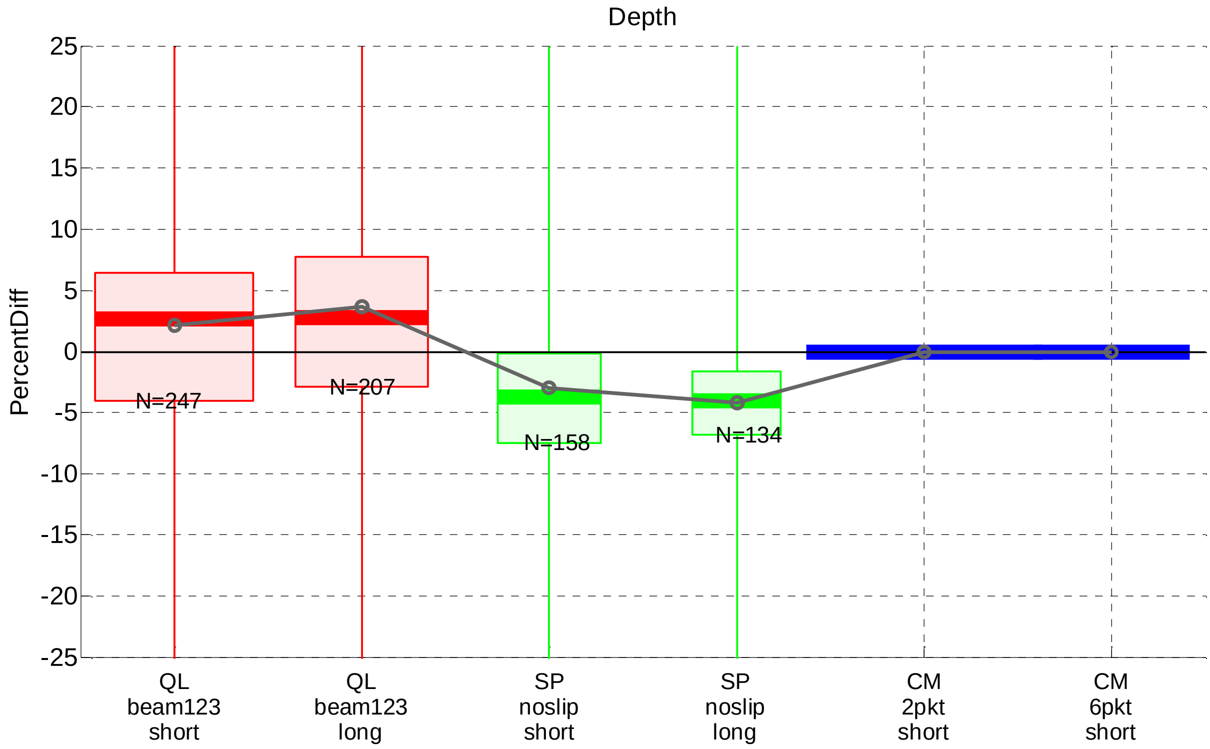


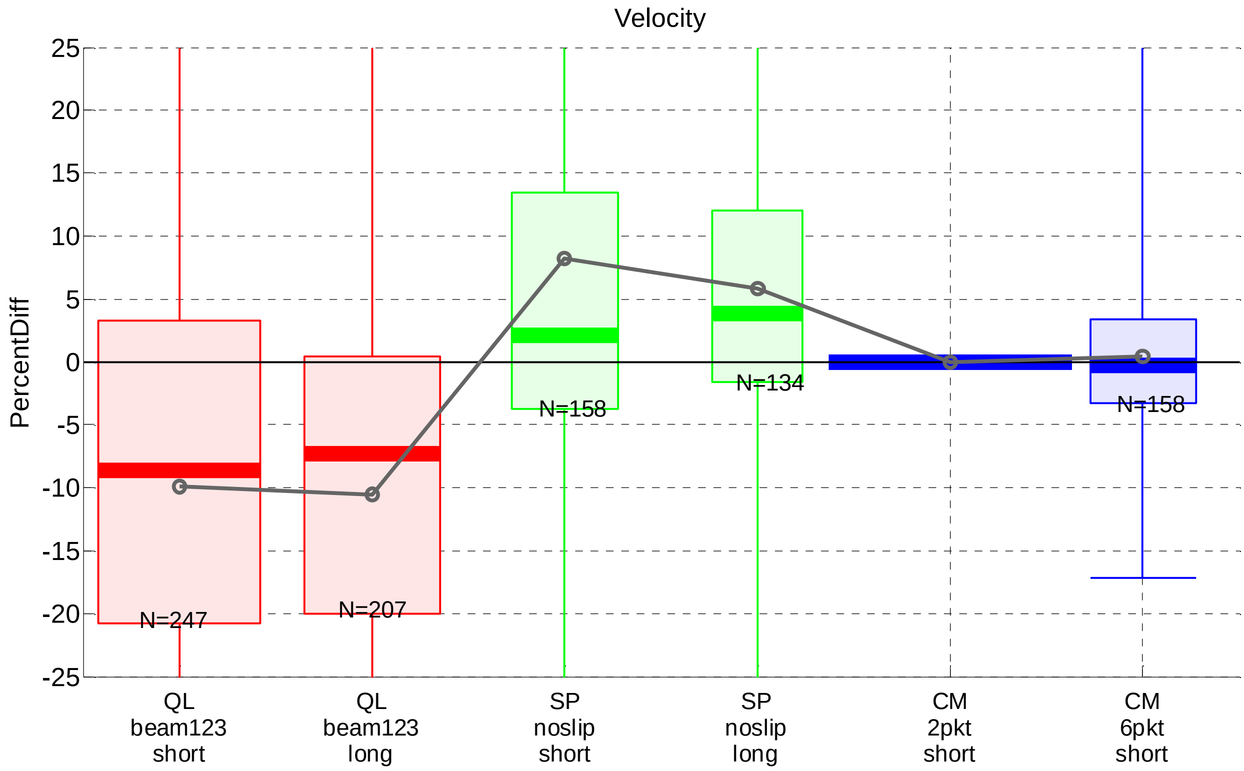
The table below shows mean and median values for discharge. We observe that compared to current meter 2 points per vertical, current meter 6 points performs best. It is followed by StreamPro as second best, and then by QLiner. For StreamPro and QLiner those with long averaging interval perform better than those with short averaging intervals.
Observe that all instruments measure smaller discharges than the 2 points current meter measurements.

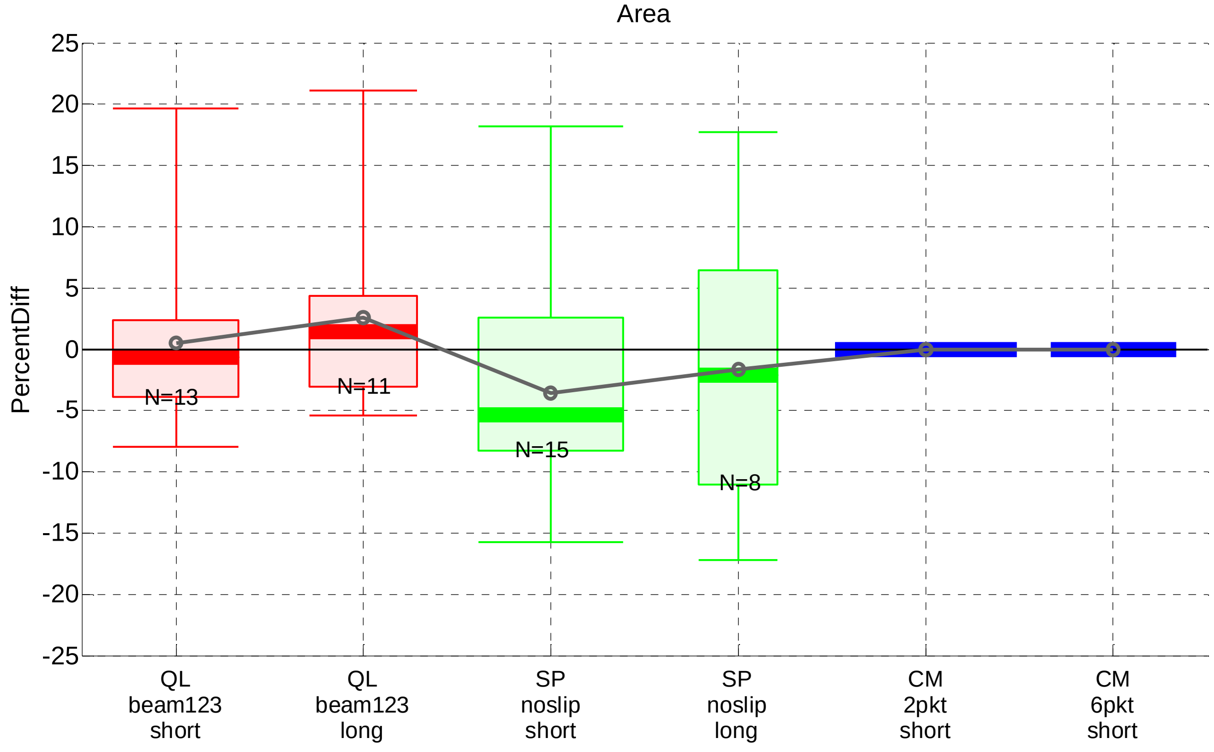
Discharge		Percent diff		Deviation	
	N	Mean	Median	Mean	Median
QL-beam123-short	13	-4,9	-7,4	10,3	8,0
QL-beam123-long	11	-6,0	-7,5	8,1	7,5
SP-noslip-short	15	-1,2	-0,2	6,3	4,4
SP-noslip-long	8	-0,3	-0,1	1,9	0,6
CM-2pkt-short	19	0	0	0	0
CM-6pkt-short	13	-0,3	-0,7	1,7	1,2

The following plots are box plots where the centre lines in each box show median values and the top and bottom lines show the 75 and 25 percentiles. The lines above and under the boxes show maximum and minimum values and the grey lines show the mean values. The numbers below each box is the number of samples.

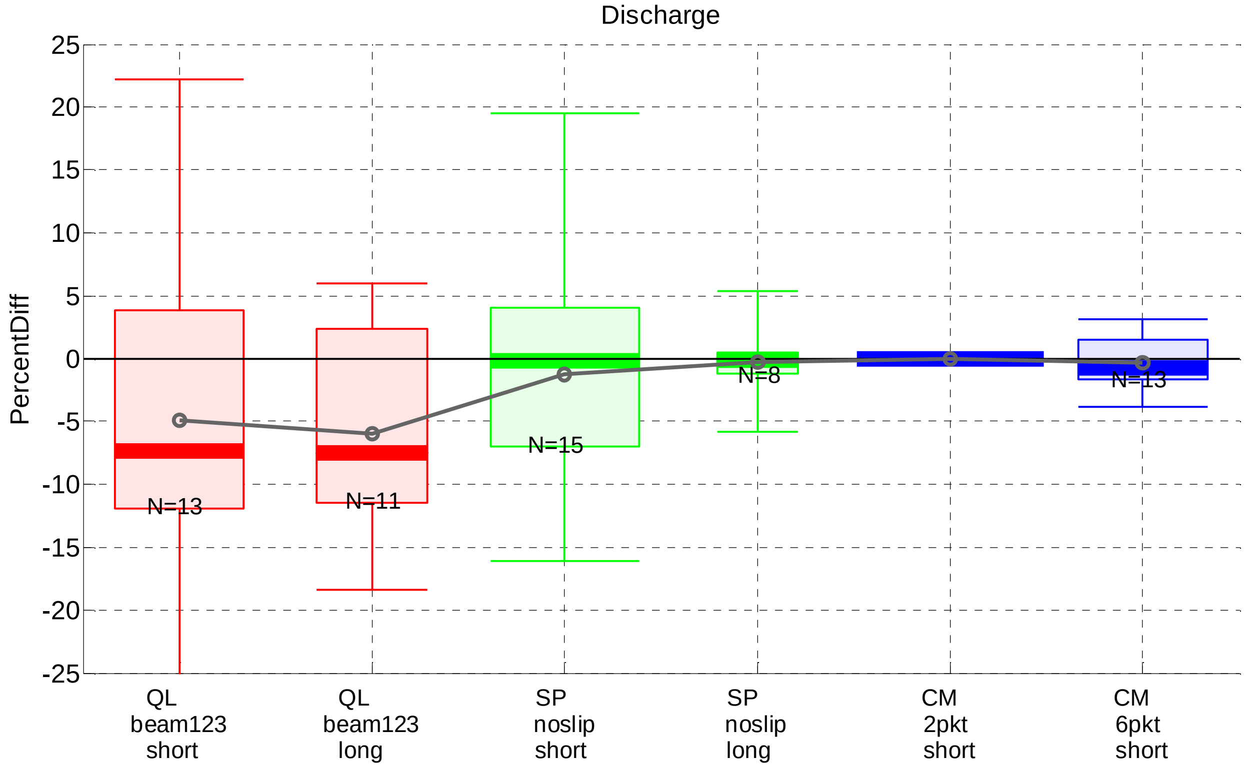
Comparing the plots for depth and velocity, we observe that the QLiner measures greater depths and smaller velocities than the current meter. For the StreamPro, it is opposite. It measures smaller depths and larger velocities.
The plot for area confirms the depth plots: The QLiner measures larger areas than the current meter and that the StreamPro measures smaller areas. The results for discharge show that the deviations in depths and velocities cancel each other better for StreamPro than for the QLiner.


Depth
PercentDiff
25
20
15
10
5
0
-5
-10
-15
-20
-25
N=247
N=207
N=158
N=134
QL beam123 short
QL beam123 long
SP noslip short
SP noslip long
CM 2pkt short
CM 6pkt short


Velocity
PercentDiff
25
20
15
10
5
0
-5
-10
-15
-20
-25
N=247
N=207
N=158
N=134
N=158
QL beam123 short
QL beam123 long
SP noslip short
SP noslip long
CM 2pkt short
CM 6pkt short



Area
PercentDiff
25
20
15
10
5
0
-5
-10
-15
-20
-25
N=13
N=11
N=15
N=8
QL beam123 short
QL beam123 long
SP noslip short
SP noslip long
CM 2pkt short
CM 6pkt short



Discharge
PercentDiff
25
20
15
10
5
0
-5
-10
-15
-20
-25
N=13
N=11
N=15
N=8
N=13
QL beam123 short
QL beam123 long
SP noslip short
SP noslip long
CM 2pkt short
CM 6pkt short

Conclusion

The current meter 2 and 6 points per vertical are very close to each other, and from this data set we can conclude that 2 points per vertical is sufficient for measuring under ice.

It is not satisfactory that StreamPro measures smaller depths and larger velocities than the 2 points current meter measurements, and still calculates a discharge that is very close to reference. Yet, based on the measurements in this study, we can recommend StreamPro, and in particular for the longest averaging interval.

QLiner measure less discharge than the two other instruments, and it can not be recommended if it is important to measure discharge within 5% from what the current meter would. However, on sites with oblique currents and/or back water the QLiner might measure more correctly than any of the two other instruments.

RQ-24 NON-CONTACT DISCHARGE MEASUREMENT

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ABSTRACT

River discharge is one of important hydrological quantities for river design, river management, and disaster prevention, etc. The RQ-24 non-contact system measures the discharge by radar technology. The unique feature of the RQ-24 system is the continuous capturing of flow velocity which enables an exact discharge measurement and evaluation of specific discharge situations. In case of flood the system measures the exact discharge and because of the non-contact radar technology there is no damage of the measurement system by bed loads or trees. If the floodplains get flooded the discharge is determined by combining several RQ-24 sensors to one system. The RQ-24 system measures from very low water depth up to the maximum possible discharge of a 100-year flood or even greater. To measure any discharge situation at rivers, torrents, creeks, mountain torrents or open channels the RQ-24 is a unique and reliable system.

1. INTRODUCTION

The RQ-24 sensor enables the continual measurement of flow velocity, level and determines automatically the discharge of any natural or semi-natural stream. Based on the non-contact measurement principle by radar technology the quality of the RQ-24's measurements and its flexibility of deployment make it unique in its sector. The RQ-24 system consists of a radar flow velocity sensor with integrated discharge calculation, radar level sensor and system-casing. The flow velocity is measured using the principle of Doppler frequency shift; the level is measured by means of a delay-time measurement.

2. DISCHARGE DETERMINATION

The sensor determines the discharge Q, the volume currently flowing out. Based on the continuity principle, discharge is calculated by multiplying the area of the cross section through which the water flows (A) at a particular water level (h) by the mean flow velocity (v_m). The sensor measures the water level and a local flow velocity. To convert from the local flow velocity v_l to mean flow velocity v_m the dimensionless factor k is needed and determined by calibration of the measurement site. The factor k and profile of the river is determined only once. All the calculation of the discharge is done by the sensor in liter/s or m³/s.

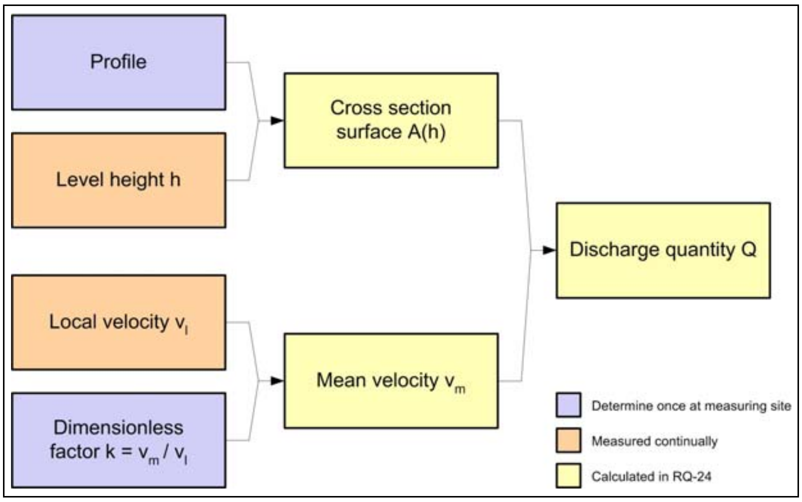

Figure 1. Measuring principle of RQ-24 system.

continuity equation	Convert local velocity to mean velocity	Extended equation
(1)	(2)	(2) into (1) = (3)
$\boxed{\mathbf{Q = v_m \cdot A\ (h)}}$	$\mathbf{v_m = v_l \cdot k}$	$\boxed{\mathbf{Q = A\ (h) \cdot v_l \cdot k}}$
Q…….discharge [m³/s] v_m....... area averaged mean flow velocity [m/s] A(h).... stage h dependent wetted section [m²]	v_l........ At a known cross section position (x,y) measured local flow velocity [m/s] k........: dimensionless factor	

(3) reveals, that accurate discharge measurements depend to the same extent on the accuracy of

- the site - specific and stage dependent cross sectional area A(h),
- the likewise site - specific and stage dependent dimensionless velocity ratios k and
- the local velocities vl(x,y), being measured at known cross sectional positions x, y.

Therefore, accurate stage and velocity measurements have to be complemented by an universally applicable evaluation procedure, which provides the strongly site - specific and stage dependent k - scaling - functions (2). This method must provide the site - specific velocity ratios k accurately, short - term and for the complete range of stage variations

$$h_{min} \leq h \leq h_{max} \qquad (4)$$

which may occur at the investigated discharge measuring site, comprising extreme high - water levels.

2.1. Calibration of measurement site

The RQ-24 system measures a local flow velocity v_l of the stream. Since the area averaged mean velocities v_m of the wetted section usually strongly deviate from the measured local velocities v_l, accurate discharge measurements additionally require accurate knowledges of the site - specific and stage dependent dimensionless velocity ratios which have to be determined by calibration. Following calibration methods can be used:

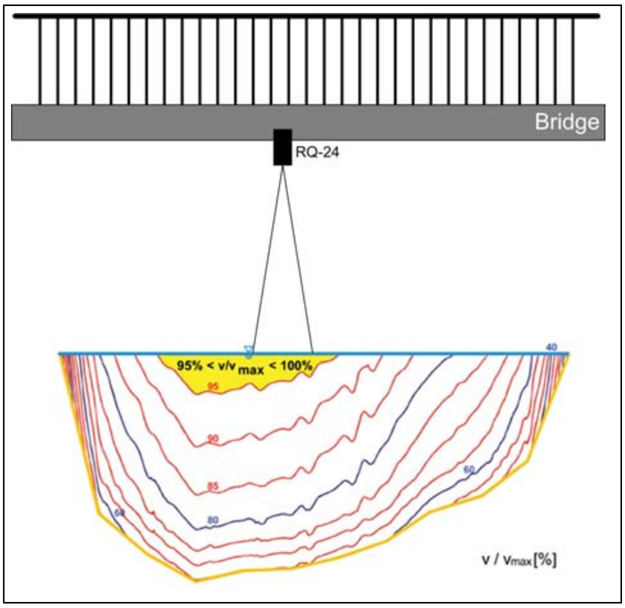

Figure 2. Measure the local velocity v_l at the radar measurement spot. The factor k converts the local velocity v_l to the mean velocity v_m..

- Two-dimensional numeric model [1]
- Three-dimensional numeric model for complex measurement sites [1]
- Extensive manual flow velocity and discharge measurements at various levels.

2.2. Advantages of numeric model calibration

Numeric models transforms existing or simply available geometrical basis informations (like cross sections and / or a digital terrain model) into hydraulic characteristics, describing the typically strongly site - specific and stage dependent flow conditions of the investigated streamflow - gauging station. Numeric models provides these site - specific and stage dependent hydraulic characteristics for the complete practically relevant range $h_{min} \leq h \leq h_{max}$ of stage variations, which may occur at the investigated discharge measuring site, comprising extreme high - water levels. Characterization of numeric model by the example of SIMK® [1]:

- an universal applicability to rivers and canals of any shape and size,
- systematic site - specific and stage dependent calibrations including extreme high water levels,
- high accuracies,
- independence of the actual (high water) discharge and therefore,
- discharge independent fast availability at any time.

The SIMK® - calibration results are summarized in a small site - specific and stage dependent dimensionless SIMK® - calibration lookup - table k(h) = vm / vl, which has to be determined only once and which is digitally stored in the RQ-24 discharge measuring system.

Immediately afterwards these SIMK® - results allow accurate discharge measurements even in backwater situations for the complete range of stage variations hmin ≤ h ≤ hmax (including extreme high water).

2.3. Advantages of continuous measurement of flow velocity

Among the determination of the discharge cross section conditioned by the water level, the flow velocity is until now an untended parameter of the continuousness equation to calculate the discharge. The flow velocity is determined by conventional measurement methods only in large time intervals. The RQ-24 system measures the flow velocity continuously even in case of floods. The advantage of this innovate system is the continuous analysis of hydraulic alterations of the stream by the correlation analysis of “discharge / water level” and “flow velocity / water level”. These analyses enable a better understanding of hydraulic situations like:

- Fluctuation of discharge - splash or sunk situation
- River bed change – aggradation / degradation effects
- Increase or decrease of backwater

Summarizing the advantages of continuous flow velocity measurement:

- Accurate discharge measurement especial during floods
- Immediate availability of discharge, level and flow velocity
- Better understanding and analysis of hydraulic processes

2.3.1. Example: Detect River bed change

Because of the continuous measurement also during floods the RQ-24 sensor produces a permanent graph of the flow velocity. Normally when the water level increases the flow velocity increases too and vice versa. A river bed change shifts the correlation “discharge / stage” and “flow velocity / stage”. This shift can be detected immediately by the RQ-24 system. The following graph demonstrates a river bed change after a flood. The correlation “discharge/stage” shifts from the black curve to the red one (see Fig. 6). When a river bed change is detected a new profile of the channel is manual measured again to quantify the chance in are a of the cross sectional area of the river bed. The RQ-24 system is parameterized by addition or subtraction of the aggradation or degradation area in m².

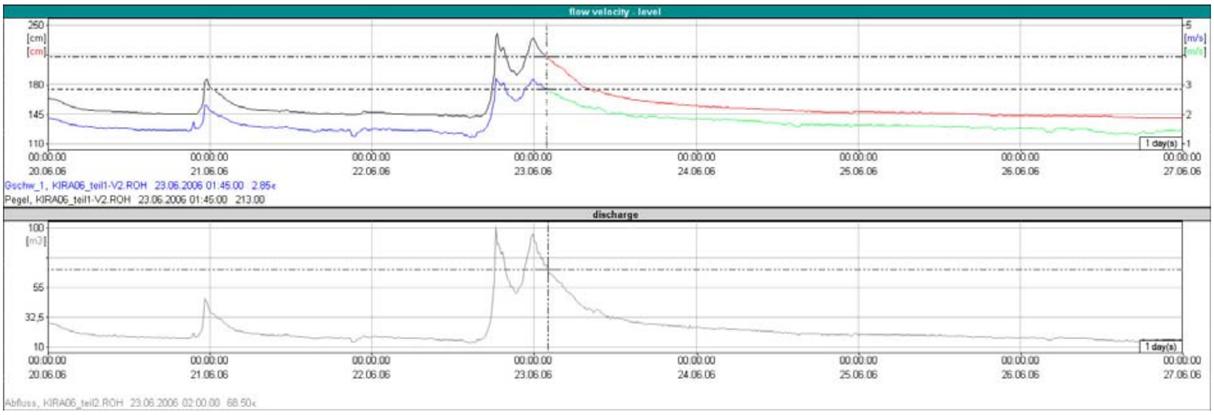

Figure 3. Flow velocity, stage and discharge – after the flood - flow velocity and level increased

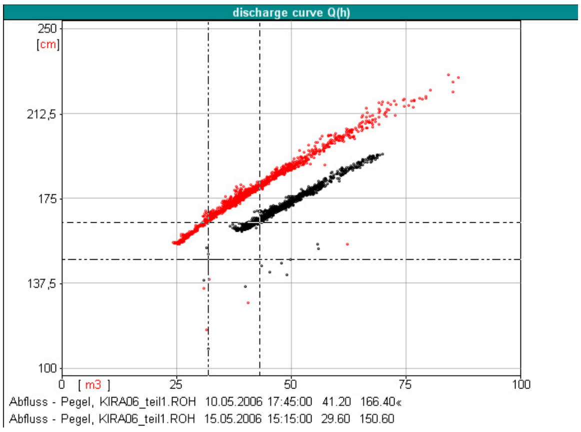

Figure 4: Correlation discharge/stage (Q/h). Black curve before flood event, red curve after the event. A river bed change is detected.

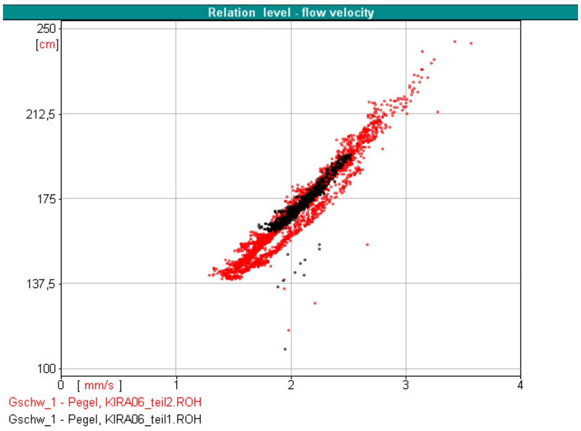

Figure 5: Correlation velocity/stage (v/h). Black curve before flood event, red curve after the event.

2.4. Measures even in case of floods including floodplains

At normal discharge condition the river flows through its river bed. In case of flood the level increases until floodplains, e.g. surrounding grassland, are overflowed. The flow area of the river increases and the flow velocity distribution of the river is changing basically. The RQ-24 system measures from low water up to the maximum possible discharge of a 100-year flood or even greater.

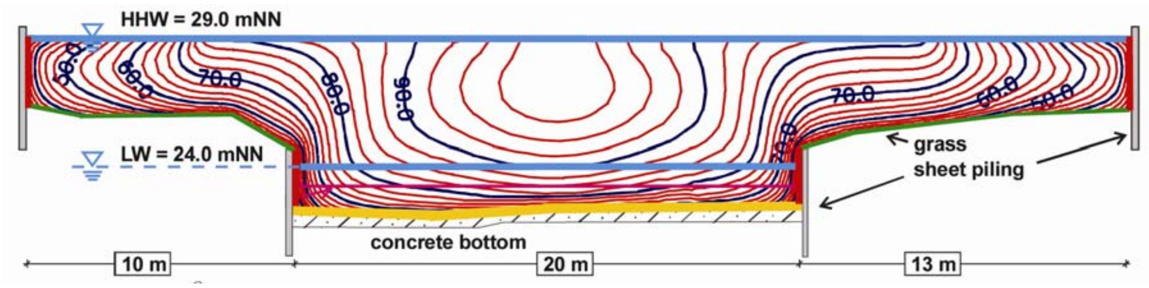

Figure 6. Overflow situation of the floodplains by flood and changing distribution of flow velocity.

3. SET UP OF RQ-24 SYSTEM

Measurement quality is determined primarily by the selection of the measurement site. The ease of installation of the sensor on bridges, ceilings of enclosed channels or any structure spanning the flow channel means that sites that previously had entailed major difficulties are now realistic options. The most important measuring site criteria are river bed character, water surface and flow conditions. The stability of the river bed is the decisive factor in ensuring uniform measurement. The water surface should be neither completely calm nor extremely agitated: there should be a recognizable swell on the surface. The area being measured should contain no rocks, eddies, falls or gullies. Depending on the composition of the water surface, installation height can vary from a maximum of 25m and a minimum of 1m above the water surface. The direction of flow does not affect the measurement of velocity so measurements can be performed with the current or against it. The direction of flow will not be captured.

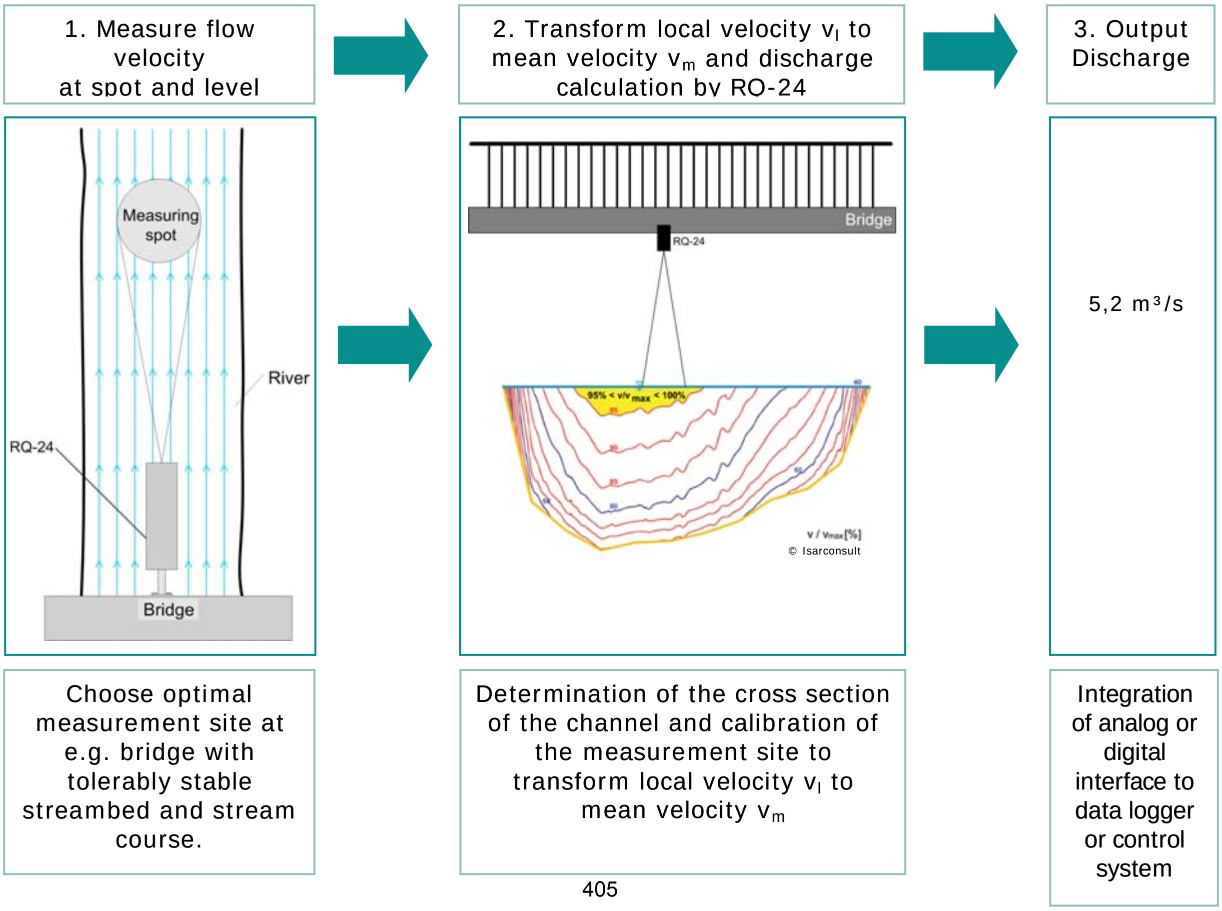

Figure 7. Mountain torrent in Austria (Tyrol), installation gibbet.

Figure 8. Torrent in Germany (Rheinland-Pfalz), installation measurement bridge.

Figure 9. River in Italy (South Tyrol), installation bridge.

Figure 10. Creek in Germany (Rheinland-Pfalz), installation bridge (like an open channel).

4. EXAMPLE OF USE

4.1. 100-year flood August 2005 in Austria

Measurement site at the Rhine in Austria. Installation at a railway bridge. During the 100-year floodwater in August 2005 the RQ-24 system reliable measured the discharge.

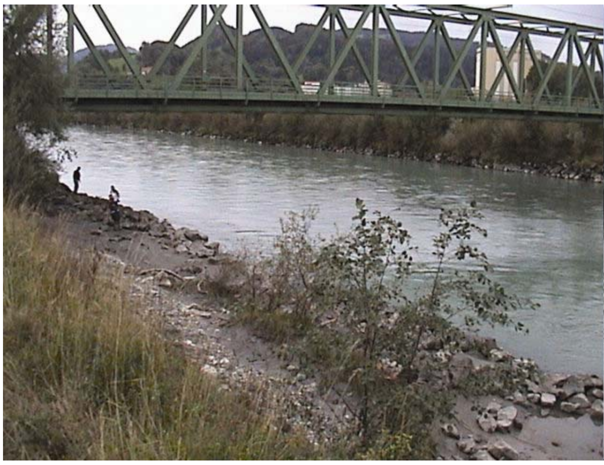

Figure 11. Mean discharge (250 m^3/s).

Figure 12. Discharge at 100-year flood (> 1100 m^3/s).

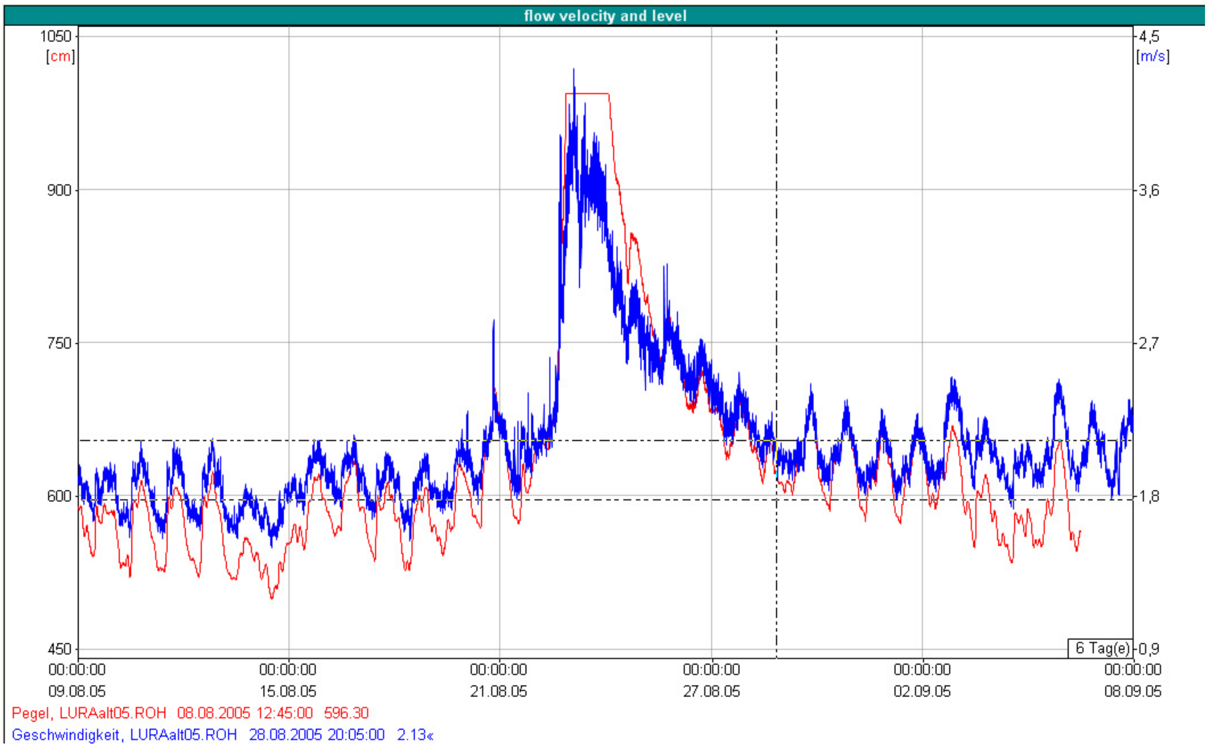

Figure 13. Measurement of the flow velocity (light grey graph) and the water level (black graph) during the 100-year flood water in August 2005.

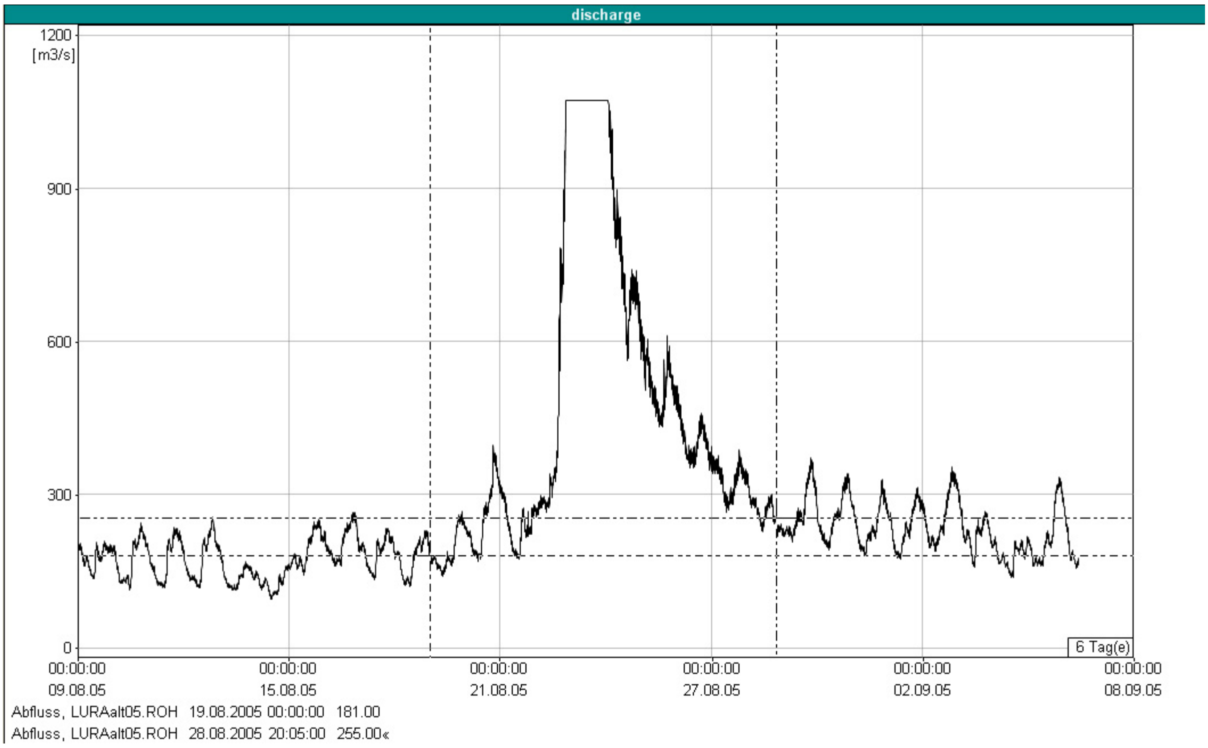

Figure 14. Discharge graph during the 100-year flood water. The cut off of the graph result from the limit of the minimum distance of the radar level measurement. The railway bridge was nearly overflowed.

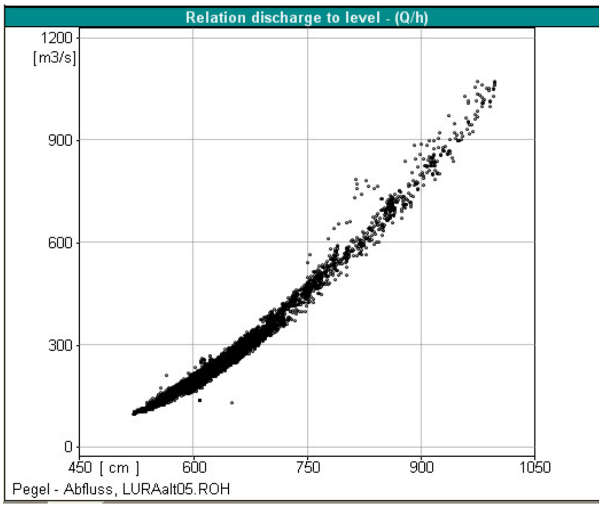

Figure 15. Discharge curve is reengineered online by measured flow velocity and calculated discharge. The Graph enables evaluation of the discharge and river bed change.

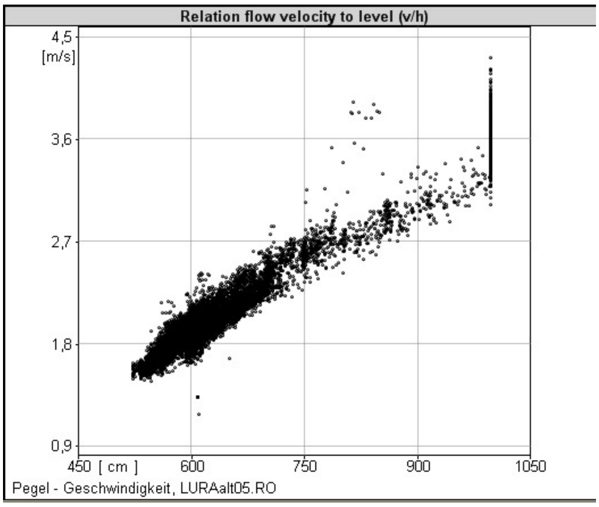

Figure 16. Correlation of flow velocity and water level to evaluate the discharge and river bed change.

4.2. Discharge measurement at broad rivers

The river "Inn" in Austria is about 300m broad before it flows into the "Danube" river. The measurement site is located close to the town "Schärding". At this discharge measurement site two RQ-24 sensors are combined. Each sensor measures a partial discharge of the river and automatically added to the total discharge. One sensor works as a master and receives the measured value from the second sensor via radio transmission and calculates as well as outputs the total discharge of the river via analogue or digital interface. Both RQ-24 sensors and the integrated radio transmission are powered by solar which enabled an easy installation at the bridge.

Figure 17. Measurement site with 2 x RQ-24.

Figure 18. Solar powered RQ-24 and radio transmission.

5. CONCLUSION

Hence the implemented direct combination of the non - contact RQ-24 radar discharge measuring system and a numeric model like the universally applicable SIMK® calibration technology enables fast realisations of adaptable streamflow - gauging stations, being characterized by

- highly accurate measurement of discharge
- measurement even during floods including extreme high water levels with overflowed floodplains
- Continuous measurement of flow velocity instead of periodic measuring campaigns by manpower to determine the discharge
- Low one time investment costs and no structural modifications at the river
- Maintenance - free operation and almost failure - free operation because of non-contact measurement by radar. The system is secured from damage especial during floods by bed load, trees, etc.
- The feasibility of realizing small measuring intervals and

- immediate digital online availability of the actual discharge measurement values at any time without any additional post processing.

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SNOW WATER SENSOR (SWS) TO MEASURE SNOW WATER EQUIVALENT (SWE) AND LIQUID WATER CONTENT

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1. Abstract

Improved estimation of the spatial distribution of snow water equivalent (SWE) is a key task in current snow research. Quantifying the complex variability of the SWE both in time and space is essential for hydropower production, risk assessment with regard to natural hazards (avalanches, floods, debris flows), as well as for tourism issues in alpine areas. In order to achieve an improved spatial estimation of the SWE numeric models need to be linked with remote sensing and ground-truth snow data.

SWS is a new in-situ sensor. Along a cable the complex capacity at low and high frequencies is measured for real-time determination of the snow density, snow water equivalent and liquid water content. The sensor is available in two different set up options depending on the dimension of the area to measure. For covering of a large area the system uses 4x10m cables and measures the average snow parameter of the area and eliminates variances of the snow pack. An application is the calibration of remote sensing data to ground-truth snow data. For small areas a single 10m cable is used to measure the parameters at a specific hillside.

The continuous determination of the liquid water content is unique. In periods of thaw, especially in spring, the sensor detects the liquid water content of the snow cover. This measurement enables a forecast of the point in time when the water run-off of the snow starts and provides important information for rationing of reservoirs (hydro power plant, drinking water), flood water warning or avalanche services to estimate wet slab avalanches.

2. Introduction

On one hand the forecast uncertainty of snow water equivalent (SWE) is a basic problem for Nordic and Alpine regions. The precision of melt water prognoses for hydro power reservoirs is today too inaccurate, it varies from 30 to 50%. As example for the La Grande Riviere catchment in Quebec (Canada) a 10% gain of prognoses precision would correspond to a yield of 2,2 TWh of the hydro power plants. To improve the accuracy of SWE measurement enables an enhancement of economic efficiency for hydro power plant or drinking water reservoir. A further aspect is the realisation of long-term monitoring instead of periodic measuring campaign by manpower.

On the other hand in snow melting periods the flood prediction improves by accurate determination of SWE, liquid water content and the point in time of water run-off of the snow cover. Snow melting and melt water run-off does not only affect mountainous and alpine regions, but all the areas where rivers are fed by these catchments. As an example, rapid snow melting in the Alps is known to be one reason for flooding along the River Rhine valley from Germany to the Netherlands. These snow parameter data may be used for flood warning as well and may reduce the danger or effects of natural catastrophes.

Additional applications are for avalanche services. The determination of liquid water content of the snow cover is an additional parameter to SWE and also important to predict wet snow avalanches in periods of thaw, especially in spring.

3. Historical overview of the sensor development

In the year 2000 an international EU-funded research project, SNOWPOWER [1][2][3], was started. The project goal was precision improvement of at least 10% by the enhancement of the in-situ and in consequence the remote measurement accuracy. The two most important snow parameters, SWE and snow density, will be in-situ and non destructive measured by the same device, in the very same location, in large areas and over the entire season. The formation of water-saturated layers will be studied in order to establish an improved model and a better prediction of wet snow movement and melting. The vertical and lateral snow stratification will be resolved and used to a better quantification of remote sense data. By this way the project will quantitatively improve the snow modelling, the water equivalent measurements including in-situ and remote sensing and consequently the reservoir filling prediction and the run-off management.

The sensor was tested during 3 winter seasons (2001-04) at two sites in Switzerland and Canada. The measurement site in Switzerland close to Davos (Weissfluhjoch) is operated by Swiss Federal Institute for Snow and Avalanche Research. This is a high Alpine test field and harsh winter conditions with air temperatures below -20 °C and wind speeds of 25 to 30 m/s occur occasionally every year. Intermediate snow melt is rare during the accumulation phase. The main melt starts in April wetting the snow pack from its top to the bottom. The other measurement site is located in the Bras d'Henri watershed, Quebec, Canada [4]. The field has a smooth surface with a maximum slope of 0.5 % and the snow cover remained relatively dry

Continuous measurements of standard meteorological variables, such as air temperature, wind speed, relative humidity, solar radiation and precipitation were conducted at both sites throughout the entire investigation period. Also snow depth and snow temperatures were recorded automatically.
At Weissfluhjoch, a detailed snow profile description was made twice a month. At these occasions, density, SWE, temperature and the degree of wetness were determined manually for each snow layer. Outflow of meltwater from the snowpack was measured continuously in a lysimeter of 2x2-m ground area.
At the test field in Canada, six snow cores were collected twice a week to measure snow depth, SWE and mean snow density around the three flat-band cables. At the same time, a detailed snow profile description was made to determine the liquid water content, density and temperature at every 10 cm, using the Denoth meter, snow density sampling and the Dial Stem Thermometer.

Continuous improvements of the system were done to finalise the sensor development.

4. Snow Water Sensor (SWS)

The result of the project SNOWPOWER is the „Snow Water Sensor (SWS)". The SWS is a complete measurement system to detect the snow water equivalent, snow density and liquid water content of snow. The sensor system consists of:

- Sensor cable: A 5cm broad and up to 10m long ribbon cable.
- Analyser to measure and calculate the snow water equivalent (SWE), density and liquid water content of the snow cover.
- USH-8 ultrasonic snow height sensor. Interface integrated to analyser unit.
- Mechanical equipment to set up sensor cable with integrated temperature profile sensors.

Fig. 1: White sensor cable mounted at tower with analyser unit (grey cabinet)

Fig. 2: Measurement site at Davos (Switzerland)

Fig. 3: White sensor cable with guidance cable and integrated temperature sensors

Fig. 4: Measurement site at Davos (Switzerland) in summer

4.1. Measurement parameters

The following measurement data are from the test field at Weissfluhjoch in Switzerland close to Davos. The test field is operated by Swiss Federal Institute for Snow and Avalanche Research (SLF).

During the whole winter season manual measurement are done by observer. The manual measurements are compared to the automatic measurement values determined by the snow water sensor.

Periodically manual measurement by observer	Continuous measurement
Measurement done by snow profile • Snow water equivalent • Snow height • Snow density	Continuous measurement by SWS • Snow water equivalent • Snow height (USH-8 sensor) • Snow density Reference measurement by snow pillow • Snow water equivalent

4.1.1. Snow water equivalent (SWE)

The measured trend of snow water equivalent by the snow water sensor (SWS, blue curve) correlates to the reference measurement of the snow pillow (red curve) and the manual measurement of the observer (green square). The behaviour between snow height and snow water equivalent is conform to the natural process of settlement of the snow cover. After the end of snow fall the snow height decreases due to the compression of the snow cover but the snow water equivalent remains constant (e.g. periode 28. Jan. to 11. Feb. 2007). With the starting melting period in March the snow height and SWE begin to decrease.

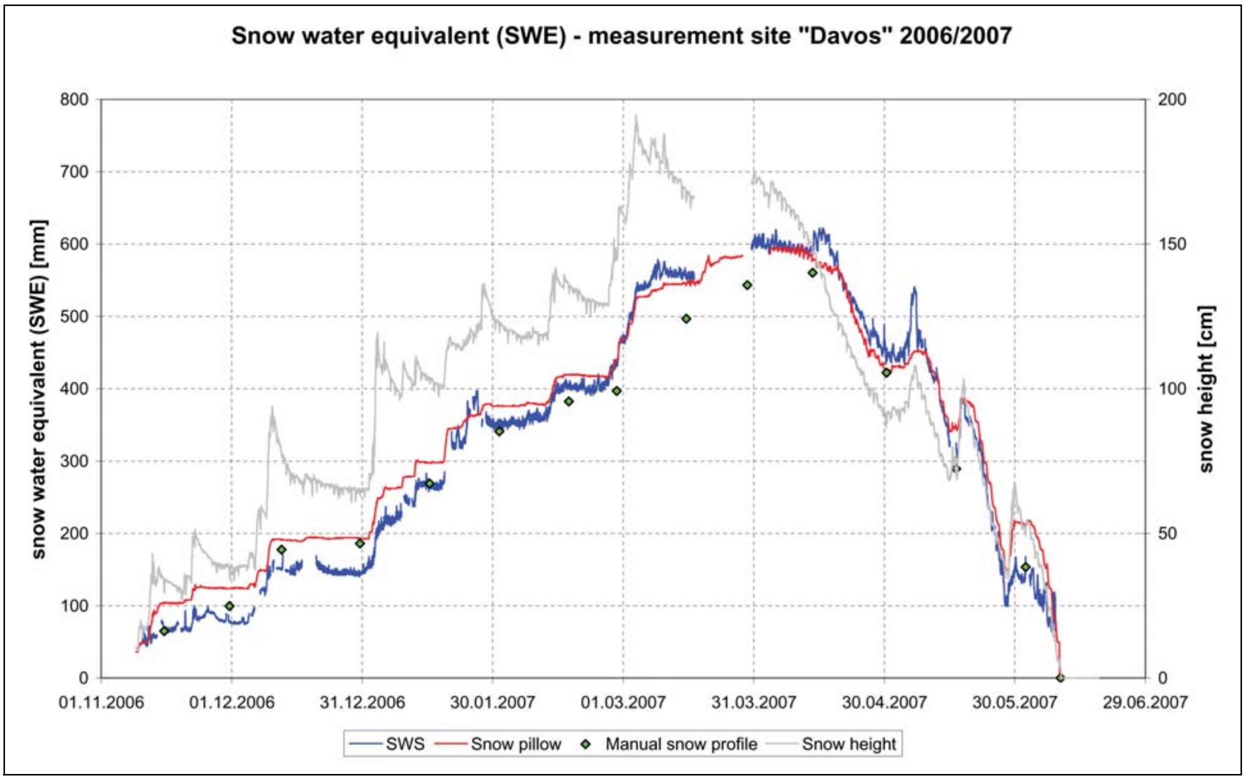

Fig. 5: Measurement of snow water equivalent (SWE) by the snow water sensor (SWS) compared to different measurement methods.

4.1.2. Snow density

The density graph of the SWS is similar to the measurement done by snow pillow and manual measurement by observer. During snow fall the density decreases and in time periods of snow compression the density increases.

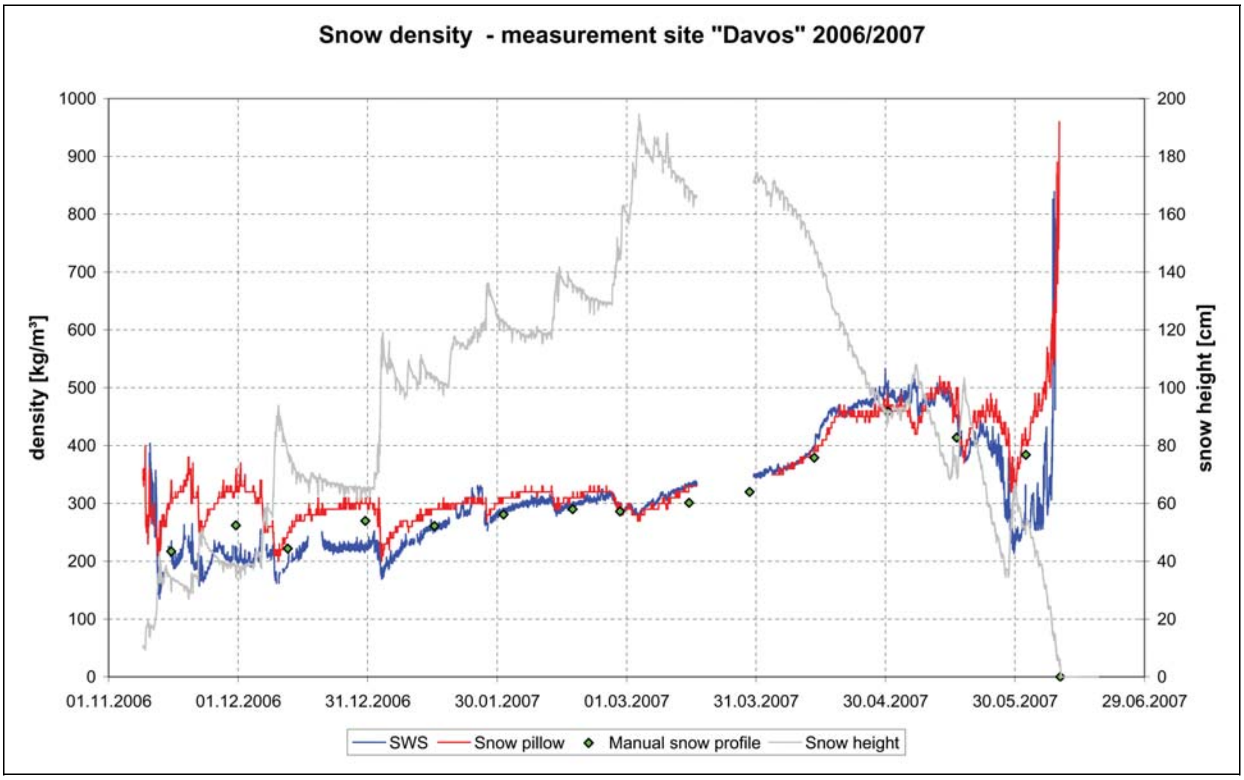

Fig. 6: Measurement of snow density by the snow water sensor (SWS) compared to different measurement methods.

4.1.3. Liquid water content of the snow cover

During the winter until middle of April the liquid water content increases slowly. This unexpected behaviour was analysed after the last winter and has been eliminated for the season 2007/08. With the starting melting season a significant increase of liquid water content (Fig 7, blue curve, middle of March) was measured. The peaks at the end of the winter season marks very wet snow conditions before the snow free season started.

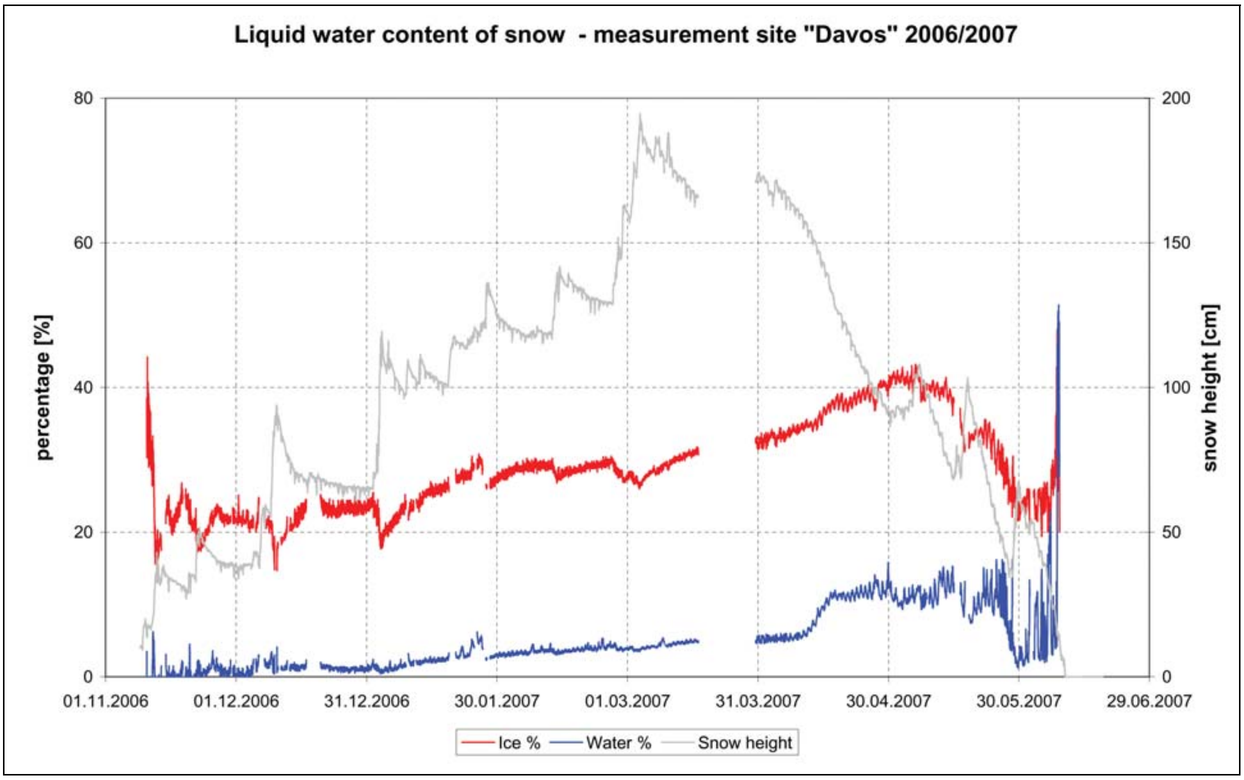

Fig. 7: Measurement of liquid water content of the snow cover.

4.1.4. Forecast of the point in time when run-off of snow cover starts

At begin of March (Fig. 8, point A) a compression of the snow cover occurs while the SWE stays constant. The start of the melting period is defined by the decrease of the SWE (Fig. 8, point B) and the water run-off of the snow cover starts. A significant increase of liquid water content is measured prior to the start of melting period (Fig. 8, Point C). The measurement of liquid water provides a forecast of the point in time of the water run-off.

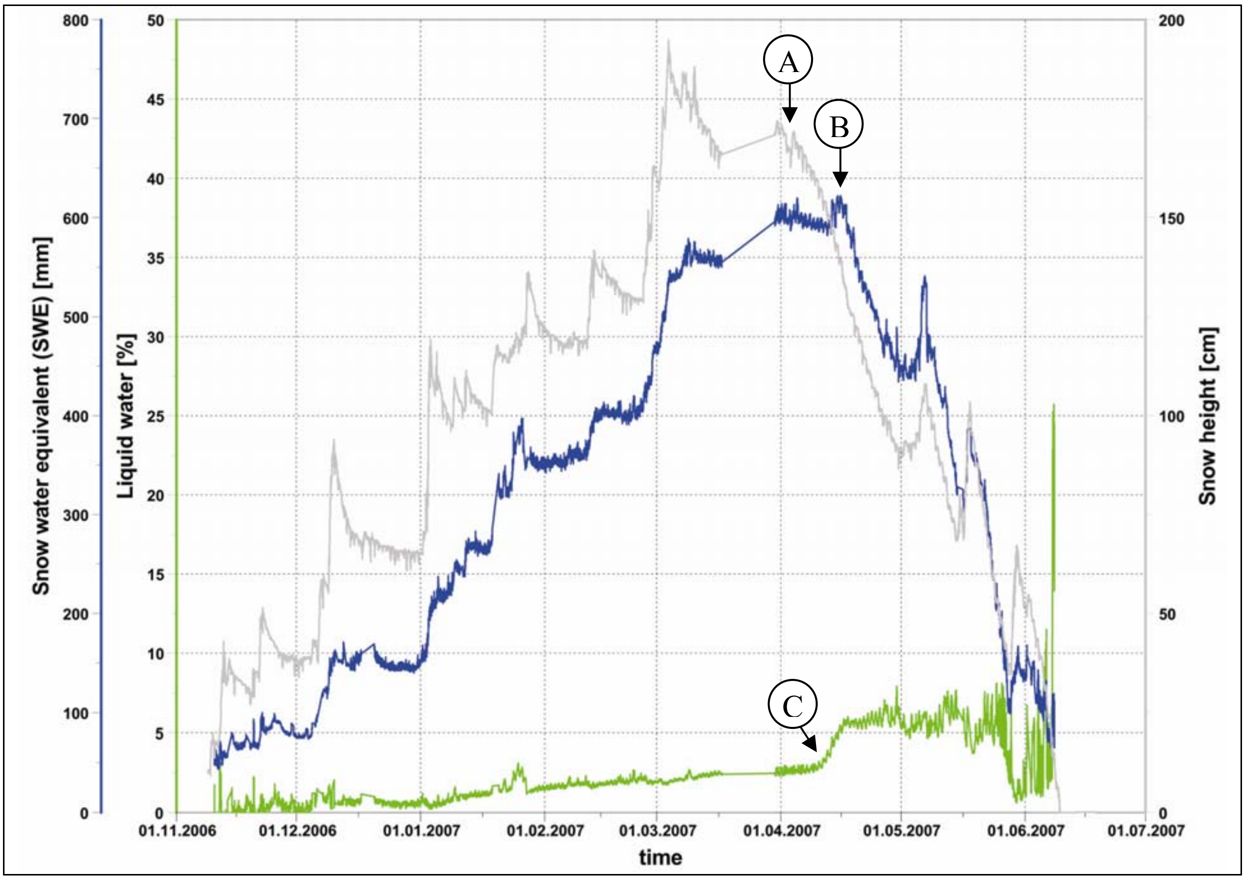

Fig. 8: Determination of the point in time run-off of snow cover starts
SWE…………blue curve
Liquid water…green curve
Snow height….grey curve

4.2. Set up options SWS

Depending on the measurement task there are different options to set up the snow water sensor. Generally the maximal length of a sensor cable is 10m. Both set up options can also be combined at one measurement field.

4.2.1. Integral measurement of snow cover – slope set up

To measure the integral parameters like SWS, density and liquid water content of the snow cover the sensor cable is set up in a slope from the tower to the soil. The height of the bracing at the tower should the maximum expected snow height. The cables are routed trough the whole snow cover.

<table>
<tr><th>Large measurement area</th><th>Small measurement area</th></tr>
<tr><td>
The snow-water-sensor consists of 4 sensor cables and one analyser unit. This type of installation enables an integral measurement of a large area.

Example of use:

Calibration of remote sensing by satellite
Calibration of SWE numeric models

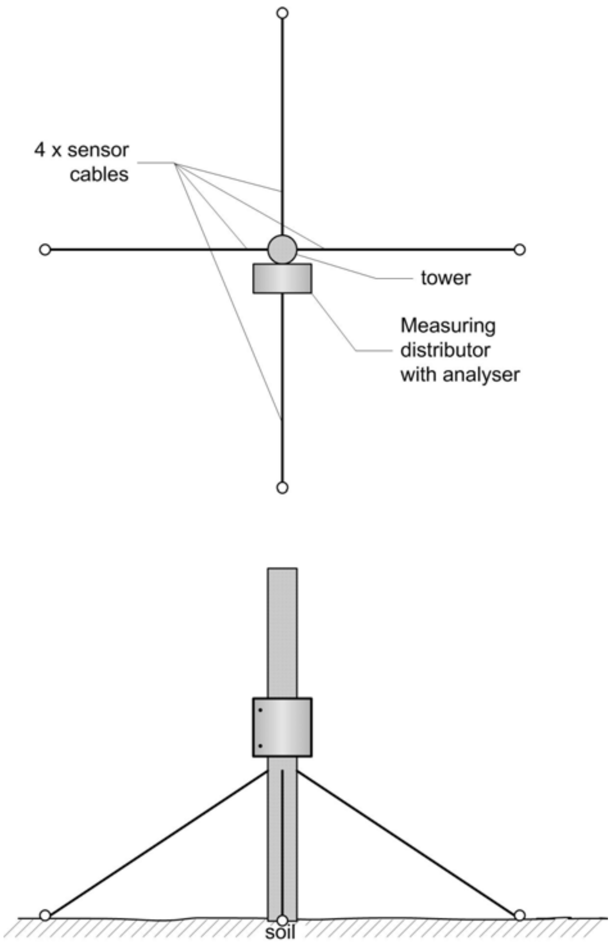

Fig. 9: Slope set up SWS with 4 sensor cables
</td><td>
A single cable and one analyser unit is used. This type of system enables an integral measurement at a small area.

Example of use:

Flood prediction
Avalanche forecast for wet slab avalanches

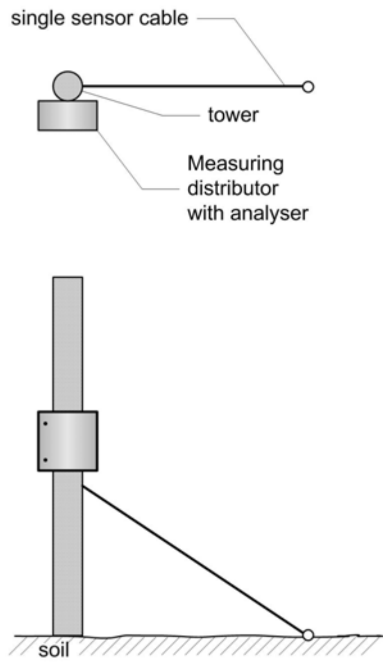

Fig. 10: Slope set up SWS single sensor cable
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4.2.2. Measurement for horizontal set up

To determine the liquid water content for example at the grassroots one or several sensor cables are installed horizontal over the soil. This set up enables the accurate measurement of the water run-off over the soil and enhances the prediction essential. The measuring distributor can be placed next to the cable or out of harm's way.

A single cable and one analyser unit is used. The cable is routed horizontal over the soil. The advantage of this compact set up is the possibility to place the sensor cable direct at the starting zone of avalanche areas.

Example of use:

- Flood prediction
- Avalanche forecast for wet slab avalanches

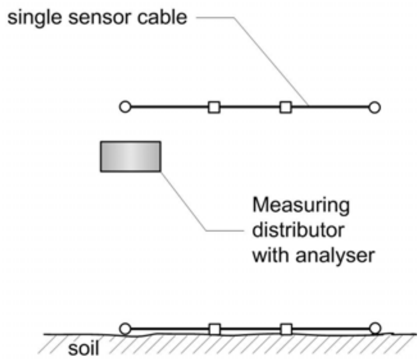

Fig. 11: Horizontal set up SWS single sensor cable

5. Conclusion

The snow water sensor (SWS) is installed at the test field Weissfluhjoch (Switzerland, Davos) since 2001 and was improved continuously. The first commercial measurement sites are installed in Germany and Sweden for the winter season 2007/08.

The advantages of the sensor are:

- In-situ measurement of snow water equivalent (SWE) and snow density
- Unique in-situ determination of liquid water content which enables new applications
- Accurate forecast of the point in time when the water run-off of the snow starts to improve management of reservoirs, flood prediction and avalanche forecast.
- Accurate measurement even for large amounts of snow and different type of snow conditions.
- Measurement at large areas to determine an integral snow parameters for calibration of numeric models or remote sensing
- Realisation of long-term monitoring instead of periodic measuring campaigns by manpower.

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Hydro Acoustic Measurement Techniques All the Way – Consequences and Experiences

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Abstract

Since 1992 SMHI and other agencies around the in world have used Doppler current profilers (ADCP) to measure discharge in waterways. 1996 Nils Sjödin presented the early work at the Nordic Hydrological Conference, Iceland. Since then the techniques have developed very quickly and now cover most of the need for discharge measurements from the small streams to the large rivers.

The technique is however complex to learn and also initial cost for investments in instruments is considerably higher than the traditional mechanical current meters. The demands to keep good quality in measurements is critical as developments still continue fast. SMHI has organized the work from the very beginning to only keeping a small number of field working hydrologists updated - to now completely using the technology for all field working hydrologists. This policy means organized education and planning in investments.

This paper is a summary over actions and experiences up till today, and also some reflections over future challenges. The use of trademarks and product names is only for clarifying purpose and does not mean endorsement by SMHI.

Definitions

SMHI	Swedish Meteorological and Hydrological Institute
ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocimeter
TRDI	Teledyne RD Instruments
USGS	United States Geological Survey
NVE	Norwegian Water Resources and Energy Directorate
UVM	Ultrasonic VelociMeter

Introduction

Since 1996, the hydroacoustic instrument family has grown. Today there are narrowband profilers with and without bottom track, broad bands with and without compass, ways of connecting GPS, echo sounders, pressure sensors and gyrocompass. Users have wireless communications creating possibilities for a number of alternative ways to carry out measurements. We also have mono static instruments like the ADV and the field version called Flowtracker. Profilers are also used as stationary instruments from riverbank or riverbed with index-velocity technique for calculating flow.

SMHI uses all these instruments in regular work with the exception so far of index-velocity technique. The narrowband in use are all in stationary oceanographic (velocity and wave) operation.

The ADV Flowtracker is a good example of learning the hydroacoustic technique from both a positive and negative side. Without the knowledge of operation, human errors might easily bias velocities towards zero.

Benefits and Limitations

The Flowtracker ADV covers measurements in small and shallow streams up to the limits for wading. True velocities x and y (z as optional) are measured. New users are often surprised when negative velocities show up close to edges of the stream. Most traditional current meters never showed upstream velocities. ADV limitation is lack of backscatter material at some locations. Human errors in holding the rod and unsafe distance to riverbed will bias velocities towards zero.
The Streampro ADCP will start working in streams from 15 cm to 4 meters. The Streampro has no compass and tilt sensor but profiles with bottom track and orient presentation of velocities with long ship keel for reference. This might confuse operators used to the old ADCP Broadband. For the discharge measurements the compass is not needed. The Streampro has quickly become a favourite in Sweden because it covers the majority of measurement needs. It is also very easy to set-up before measurement start.

The operation signal processing mode with a number of sub pings for water track before a bottom track signal, requires the moving boat crossing to be very uniform, straight, smooth and really slow. To move the Streampro in a jerky crossing will influence data badly.
Limitation is the maximum of resolution depth cells set to 20. Streams with deep centres and wide side edge flood plains will have to be measured in individual subsections if estimation of edges is uncertain. The original float was designed to fit the transport box and often a bigger hull (optional) is needed in faster and turbulent streams. The Streampro has an improved signal processing technique compared to the bigger sized ADCP Rio Grande.

The traditional ADCP Rio Grande has also the new water mode 12, similar to the Streampro. With this ADCP the user has a lot of options in set-up of mode 12 but it also holds some older water modes which sometimes are favourable to use. The 1200 kHz ADCP is useful from 3 to 20 meter deep rivers and the 600 kHz will work for deeper situations.

ADCP calculations assume the backscatter material to move at the same speed as the water molecule, which is almost true. For trigonometry the different transducers should read homogeneous velocities for single pings. This is often the case in the sea but not in turbulent

rivers. The four transducer system in TRDI ADCP presents the difference between transducer pair, called error velocity. This option gives one way of quality checking the measurement.
Limitations are still either lack of backscatter, which is rare, or too much. Too much will unable normal bottom track which is a well known situation on Iceland. Another limitation is streams with massive aquatic growth. This is well known in Denmark. Some profilers have developed software for traditional holding still position in section by section. This way making it possible to work in situations described. Systems with compass have better performance in these situations.
As early as 1996 SMHI had experience of biased bottom track i.e. "moving bed" mostly during flood situations. Later use of GPS has helped but without access of GPS, the loop method has resolved this problem. The loop method is now part of the latest software, WinRiver II as a tool.

Validations

In 1996 Sjödin presented an extensive comparison material from measurements with the RDI Broadband ADCP at well rated hydrological stations and hydro power stations. Also in 1996 Jonsson and Nilsson presented a report to the VASO (the Swedish regulation company's cooperation) where ADCP was evaluated for optimising hydro power production.
International work was under way by USGS, USA and Environment Canada and other countries also trying to validate ADCP production. In England comparison was carried out in small streams at the British standard dam structures.

To make good comparisons is difficult. The differences in instrument applications and environmental circumstances are not easy to match at the same site so that a fair comparison can be carried out. NVE and SMHI tried it out at Älgån with a field seminar using a number of techniques. Part of this seminar was successful and is now part of a more extensive material that was presented by USGS in 2007 (Validation of Streamflow Measurements Made with Acoustic Doppler Current Profilers, Kevin Oberg & David S. Mueller).

ADCP has also on a number of occasions been tried out in test tanks. Not even the David Taylor model basin in Carderock, Maryland sized 363 meter long and 15, 5 meter wide made test environment ideal enough. The work in these environments has had a number of limitations making it difficult to evaluate in a desired matter.

Accuracy

A moving boat ADCP is adding a great number of vectors for the cross product. This makes it possible to measure across a river without going on a straight perpendicular course. Comparing ADCP moving boat with the way a traditional area/velocity measurement is carried out will not be correct at similar subsections. The single ping standard deviation is high for Doppler profilers, especially for narrowband. Single transects will not be representative for total discharge. The number of needed transects depends on the difference between the discharge measurements. If the discharge for any of 4 transect differs more than 5 percent, a minimum of 4 additional transects should be obtained and the average of all 8 transects will be the measured discharge. Sometimes even more transects are made to reduce potential directional biases. However, the user has to set proper ADCP depth, distance to the edges and make sure that the roll and pitch and the speed of the boat/instrument is correct during the measurements. A bias in some of this can result in a significant bias in the resulting measured discharge. In shallow water it is important to measure enough of the depth so the extrapolation, especially up to the surface, is not the main part of the profile. Many ADCP measurement problems can be solved by moving to a better measurement section. The coefficient of variation over a number of transects gives a fair estimate over the accuracy.

Calculations on moving boat ADCP total discharge measurement accuracy are often very complex. One way of simplifying is to look at the standard deviation for a single transect. The equation below is one example of how to review factors affecting the measurement quality.

$$\sigma_Q = \frac{\sqrt{\left(100\frac{x_w}{v_m}\right)^2 + \left(100\frac{x_b}{v_m}\right)^2 + \sigma_p^2 + \sigma_{bt}^2}}{\sqrt{0.75 N_b N_s}}$$

where

σ_Q = standard error of a single ADCP discharge measurement of channel discharge, in percent.
x_w = broadband ADCP single ping water velocity uncertainty, in cm/sec.

v_m = mean stream velocity, in cm/sec.
x_b = broadband ADCP single ping bottom track velocity uncertainty, in cm/sec.
σ_p =estimated standard deviation of natural stream pulsations, in percent of mean velocity.
σ_{bt} = standard deviation of measured depth, in percent of mean depth.
N_b = average number of depth cells in vertical.
N_s = total number of subsection measurements.

The constant 0.75 in the equation above is a rough approximation based on ADCP bin-to-bin correlation of 15 percent. Based on Bowden, natural stream pulsation is conservatively estimated at 12 percent of the mean velocity for the purposes of analysis. Bottom track random error is estimated by the manufacturer to be two percent for four beam ADCP.

Standard error in ADCP measurements. Simpson/Bland (Proceedings IEEE currents and waves sixth conference)

It is important to know the natural variation/pulsation in the river before an estimate of accuracy can be done. One way to do it is to hold stationary position (on a tag wire) for two measurements over a period of 15 to 20 minutes. The velocity profiles should be exactly the same when compared if the river flow is stable.

The key to good working procedures is concentrating on the factors the operator can influence. First priority is a slow and steady movement of the moving boat without changing the course. Make also sure the temperature sensor has acclimatised to the river temperature. The correct distances at start and end of transect and the shape is especially important in the small streams.

Testing Procedures

ADCP instruments are individuals. This means that the acoustic backscatter is relative to the instrument. This does not mean that individual instruments should differ in discharge calculations but we need to make sure in some way. Rating tank was not the solution. The instrument has special test programs for the internal electronics. These tests are not completely safe for detecting all possible faults. For instance a transducer that does not send signal can still detect backscatter and all electronic tests will still show PASS. Yet the instrument will not be able to collect and measure discharge.

In England and Sweden we do a regatta where all instruments are tested at the same site where good reference discharge data can be obtained. In England this method is carried out at the river Severn at a well rated UVM station with good and straight channel sections. The results show that even with the same technical circumstances there is a risk of human error factor that has to be minimized.

A number of documents and manuals are used as rulebooks. Documents produced by SMHI contain guidelines for maintenance and quality assurance. However, these issues are supported by documents from manufacturers. When it comes to policy documents for measurements and post-processing, SMHI has mainly defined procedures with reference to reports by USGS.

Instruments are checked on a yearly basis by supervisors. This is usually done by comparing measurement results and controlling instrument functionality. In many cases functionality tests are provided by the manufacturer. All acoustic instruments are tested for bias in internal thermo element. The supervisors are also responsible for updates in firmware or software. The set of acoustic instruments currently consists of six SonTek Flowtrackers (ADV), two TRDI Broadbands (ADCP), two TRDI Workhorse RioGrande (ADCP), two TRDI Workhorse Rio Grande Zed-head (ADCP) and five TRDI Streampro (ADCP). Various equipment comes with the instruments, such as laptops, PDAs, wading rods and boats.

Training

The education of field hydrologists is the key to good data. The complexity in the ADCP technique compared with traditional technique makes it difficult to use the instrument if work is not on a very regular and frequent basis. The latest instrument in the ADCP family the TRDI Streampro, has simplified the set-up for fieldwork. Make no mistake – it is still ADCP data that has to be properly evaluated in post-processing. It takes a lot of experience and training to this work.

Internal training with senior staff is mandatory for at least one year before new employees are considered self-going. At least once every second year SMHI assembles its measurement team to discuss and test different approaches to handling instruments and data. This usually consists of one day in the field and one day in the office, to verify that measurements and post-processing are made in a uniform way. SMHI sends all staff to other agencies for ADCP training. Up until now the choice has been courses given by USGS, but there are other options.

International Collaborations

A small country can not stand alone due to the fast development in instrument and software. Close contact with, especially, major international users is essential. One of the duties of the instrument supervisors is to attend workshops and seminars, providing test results and being active in the international forum provided by USGS. The resources and competence of USGS is a leading influence over software and instrument development.

There is also a more selective forum that SMHI takes part in, with members from countries developing guidelines for measurements with acoustic instruments. This hydroacoustic community consists of USGS, Environment Canada, Environment UK, NVE, New Zealand National Institute of Water and Atmospheric Research Ltd and SMHI.

WMO guidelines are under way, which are drawn up by a proposal (http://www.wmo.ch/pages/prog/hwrp/documents/Proposal_20070606.pdf).

Extended Applications

Instruments used by SMHI are always standing by to be used during high-flows. In such an event, at least two persons must be ready to assemble equipment and head out to measure at short notice. Our role is to deliver measurement results as soon as possible from areas where people and property might be at risk from high-flows. These measurements are often done at sites where SMHI normally does not operate stations, often lake outlets. From quick measurements hydrological forecasts can be made for future weather developments.

People making forecasts have in recent years understood the vastness of ADCP measurements. There are many ways the data collected could be used for more than just measure flows. Models for forecasts, such as HBV or HYPE, makes ADCP measurements more and more interesting. Some agencies are already using measurements to extract data that can be used to calculate for example Froude number, hydraulic radius and Manning's coefficient.

In recent years Sweden has begun to re-establish fish populations in rivers. Due to previous exploitation of rivers, by power companies and for the purpose of logging, a lot of natural habitats for certain species have disappeared. Lately people working with these questions have realized that measurements done by SMHI could be used to determine if certain parts of rivers are suitable for re-population of fish.

PREVIEW/NORTHERN FLOOD FORECASTING SERVICE A MODERN FLOOD FORECASTING SERVICE FOR BETTER RISK MANAGEMENT

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PREVIEW, **PREV**ention, **I**nformation and **E**arly **W**arning, an EC FP6 Integrated Project, aims at developing new geo-information services for atmospheric, geophysical and man-made risk management on a European level. The project started at mid 2005 and will end in September 2008. A three months period of "lessons learnt" will follow, between October and December 2008.

Northern Flood Forecasting Service is one of the operational services provided under the Atmospheric Cluster/Flood Platform. The service aims to develop new hydrological warning products in order to provide better flood forecasting tools on time scale 1 to 10 days within the region
(Sweden).

….The goals for Northern Flood are to develop new hydrological (early) warning products for a better decision making within a flood situation and to introduce the concept of probabilistic flood forecasting. Better geometric resolution for the models used has been taken into account. The meteorological analyse is made on a grid database of 4*4 km, i.e. precipitation and temperature analyse, where radar and satellite data are used (pt-hbv analyse). Both deterministic (11*11 km grid) and probabilistic forecasts (ECMWF 110*110 km) are used.

The hydrological model used is an application of HBV model, called HBV-Sv, and consists of 1001 sub-basins of 200-700 km^2 that covers whole Sweden. Even extension to large basin (> 2000 km^2) is taken into account).

….The end-users that benefit from the developed products/services are Local Civil Protection Services, Local Authorities, such as Municipalities and County Administrative Boards, SRSA (Swedish Rescue Services Agency) and the server provider itself, e.g. the Flood Forecasting Service at SMHI. The interactivity between the service provider and the end-users has been a major issue during the project.

….Validations have been done at different points during the project and aspects of both technical and functional validation have been taken into account. While the technical validation has been a matter for the service provider, the functional validation has involved the end-users and their needs.

Criteria such as service utility, efficiency, delivery means, availability, "easy to use", and training were taken into account when accomplishing the functional validation.

….A common platform of warning products and services has been developed and runs on operational mode. It contains flood probability forecasts and water balance computations/forecasts based on HBV-Sv model. The platform is suitable for all end-users and can be applied for the whole region and downscaled at local level (end-users test sites, i.e. Kristianstad, Västerås, Sunsvall).

….The flood probability forecast shows the probability of exceeding a certain flood threshold in every sub-basin of HBV-Sv model. Statistical flood levels have been computed for each river sub-basin. The flood probability forecasts are based on hydrological EPS, which, in its turn, use the ECMWF EPS as input to the hydrological model. An example of probabilistic flood forecast presented in map form is showed in Fig. 1.

….The main limitations with probability forecasts are, on one hand, difficulties to catch small-scale rain (mainly due to resolution of meteorological models), and, on the other hand, the hydrological model can't be updated against observations in all sub-basins.

….The benefits of working with probabilities consist, first of all, of a new approach when working with risk management and scenarios. A probability forecast can give an early indication that "something is going to happen", and even gives the possibility to address the "what if?".

….The common platform of warning products and services has been further adjusted and developed to fits the special requirements from Civil Protection Services, e.g. the end-users who have been an interactive part of the project.

….End-users designed services have been delivered as for example to the Civil Protection/Municipality of Kristianstad. The service contains products such as observations (precipitation and temperature), and forecasts (both deterministic and probabilistic) for Helge river basin. The products delivered by the service provider (SMHI), either as data files on ftp or as tables/graphs presented into a web based real time presentation system, are used as in data to the local hydraulic model that is ran by the Municipality of Kristianstad. The output is water stage forecasts for river Helge in Kristianstad, with possibility of running scenarios and to address the "what if?".

….Another example is the water level forecast service delivered to the Civil Protection/Municipality of Västerås. The water level forecasts for the Lake Mälaren delivered by SMHI are used as in data to the local GIS-system. The output is flood risk mapping within Municipality of Västerås.

FIGURES

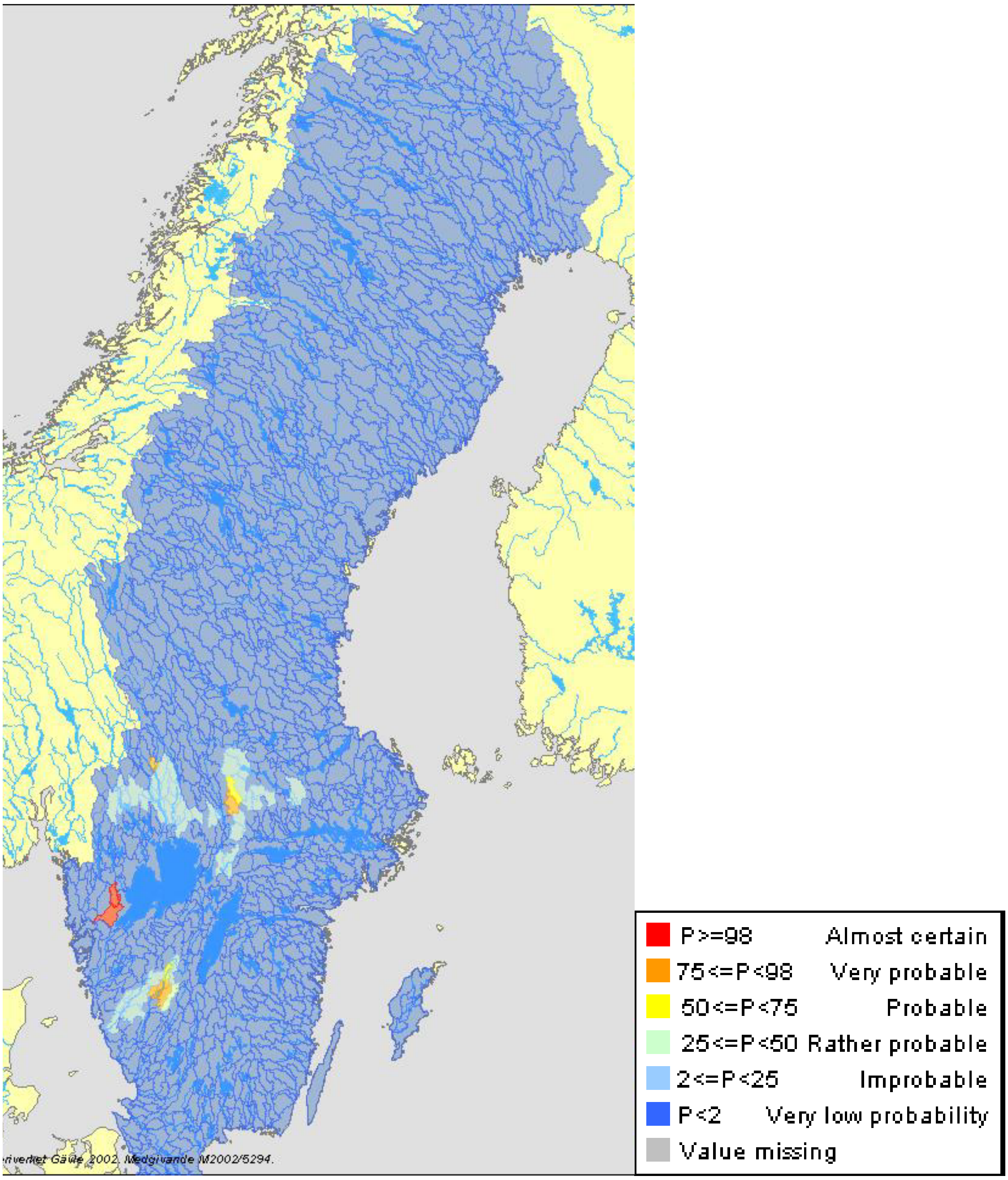

Figure 1. Probability flood forecast map for exceeding the first warning level (e.g. flood with return period of 2-5 years).

DYNAMIC FLOOD MAPPING

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ABSTRACT

The primary purpose of the national flood forecasting service in Norway is to warn and inform the regional emergency organizations when floods of a certain size are expected.

Especially sudden very heavy rain showers can cause serious local floods.

Considering climate change it is to be expected that these kinds of rain showers will occur more often in the future, making flood warning an important tool for emergency preparedness in the future. Providing the right information in case of an emergency is the key factor.

The Dynamic Flood Map tool is being developed at NVE to provide the necessary information. Discharges are estimated based on precipitation (forecast), water stage observations and catchment properties. These discharges are then input for a hydraulic model to simulate water levels. Using GIS water levels area interpolated to create a flood surface model. Overlaying the flood surface model with a detailed terrain model provides inundated areas. Maps of the inundated areas are published so they are accessible through the internet.

In addition to the flood inundation maps important information for emergency organizations is provided. Levees that might be in danger for breaking or being washed over by waves are shown. Furthermore water levels are published at critical (infrastructural) locations.

Keywords: Dynamic flood map, real time flood warning, forecast, automatic system, hydrological analysis, hydraulic modeling, GIS

INTRODUCTION

NVE is in charge of operating the national flood warning service for Norway.

The overall purpose of the national flood warning service is to avoid loss of life and prevent damages in and along water courses. In an operational context, the primary purpose of the national flood forecasting service in Norway is to:

- Warn regional emergency organizations when floods of a certain size are expected.
- Inform the same regional emergency organizations about other special situations that may cause damage along the rivers.
- Inform and update the public

The flood warnings and the information about special situations that may cause damage are sent to regional and local government bodies and published on the internet. In addition a 24 hour answering service can be reached all year around.

The warning system operates in three consecutive steps.

Step 1 is the review of status. This requires access to real time observations from measuring stations providing hydrological and meteorological data. Step 2 is the preparation of forecasts. Here the data is used for forecast calculations giving expected data in the future. In Step 3 warnings are broadcasted and measures are initiated if necessary based on the forecasted data.

Recent evaluation shows an increasing to receive forecasts in a more palpable form, easier to understand, easier to relate to possible actions to be taken and that are accessible via modern media channels. New tools developed during the recent years contribute to meet the information demands from society and public.

COMMUNICATING FLOOD WARNINGS

Not all receivers of flood warnings have a good understanding of the content of an issued flood warning. Flood warning come in terms of return periods of given discharge magnitudes. The flood will be like a 5 year flood.

Meaning the discharge is like the discharge of a flood that happens on average every 5 year.

For most people it is easier to understand water levels. The problem is that discharge is a parameter that is the same for the length of a river stretch. It first changes when tributaries or brooks add more water to the river. Water levels however can vary a lot along the same stretch. Bottlenecks can increase water levels dramatically. Topography is thus another key parameter that defines water levels. To calculate water levels means running a hydraulic simulation using both discharge and topography as input and water levels as outcome. (see article from Péter Borsányi, NVE).

Understanding a warning is not enough. In a flood situation specific information is needed to take the right decisions. To decide if or not evacuation is needed you need to know what area will flood with a certain water level. That means mapping the floodplain.

These Flood maps with its discharge tables and water level tables make it possible for people to translate a discharge to a specific water level at a specific location. And get an idea which area will flood with a specific water level.

For approximately 150 river stretches flood maps have been produced over the last ten years in the flood plane project. For these mapped places the information is available to "translate" a flood warning to more operational parameters. In case of continuance quick access to correct information is paramount. Using a flood map to translate doesn't do much for both. It is not quick and also not always accurate. When it comes to flood planes are not all floods mapped.

The aim of the dynamic flood mapping project is to improve the quality of flood warning in terms of increased usefulness. That can be done by distributing flood prognoses over the internet in the form of maps that show flood plane areas and water depths.

DYNAMIC FLOOD MAPPING

In order to produce flood prognoses in the form of maps over the internet the flood maps must be produced automatically from the results of a hydraulic model. The process of automatically running flood analysis and thereafter hydraulic simulation to calculate water levels along a river stretch are not within the scope of this article. This paper describes the process of using an automated GIS procedure to make flood maps ready for publishing on the internet.

In the Dynamic Flood Mapping project we used ArcGis 9.2 in combination with python. The use of the python script makes it possible to start the GIS analysis automatically at a preset time. It also allows for calculation without opening the ArcGis UserInterface.

The process of mapping a flood plane contains the following 6 steps

1. coupling water levels to lines (GIS) representing the cross-sections
2. interpolating water levels to a water surface
3. combining water surface with a digital elevation model (dtm) to find flood surface areas
4. differentiate between direct exposed flood plane and "low areas"
5. levees and checkpoints
6. preparing for presentation

All these steps are programmed in python.

1) The 1D hydraulic simulation returns water levels at surveyed cross-sections. These cross-sections are converted to lines in our GIS. The water levels are then placed on the cross-sections.
2) Linear interpolation (using TIN, Triangulated Irregular Network) between the water levels at the cross-sections generates a 3D water surface.
3) Using topographic data on a 1:5000 scale or laser scanning when available a detailed digital terrain model or dtm (5*5m raster) is constructed. Overlaying the dtm with the water surface results in inundated areas.
4) This overlay provides us with all areas in the dtm lower than the water surface. This can however produce flood surface areas that are not directly in contact with the flood surface. These areas are classified as "low areas". Water from the river will not directly flood these areas but risen groundwater levels or local down poor may cause inundation nonetheless. By checking connections between flood surface areas and the river these "low areas" are identified and classified separately.
5) Similar to calculating the flood surface areas a check is performed on levees to evaluate whether there is danger for collapsing or waves washing over. Generally a 0.5 m security margin is applied meaning flood water levels higher than 0.5 m below the top of the levee are considered a risk and these locations are shown on the map.
   Besides checking the levees checkpoints can be used to evaluate water levels at specific locations. For example on roads to evaluate whether escape routes are available. Another example is to provide water levels at power or telephone switches to evaluate if they might brake down an add considerable difficulties to the situations for both civilians and rescue crews. A table is produced showing water levels at predefined checkpoint locations.
6) The final step is to prepare the results so that the can be easily distributed to both involved organizations (communities, police, etc) and the general public. The tables with water levels at critical points are saved as html for easy publishing on the internet.
   The rasters representing flood surface areas and endangered levees are converted to a picture format (png) with a predefined color representation. These pictures are made available for internet using ArcIms.

A website is used to publish the results on the internet and thus make them accessible for the public. Using ArcIms furthermore makes it possible for local government bodies to implement the flood forecasts maps into their own GIS systems. Allowing visual overlays with local datasets like detailed topography or aerial photos.

CONCLUSION

The Dynamic Flood Mapping project helps in closing the gap between hydrologists monitoring and calculating prognoses for floods and the responsible government bodies dealing with the effects of floods.

It changes the way of communication and thus enhancing understanding which helps in decision making to prevent damages in case of a flood.

It takes however considerable effort to implement the whole chain of data gathering, flood calculations, hydraulic simulations and dynamic flood mapping. For all locations from the Flood Mapping Project a lot of the work has already been done. For these locations hydraulic models exist, together with cross-sections, a dtm and (if exists) levees.

A period of testing and evaluation the system will have to show its use so we can consider implementing more areas in the system.

ON THE APPLICABILITY OF A 3D HYDRODYNAMIC MODEL FOR THE CALCULATION OF CURRENTS IN A LOCAL COASTAL SEA AREA

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ABSTRACT

The exchange of water through a strait between two water basins is important for many hydrological processes, one of which is the transport of substances. A 3D hydrodynamic model incorporating sigma-coordinates (COHERENS), was applied to a small area in the archipelago of the Gulf of Finland. The aim of the study was to map the current patterns around the islands and quantify the exchange of water through a strait between two islands. The results show that the model is suitable for this kind of work. Wind speed data from an open ocean weather station can be used as forcing if it is reduced by a factor of 2.

INTRODUCTION

3D hydrodynamic numerical models have existed for many years and they have been used in many applications to e.g. study the distribution of substances and different processes in oceans and coastal sees (Bendtsen et al. 2006, Kiirikki. et al., 2006; Koponen et al, 1994). Modelling studies have also been carried out successfully on large lakes (Huttula et al, 1996). In basin scales (~100km) the models work well and are an effective research and forecasting tool. In local scales (~1km), the bathymetry starts to produce problems. If a complicated bathymetry is to be modeled in sufficient detail, the grid size needs to made very small producing a very small time step leading to very high time costs in using the model. Complicated model setups are therefore not easily usable in the decision making process.

This study aims to take a sophisticated 3D hydrodynamic model and apply it to a complex archipelago situation in a simple way. The end result would be a 'throw-away' hydrodynamic model for the specific case where some kind of current field estimate was needed. The goal was to see whether the simple model could produce additional information that could be used to augment measurements and expert judgment in the decision making processes.

The results of this study show that in this case the 3D model produced current speed similar to measured current speeds in the area of interest. This means that the model can give additional backing to the expert's judgment of the situation.

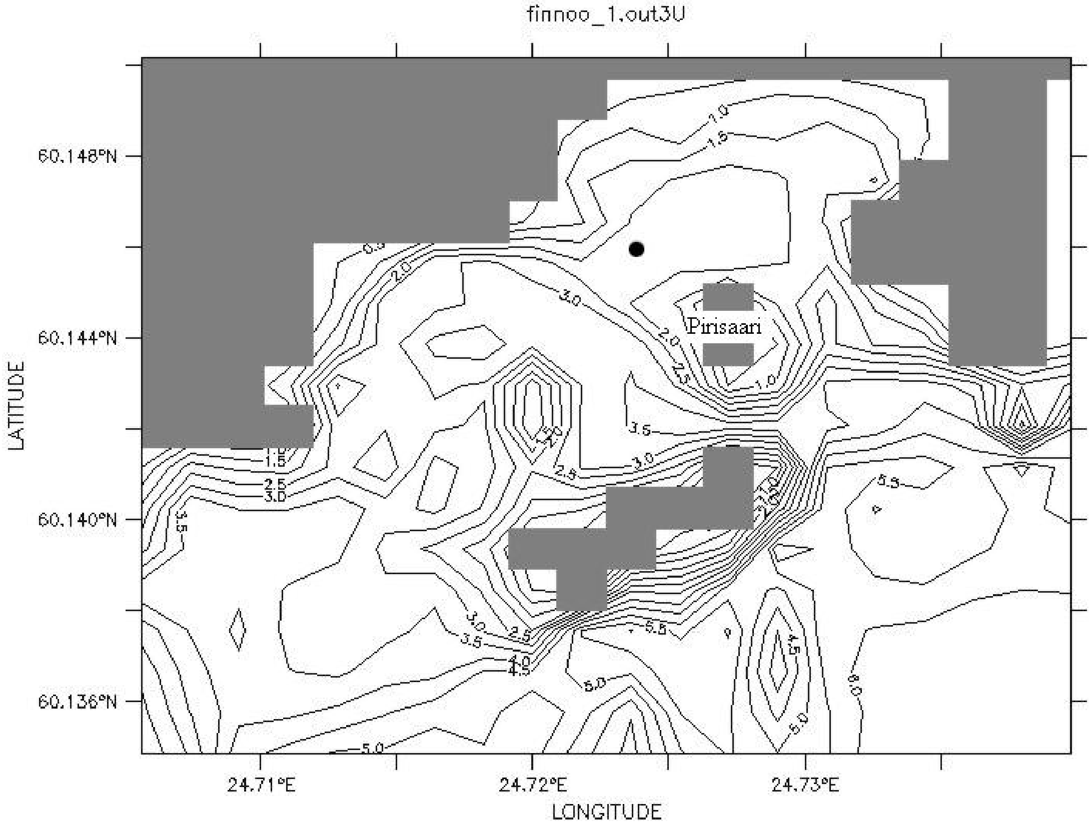

Figure 1. Bathymetry of the model domain. The location of the current measurements is shown by the black dot. The land areas are shown in the resolution of the model.

THE CASE STUDY

The study area consists of the Finnoo harbour area on the northern coast of the Gulf of Finland. The area consists of an enclosed bay with a mean depth of 2.5m open to the east with several large islands obstructing the flow of water (Fig. 1). The area of interest was the very northern part of the bay between the island of Pirisaari and the mainland.

Water velocity measurements at a depth of 2m were made to study the currents in the area with an Aanderaa DCS-3900R current meter in this area. The measurement location is shown in Fig. 1 as a black dot. The measurements were made for 1 month between 8.11.2006 and 8.12.2006 and the measured current speeds were used to validate the model.

THE MODEL

The model used in this study is based on the COHERENS model (Luyten et al. 1999) which was originally designed as a regional model for the North Sea. The aim of the work that produced the model was to predict the effect of the changing conditions on the biota and to simulate the input and dispersion of contaminants in coastal and shelf seas. This is an ambitious and multidisciplinary task and consumes a substantial number of years of effort for designing, developing and testing the model code and to validate the model against observational data. The COHERENS model is similar to the Princeton Ocean Model (Blumberg and Mellor, 1987) and utilizes sigma-coordinates in the vertical direction that follow the bathymetry. This gives it the possibility to reproduce down slope flows. A high resolution version of the model has also been used to study the ventilation of flows in the transition zone from the northern Kattegat to the Arkona Sea (Bendtsen et al. 2006).

The model was setup with 4 layers and a grid size of 100m, which forced the time step to be 1s. The boundaries were closed at all sides. Because the area of interest was in the northern part of the bay, the model domain was cut off in the south. The bay is open to the sea on the east edge. The bathymetry was filtered to remove values below 0.5m. In areas where the water depth is 0.5m the vertical resolution became 0.125m.

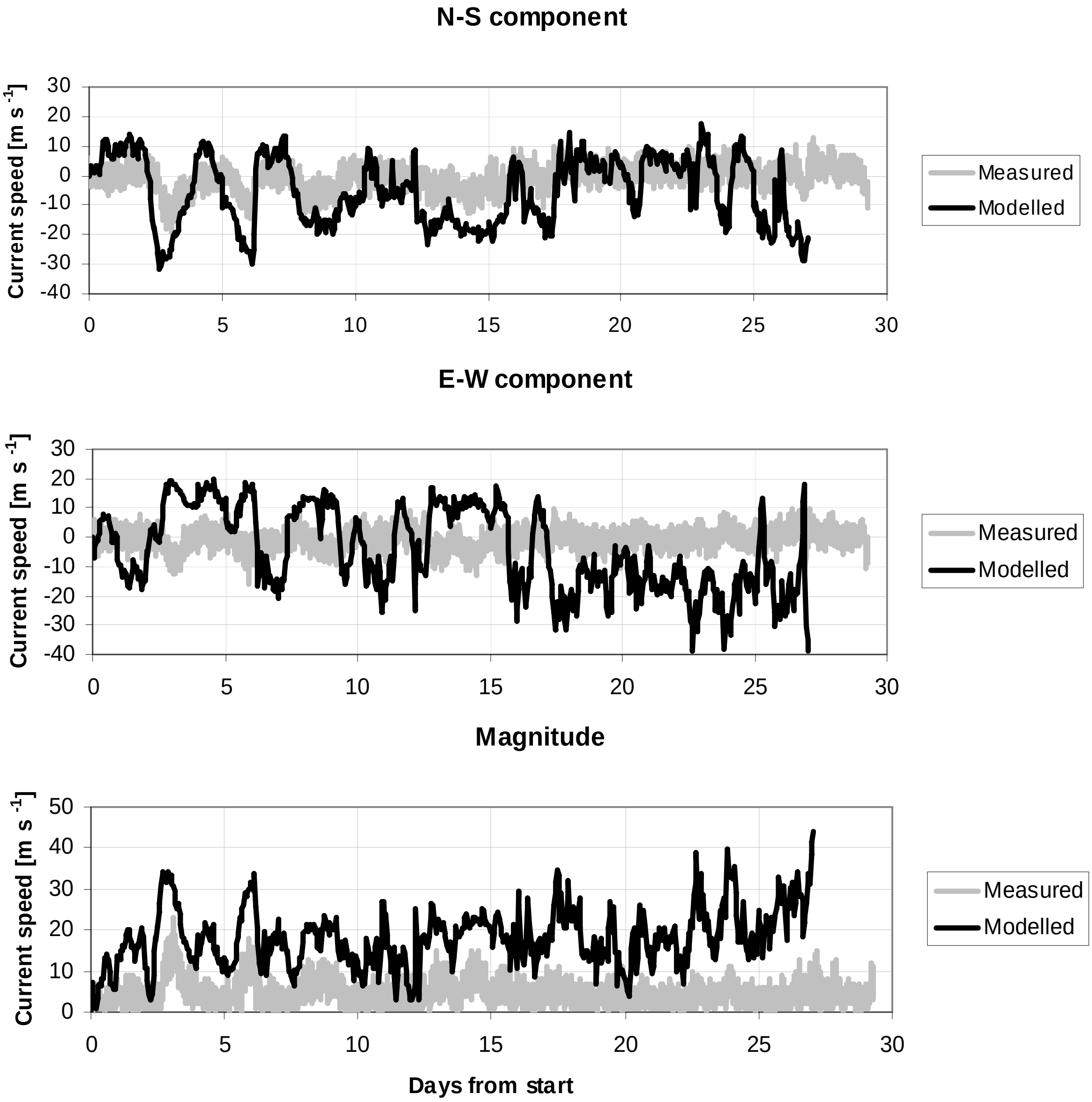

Figure 2. Simulated surface currents and measurements. The north-south component is in the top panel, the east-west component is in the middle panel and the velocity magnitude is in the bottom panel.

Wind forcing data from a meteorological station in the Gulf of Finland (Harmaja) was used to force the model. Harmaja represents the open Gulf of Finland and therefore the wind there is not entirely applicable to a closed coastal bay. Two different wind parameterizations were therefore applied. Firstly the wind was capped to $8 ms^{-1}$. Larger wind values caused the model to be unstable. Secondly the wind was multiplied by 0.5 in addition to the capping.

The model simulation started on the 8.11.2006 and the model was run for 27 days with both wind parameterizations. Hourly results were then stored for further analysis.

RESULTS

The model results at the location of the current measurement were extracted and the results are shown here. The results for the first wind speed parameterization are shown in Figs. 2 and 3. Comparisons between the measured currents and Simulated velocity u (east-west) and v (north-south) components and magnitude are shown in Fig. 2 for the surface layer. Magnitude features are reproduced well in the model and the model and measurements are in very good agreement in general. However, the model overestimates the current speed. According to the results, the v-component at the location shows a better result. This is reasonable because the strait opens to the north and south and therefore the east-west components are smaller and harder to model correctly.

The measured velocity magnitude and the simulated velocity magnitude in a layer between 0.75m and 1.5m (the second layer) are shown in Fig. 3. The velocity magnitude in this layer does not show a coincidence with the measurements except at the beginning and at certain times, for example between days 3 and 6.

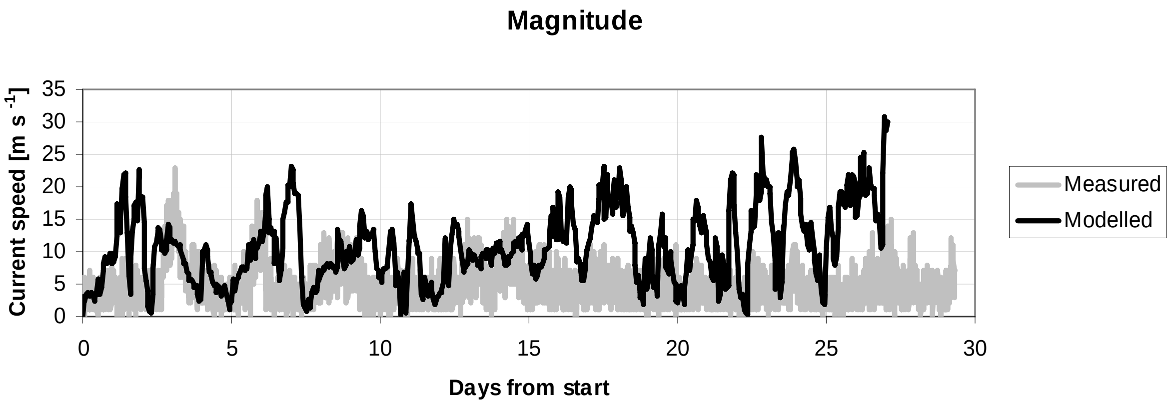

Figure 3. Simulated velocity magnitude for the 3rd layer and the measured current velocity magnitude.

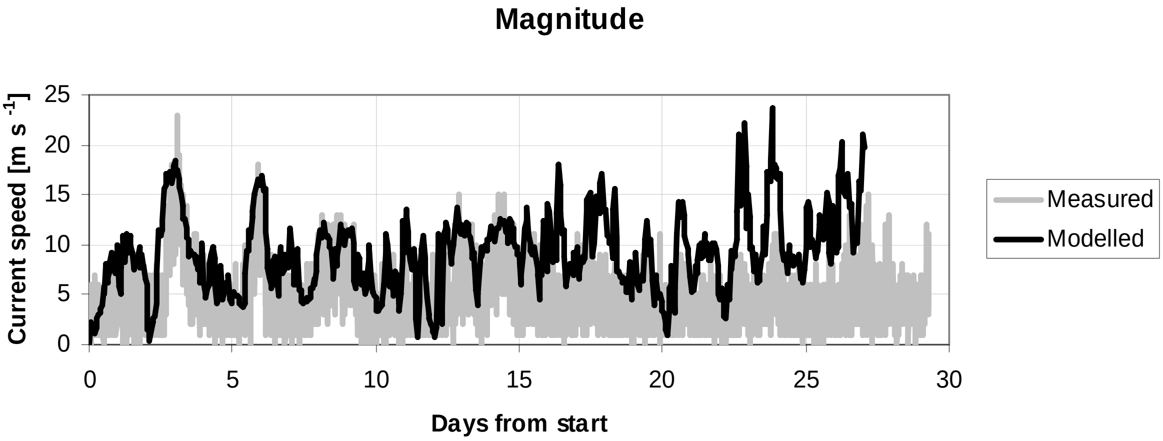

Figure 4. Surface velocity magnitude (measured and simulated) with the wind speed divided by 2.

In all of the model results the first hours of the first day show very small current velocity values. These are due to the spin up time required by the model.

DISCUSSION AND CONCLUSIONS

The model results show that the surface layer velocities coincide well with the measurements but the results from the second layer do not. The agreement for between the surface layer becomes better when the wind speed is halved. The unrealistic eastern component in the surface current comes from discrepancies in the bathymetry in the model domain with regard to the bathymetry in nature. In local applications the bathymetry can vary dramatically (see Fig. 1) within the model grid boxes.

The fact that the magnitudes of the water velocity are in coincidence with the measurements shows that the wind parameterizations works for this case. The second parameterization gives an even better agreement than the first parameterization. Open sea wind data is very often the only data available and care needs to be taken when it is used as forcing for the model.

From a decision makers point of view, the results are encouraging. The model produces currents which are similar to those measured. The model can therefore be used in this simple form as an aid to deducing the current fields in a local application. Close to the boundaries, the results will become more unrealistic. The model should not be used by itself, but together with measurements and expert judgement.

The Coherens model has been chosen as the new research model at the Finnish environment institute (SYKE). The model is being applied to several different situations in the Baltic Sea and in Finnish lakes. The ecological model developed presented in Korpinen et al. (2004) is also being implemented in the model to make Coherens, which is basically an ocean model, more suitable for ecological studies in the Gulf of Finland area and boreal lakes.

ACKNOWLEDGEMENTS

The City of Espoo is acknowledged for providing access to the measurement results. Timo Huttula is acknowledged for giving useful comments on this work.

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THE WATER RESOURCES DATABASE AT LANDSVIRKJUN

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ABSTRACT

At Landsvirkjun data on water resources has been collected for many years. The collection has been done both by the Landsvirkjun staff and by a contractor. The data was before maintained in two separate databases tailor made for this purpose here in Iceland. A new database for water resources time series at Landsvirkjun was started in June 2006. It is a Wiski database developed by Kisters in Aachen Germany. The Wiski database at Landsvirkjun includes time series of water level and discharge in rivers, water level in lakes and reservoirs, groundwater level in drill holes, measurements of pressure, settlement, stress and many more parameters in dams, measurements of pressure and discharge in geothermal wells, gate openings in hydropower stations, water temperature in reservoirs, rivers and groundwater, conductivity of water and many more. The import routes for the data into the Wiski database are very different. Some data is collected remotely from the measuring stations many times a day others only few times a year depending on how important it is to have the measurements in house early. Almost all measuring stations have continuous collection of data, most often once an hour but the periodicity varies from 1 sec to daily. The variation in types of sensors is great and also the measured units. Automatic collection is done by telemetric communication, spread spectrum radio, and direct networking.

INTRODUCTION

At Landsvirkjun data on water resources has been collected for many years. The collection has been done both by the Landsvirkjun staff and by a contractor, The National Energy Authority Hydrological Service. The data was before maintained in two separate databases tailor made for this purpose here in Iceland. In June 2006, Wiski, a new database for water resources time series at Landsvirkjun was started. The Wiski database is also used by The National Energy Authority Hydrological Service.

When Landsvirkjun began the development of hydropower stations in the Þjórsár- and Tungnaár River basin Landsvirkjun took over many of the hydrometric measurements from the Hydrometric Office at The National Energy Authority. In the year 1967 the staff of the hydrometric department of Landsvirkjun was two people and ten years later they were three. Now the staff responsible for the hydrometric measurements is six.

The first measurements in 1967 were of discharge in the rivers Þjórsá and Tungnaá, soon the measuring sites grew in number in the big rivers and in the tributaries. Groundwater level has been measured in boreholes near the Þórisvatn reservoir since 1967 and the water level of Þórisvatn reservoir has been measured since 1971. The first automatic weather stations in the basin were installed in 1993 and they are maintained by Landsvirkjun but the data is collected and quality checked by the Icelandic Meteorolocical Office.

Now groundwater is measured at about 280 stations, discharge at about 50 stations, reservoir water level at about 50 stations and the weather parameters are recorded at 15 stations.

Since the hydrological year 1986/87 some of the data has been published yearly with graphs and tables. The rest of the data has not been published in that way but has been used for calibration of conceptual rainfall-runoff models, in various reports on groundwater and other hydrological studies and dam safety, as well as for estimation of design events and in detailed design of hydropower structures.

THE WISKI WATER RESOURCES MANAGEMENT

The name Wiski is an abbreviation for “Wasserwirtschaftliche Information System Kisters” and it is a water resources management system developed by Kisters in Aachen, Germany. The Wiski water resources management system for time series management is created from twenty years of experience in the field of hydrology. The software system is built with a three-tier client-server architecture in which the user interface, business logic, data storage and data access are developed and maintained as independent modules. The system operates with a relational database.

Wiski is designed to manage hydrometric networks of stations and is used to administrate e.g. surface water sites, groundwater sites, gauging stations and weather stations. It offers a central site register to maintain the station detail information. Wisk can cope with different import routines for data, and can thus be implemented easily for different types of telemetry environments. Wiski server modules can be used to automate the import of data into the Wiski database.

The stored data is held in time series which are related to the appropriate parameter, where Wiski distinguishes between original and production data. Automatic validation routines can be run against the data to highlight data that is not plausible. The Automatic validation routines can be freely configured or standard routines can be used e.g. for checking for completeness (automated gap detection) and a min/max boundary check.

Within its powerful graphic module the time series can be corrected graphically (direct access of data points) and/or in tabular mode. The primary statistics (such as mean, min and max) of the appropriate time level (such as day, week, month and year) are calculated from the corrected production time series and are stored into separate time series.

THE DATA IN WISKI

There are 8 types of measurement sites in Landsvirkjun's Wiski database. The data collected at the various types of measurement sites is as follows:

Groundwater

At most groundwater stations only water level is measured but at some water temperature and conductivity are additionally measured. At few geothermal groundwater stations the steam pressure is measured. Both vented and un-vented sensors are used. For un-vented sensors the air pressure exerted on the water table is compensated by the Wiski system using measurement of air pressure at a nearby station. In some groundwater sites water level in boreholes is measured in up to 4 isolated aquifers. All these measurements are updated in the Wiski database. Over 670 measuring groundwater sites are in the system and about 280 of these are in use today.

Reservoirs

For reservoir sites the level of reservoirs and lakes is stored as well as water level at intakes to power stations and tailwater level. There are over 80 reservoir sites of which about 50 are active.

Rivers

There are 3 different types of river measuring stations. The most typical one contains measurement of water level and discharge is calculated by a rating curve. The second type is the one where the discharge is not of issue but only the water level. The third one is where only discharge is measured intermittently. There are about 50 river stations in Wiski.

Discharge

In the discharge stations are time series of directly measured discharge e.g. with an acoustic doppler velocity meter or calculated discharge by means of other time series like gate opening and level. There are 10 stations of this type is in the system.

Gates
In the gates station the opening of gates is stored. The gate opening is mainly used to calculate discharge. There are 43 stations of this type in the system.

Weather
The staff of the Research Department maintains 15 weather stations. The data from the stations is sent directly to The Icelandic Meteorological Office where the data is stored and quality controlled. Only intermittently the data is read into the Wiski database.

Dam
In the station type dam many types of measurement data regarding the condition of dams are stored. These are measurements of movement and pressure inside Kárahnjúkar Dam e.g. settlement, strain, load, and movement of joints. Now about 150 stations of this type are active.

Power
The power production in the hydropower stations of Landsvirkjun is kept in stations of type power.

COLLECTION OF DATA
The data in the system is of various origins. The bulk of the data is collected by the Research Department at Landsvirkjun but also the staffs at the power stations of Landsvirkjun provide measurements as well as contractors at the NEA Hydrological Service. Below we lay out the different ways of data collection for the Landsvirkjun Research Depart measurement sites and the Landsvirkjun Power stations (see also Figure 1). How the data is imported from the Meteralogical Service and the Hydrological service is not addressed here.

Most of sites maintained by the Landsvirkjun Research Department are equipped with recorders and about half of the recorders are connected by telemetric means to the Wiski database using two different programs Loggernet and Multilogger. The data from these telemetrically connected stations is automatically read into the Wiski database. Data from the other stations is collected intermittently and automatically read into the database.

Most of the data collected at the power stations is collected in a central database maintained by Landsnet and an automatic update into the Wiski database is now in function. Data from 2 power stations is read directly into Wiski by a semi-automatic routine.

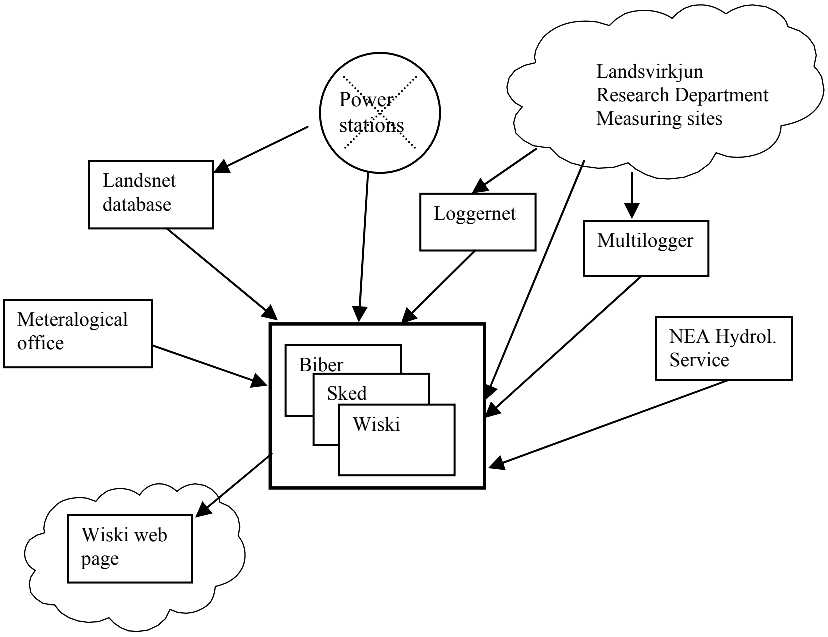

Figure 1. The integrated measurement system of Landsvirkjun.

WORKFLOW OF DATA MAINTENANCE IN WISKI

Original data is read into an “Original” time series of a parameter, which is read only. The changes or corrections of the data is done in the production time series wich are related to the original time series and to each other in a way shown in Figure 2 for a station of type groundwater and in

Figure 3 for a station of type river.

In a groundwater station the main parameter is water level. In time series “Base” incorrect data is removed by means of automatic plausibility checks. These checks can remove e.g. too high or too low values and mark periods of missing data. Data in time series “Base” is copied into the next time series in the list the “Corrected “series. In the “Corrected” series the manual corrections are made and the data is marked as good or suspect. In the “Estimated” time series estimates are made for missing data. To get the absolute water level in m.a.s.l. the measuring point height is added to the water level.

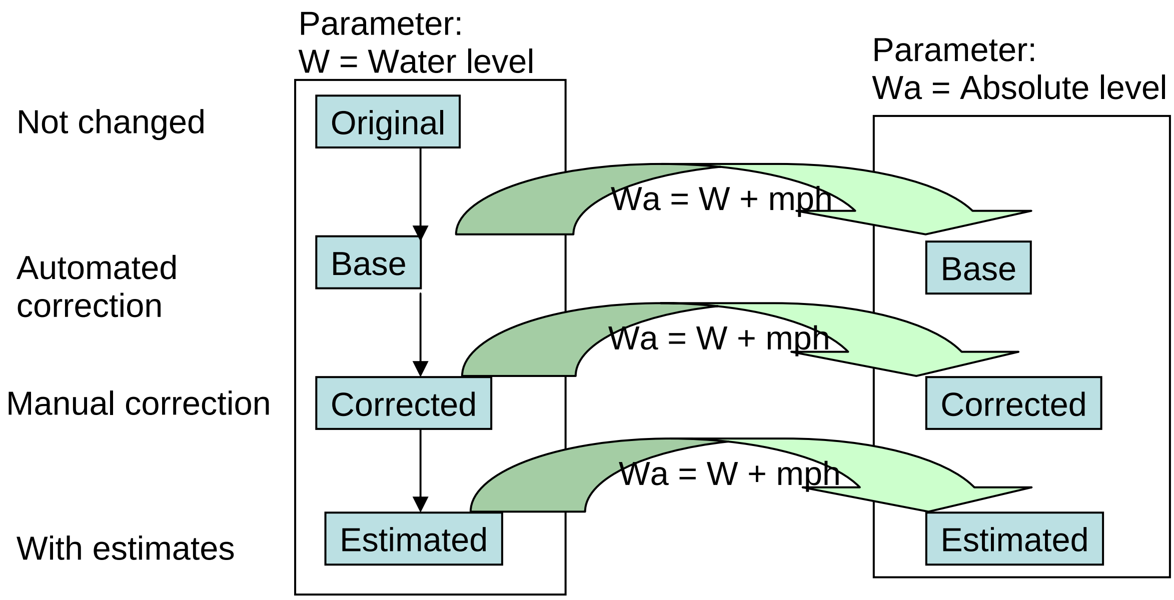

Figure 2. The relation between time series of water level and absolute water level in a site of type groundwater.

The time series in river stations are very similar to groundwater stations but some are added to take care of special needs. In Iceland there is a need to distinguish corrupted water level data caused by ice jams from other bad data and in the time series "For discharge" all water level data with suspected ice interference is deleted. As for groundwater in the "Estimated" time series estimates are made for missing data. Discharge is calculated from water level for the time series "Corrected", "For discharge" and "Estimated". The final product, time series "Published", is a copy of the time series "Estimated" with optional additions from other sources like runoff models.

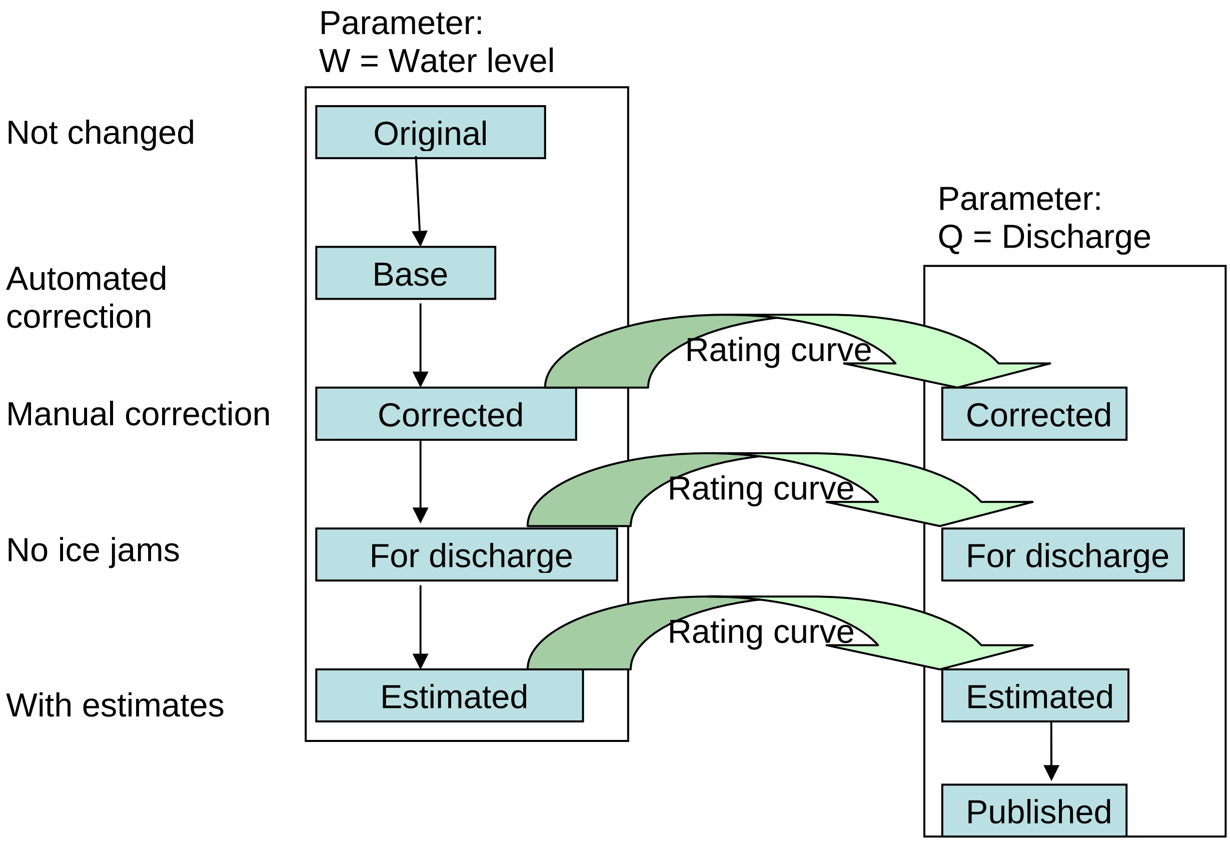

Figure 3. The relation between time series of water level and discharge in site of type river.

PUBLICATIONS AND THE WISKI WEB

Publication of the data in the Landsvirkjun water resources database is to be understood as the checkout of the data. The observer responsible for the measuring station does the checkout and after that the data can be published. The publication includes a map and a list of stations in an area and graphs and tables of the data from the stations. An example of a graph and a table are displayed below in Figs. 5 and 6. In Figure 5 the daily mean values of groundwater level are displayed, as well as monthly means and maximum and minimum values. The goodness of data is also displayed, in this case it is all good "Gott". Figure 6 shows a graph of the values of groundwater level with manual check measurements displayed as red triangles.

In the Wiski web selected measurements from stations are displayed continually. The web system is open to all within Landsvirkjun and access to it can be given to users outside the Landsvirkjun domain. Data can be exported from the web as text files. It has proven to be very important to be able to open access to the data for users making the data more valuable. An example of the web view is in Figure 4.

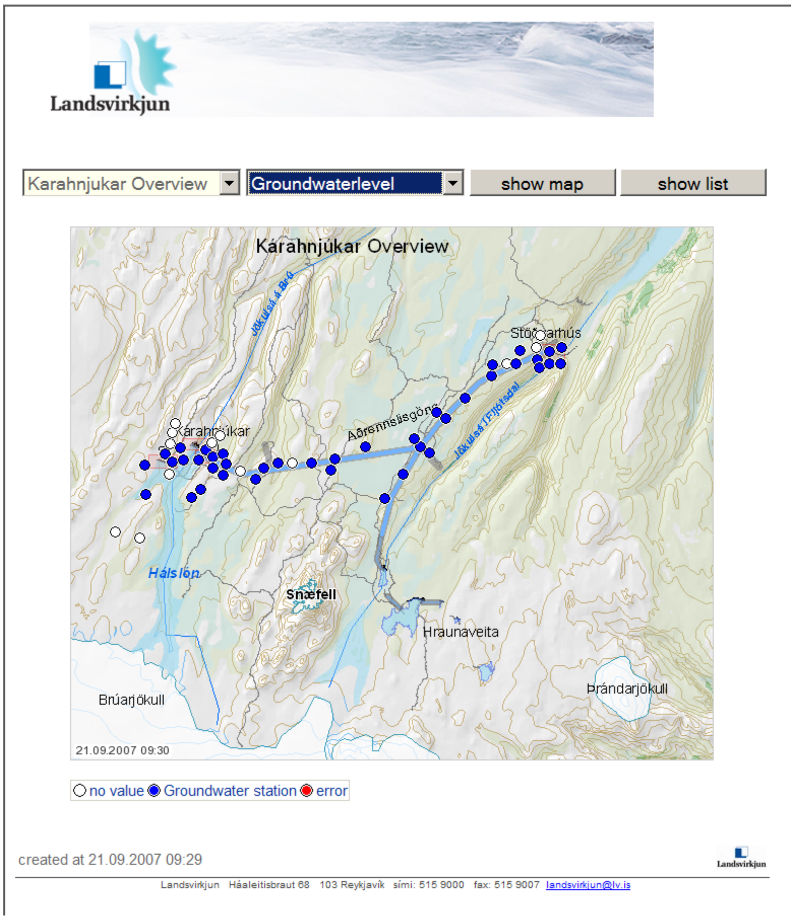

Figure 4. Groundwater stations in the Kárahnjúkar area in the Wiski web.

CONCLUSIONS

The use of the water resources management system Wiski at Landsvirkjun since June 2006 has proved to be a good success. The number of collected and stored measurements has risen while the number of employees has stayed the same. The accessibility and quality of data is better than before.

Landsvirkjun | Vatnsárið 2006/2007 | G313

BUR / Búrfell | Grunnvatn: LD-13 | ---

Meðaltal [m y.s.] af Wa1 (Vatnshæð í landi)

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6	222,00	221,77	221,21	220,94	221,74	221,57	221,24	221,72	221,95	221,85	221,82	221,77
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13	222,13	221,59	221,24	220,86	221,62	221,46	221,23	221,67	221,95	221,88	221,81	221,71
14	222,12	221,57	221,24	220,85	221,60	221,44	221,23	221,68	221,94	221,88	221,80	221,71
15	222,09	221,54	221,23	220,83	221,58	221,45	221,23	221,71	221,93	221,88	221,80	221,70
16	222,09	221,52	221,24	220,81	221,56	221,44	221,22	221,72	221,90	221,89	221,81	221,68
17	222,14	221,50	221,23	220,81	221,55	221,42	221,22	221,75	221,89	221,89	221,81	221,65
18	222,13	221,49	221,22	220,80	221,53	221,42	221,17	221,75	221,88	221,88	221,80	221,64
19	222,13	221,48	221,22	220,84	221,52	221,42	221,16	221,74	221,83	221,86	221,79	221,63
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21	222,14	221,43	221,18	221,64	221,45	221,40	221,19	221,75	221,81	221,86	221,80	221,62
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23	222,05	221,38	221,15	221,60	221,43	221,37	221,32	221,73	221,81	221,86	221,82	221,63
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25	221,99	221,34	221,11	221,64	221,41	221,34	221,43	221,69	221,83	221,87	221,83	221,64
26	221,96	221,32	221,08	221,61	221,40	221,33	221,49	221,79	221,84	221,87	221,83	221,65
27	221,94	221,31	221,09	221,65	221,42	221,33	221,51	221,86	221,84	221,87	221,82	221,66
28	221,93	221,28	221,08	221,73	221,41	221,31	221,48	221,90	221,83	221,85	221,82	221,66
29	221,90	221,27	221,04	221,77	221,46		221,46	221,88	221,81	221,82	221,81	221,66
30	221,89	221,26	221,05	221,79	221,49		221,46	221,93		221,81	221,83	221,65
31		221,24		221,74	221,54		221,49				221,83	221,64
Meðaltal	222,06	221,54	221,18	221,18	221,58	221,45	221,29	221,73	221,90	221,86	221,82	221,70
Hámark	222,18	221,88	221,29	221,82	221,83	221,59	221,52	221,95	222,01	221,89	221,85	221,83
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Lágmark	221,88	221,23	221,03	220,80	221,39	221,30	221,15	221,52	221,79	221,81	221,79	221,61
Dagur klst	30 19	31 18	29 14	17 16	26 12	28 19	19 11	01 00	22 06	29 21	14 17	20 16

Ómerkt = Gott, Á = Áætlað

Ó = Óskoðað, V = Vafasamt

Meðal ársins: 221,61 [m y.s.], hámark: 222,18 [m y.s.], lágmark: 220,8 [m y.s.]

Samkvæmt gagnabanka Landsvirkjunar 2008-2-15 (réttur áskilinn til endurskoðunar)

Figure 1 Table of daily values of groundwater level in site LD-13

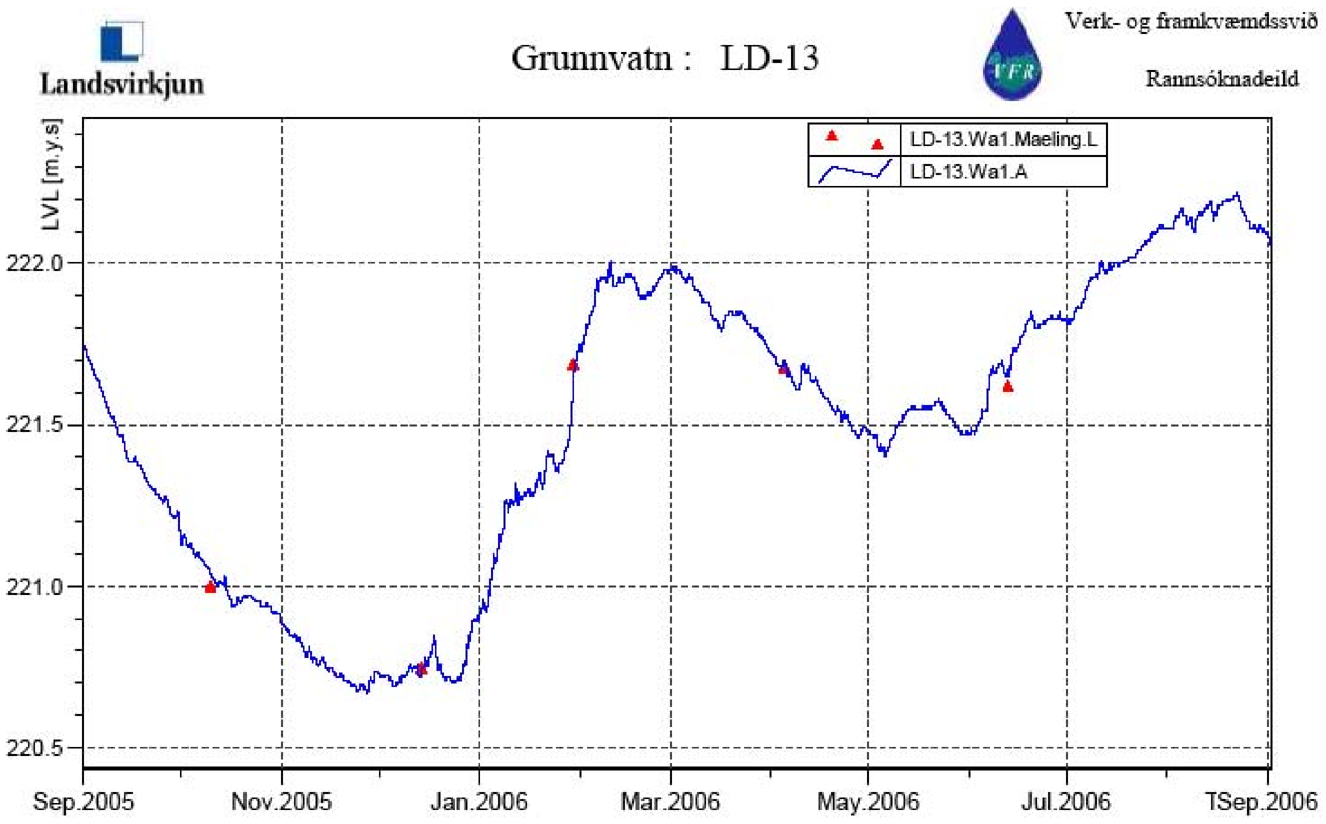

Figure 6. Graph of groundwater level in site LD-13 for the water year 2005/06.

REFERENCES

Wiski "http://www.kisters.de/german/html/homepage.html"

SESSION 6: HYDROPOWER AND HYDROLOGY

EVALUATION OF SATELLITE IMAGES OF SNOW COVER AREAS FOR IMPROVING SPRING FLOOD IN THE HBV-MODEL

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ABSTRACT

For the hydro power companies it is of major importance to know the magnitude of the spring flood. Hence, the amount of snow is crucial for forecast modelling. In mountainous areas with plenty of snow, the meteorological network is often sparse, and they lack direct observations of the snow pack. Therefore, if it is possible to combine satellite snow cover area information with a hydrologic model, it would enhance the quality of the forecasts. In this project, financed by ELFORSK, a comparison is made between snow covered area (SCA) from satellite processed images and the HBV-model. The satellite processed images are based on data from Terra/Modis and Envisat/SAR. The images are produced in near real-time by NORUT and Kongsberg Satellite Services AS, for a project called Nordic Mountain Snow Hydrology (GSE) supported by European Space Agency (ESA). The HBV-model was calibrated without the use of snow observations. The evaluation has been made for mountainous catchments with less than 30 % forest cover. In most catchments there is a consistency between the difference in observed and simulated SCA and the error in simulated runoff. During spring 2008 updates of the HBV-model will be made in real-time.

INTRODUCTION

The HBV-model is used for spring flood forecasts in Sweden. The amount of snow in a drainage area is calculated by the model from measurements of precipitation and temperature. Hence, there is an uncertainty in the estimated snow pack. This is partly due to few measurements in the most mountainous areas and partly due to the fact that the HBV-model does not consider other weather parameters. There have been several efforts to use snow observations to improve the HBV simulations (Brandt and Bergström, 1994, Johansson et al., 2001, Johansson et al., 2003, Engeset et al., 2003, Malnes et al., 2005, Boresjö Bronge et al., 2006). The results have varied, but still, no result has led to recommendations for operational use.

In this project, financed by ELFORSK, a new attempt is made to improve the estimated snow pack in the HBV-model by the use of satellite observations. The SCA products are based on a multi-sensor time-series algorithm combining snow maps retrieved from Terra/MODIS and Envisat/ASAR. The images are produced in near real-time by NORUT and Kongsberg Satellite Services AS, for a project called Nordic Mountain Snow Hydrology (GSE) supported by European Space Agency (ESA). From the Terra MODIS and Envisat ASAR images a composite or multi-sensor (MS) product is created (Figure 1). In addition to data from two satellites, the composite uses data from several days to provide a complete picture.

PURPOSE

The purpose for this project is to evaluate the possible contribution of the MS product for enhancing the SCA in already existing and calibrated drainage areas in the HBV-model. The project is concentrated on years with difficult weather situations and where less than 30 % of the total drainage area is covered by forest. The aim is to find criteria for when a problematic area in the HBV-model should be updated with data from MS product and what kind of corrections has to be made before the data from the MS product can be used in the HBV-model.

In the project data from spring 2006 and 2007 have been evaluated. There will be a try with real-time data during spring 2008. The aim is to answer these questions

- Are the data from the MS product reliable?
- Is there coherence or incoherence between snow cover data from the MS product and the HBV-model when there are large errors in simulated springflood data?
- What difference must there be between observed and simulated SCA to start update the simulated SCA with data from MS product?
- To what extent shall the simulated SCAs be corrected based on MS product?

METHODS

Satellite images, multi-sensor (MS) product

The Polar View Nordic Snow Service provides an operational SCA monitoring service and is based on the snow mapping algorithms and software developed by Norut and Norwegian Computing Center (NR). The service provides daily snow maps over Norway, most of Finland and Sweden. MODIS data is processed daily; ASAR data is used whenever available, but at least with a weekly coverage in the mountainous areas.

The optical MODIS snow cover algorithm is based on an empirical reflectance-to-snow-cover model originally proposed for NOAA AVHRR in Andersen (1982) and later refined in Solberg and Andersen (1994). The algorithm, also know as the Norwegian Linear Reflectance-to-snow-cover (NLR) algorithm retrieves the Fractional Snow Cover (FSC) for each pixel. The model is calibrated by providing two points of a linear function relating observed reflectance (or radiance) to fractional snow cover. The calibration is carried out automatically by the use of calibration areas. Statistics from the calibration areas is then used to compute the calibration points for the linear relationship.

The snow service use satellite data from the Advanced Synthetic Aperture Radar (ASAR) onboard Envisat, ESA's environmental satellite that was launched in 2003. We use the wide swath imaging mode, which covers a swath of approximately 400 km and has 100 m spatial resolution. The snow processing line use the standard Level 1B satellite products as input, and performs automatical geocoding to correct for topographical effects using a digital elevation model (Lauknes and Malnes, 2004). The geocoded SAR images are subsequently compared against geocoded reference images from dry snow conditions. Due to the strong absorption of radar waves in wet snow, there is a significant decrease in the radar backscattering when the snow becomes wet. By comparing the current SAR image with the reference image, we establish areas containing wet snow using a 3 dB threshold (Nagler and Rott, 2000). By using the digital elevation model, dry snow is subsequently inferred by postulating that the snow above the local wet snow height is dry (Storvold et al., 2006).

Optical remote sensing algorithms are able to map snow cover quite accurately, but are limited by clouds. SAR sensors penetrate the clouds, but current algorithms for satellite-borne sensors are only able to map wet snow accurately. The sensor fusion approach is to analyse each image individually and combine them into a product showing the current, most likely SCA situation. The multi-sensor product should then represent the most likely status of the monitored variable. More information about the fusion approach can be found in Solberg et al. (2004a, 2004b and 2005).

Correspond satellite data to data from the HBV-model

HBV_Sverige is a HBV-model covering entire Sweden with a thousand sub basins and is run daily at the forecast and warning centre at SMHI. The model has been calibrated regionally. Every sub basin has one value for SCA which means that an average value must be calculated for each sub basin from the MS product. This was done with a combination with the MS product, sub basin areas and land use map. Due to the poor accuracy in forested areas, these were not included in the average value. 15 sub basins were evaluated, mainly situated in the north-western mountainous areas in Sweden. The locations can be seen in Figure 2.

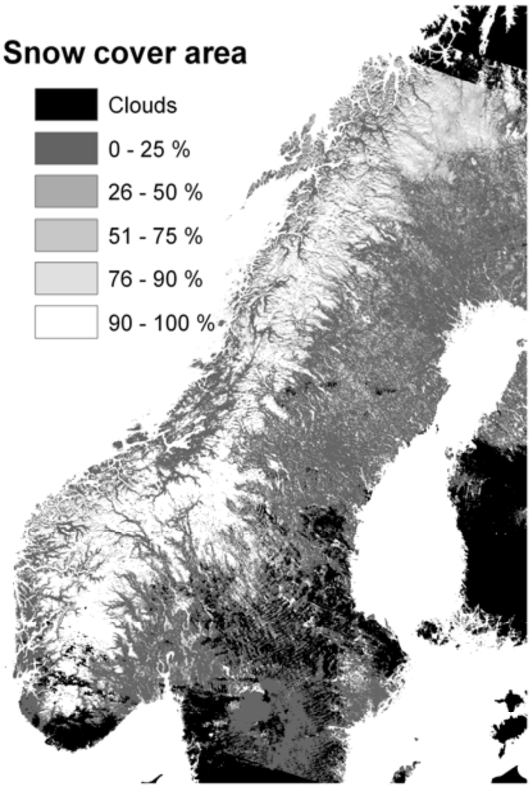


Figure 1. A multi-sensor (MS) product over Scandinavia 8th April 2006.

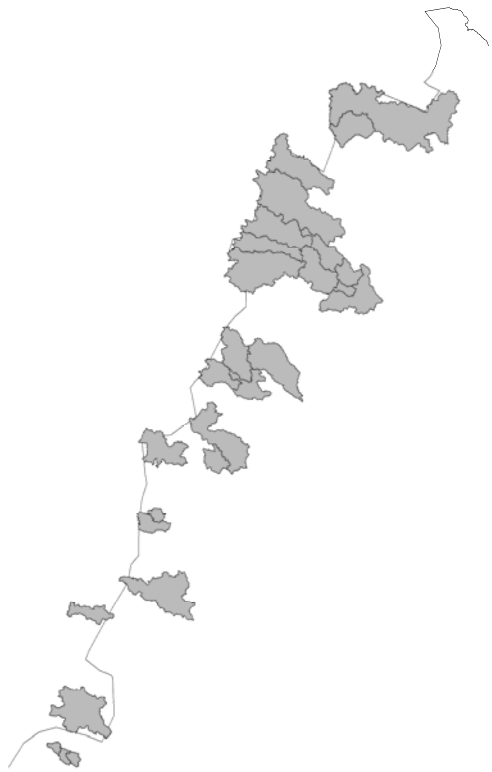


Figure 2. Areas of interest are situated close to the Swedish-Norwegian border in the northern Scandinavia. The major areas are 15, however some areas are divided in sub basins for the HBV-model.

Adjust the HBV-model

The first results show that it is not possible to compare data from the MS product directly with data from the HBV-model without any correction. It could be many factors that contributes to these differences some of them could be shadows on northern slopes (see discussion chapter) or in fact the HBV-model itself. A simple equation to adjust the satellite data was developed within the project.

RESULTS

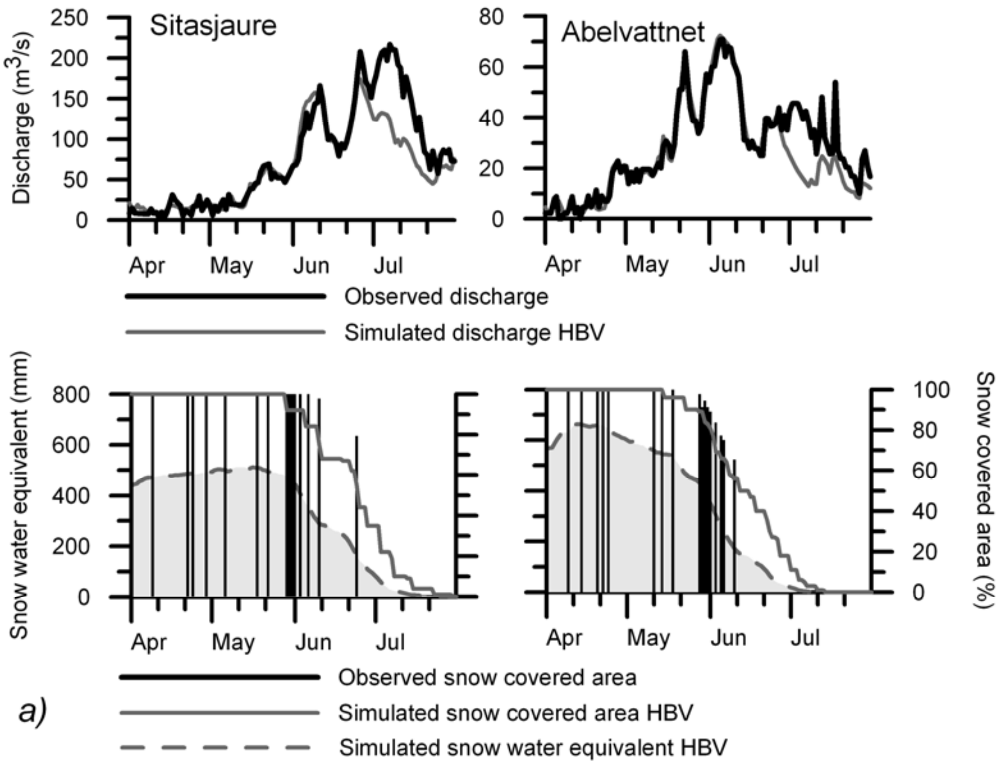
A comparison between the simulated HBV snow cover and the satellite image indicates the usefulness of the satellite data. A high snow covered area in HBV, as compared to the satellite image, generally corresponds to an overestimation of the simulated spring flood volume and vice versa (Figure 3a). With those positive results the project continued to the next step, to update the HBV-model with corrected values from the MS product. Updates were made when the difference between observed and modelled SCA were at least 10 percentage points. No updates should be done if new snow comes during the melting period and places a thin layer of snow over the majority of the sub basin area. The simulated snow pack was updated by approximately 70 % of the difference between the observed and the simulated.

The results are unambiguous for 2007 (Figure 3b). In areas with extreme spring flood volume errors according to inflow (>20 %) during spring flood, an update of the SCA gives a significant decrease of volume errors from the middle of May and onward during the spring flood. For areas with large volume errors (10-20 %) an update results in a decrease of volume error, however a bit later in the season, June and onward. For areas with minor volume errors the update has no negative effects.

DISCUSSION

The results for 2006 were not as good as 2007 after updating the HBV-model with observed SCA. One explanation could be that data from MODIS were more frequent during spring 2007. In 2006 several days at a time were cloudy for some sub basins. During spring 2007 there were also very little precipitation which led to minor variation on SCA except for melting.

It would be useful if an update could be made for areas with 10-15 % error in the simulated spring flood volume. Even though the results are not as stunning as for areas with major errors (>20 %), an update is easily made and not time consuming. During 2008 the project will continue to find a system for a real-time update with some automation for the different steps.



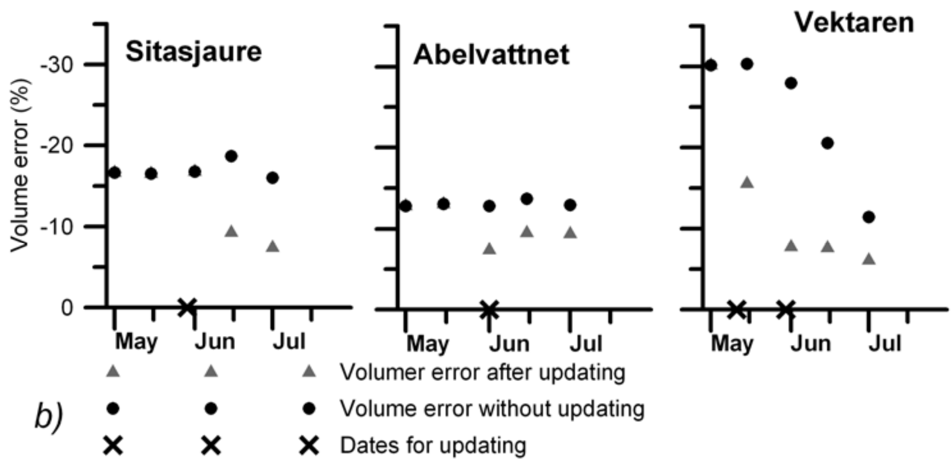


Figure 3. a) Examples of observed and simulated runoff and snow covered area (2007). An underestimation of the snow covered area also gives an underestimation of the simulated runoff.
b) Examples of volume error in simulated runoff with and without updating (2007). Every dot represents the volume error from the actual date to the end of the melt season (0731). Error expressed in % of total spring flood volume (0401-0731). In the examples updating leads to decreasing volume errors.

The NLR algorithm for Terra/MODIS SCA retrieval has been applied and evaluated in several projects. The general experience is that the algorithm typically underestimates the SCA somewhat. However, it is hard to conclude quantitatively, from experiments comparing SCA retrieved from MODIS images using NLR with SCA maps based on Landsat TM and ETM+, exactly how large the underestimation is. The underestimation is especially noticed in mountainous regions. In winter and early spring, there will be shadows because of the low sun. There will also be underestimation of snow in slopes facing northerly. These errors will decrease as the sun rises higher. The best results are obtained in April and May before significant fragmentation and pollution of the snow occurs. In this period the algorithm gives satisfying results with accuracy of 80-90%. Towards the summer the underestimation will increase because of dirty snow.

Norwegian Computing Center's cloud algorithm has been found to work quite well over Norway, and generally better than NASA's algorithm for the MOD35_L2 MODIS cloud mask product. There are small differences in general, but the main difference lies in detection of clouds over and at the borders of snow-covered areas. MOD35 frequently shows clouds along most of the edges of the snow covered area. In cases with cold weather and dry snow, the MOD35 product could show clouds over large snow-covered areas when there are no clouds. NR's cloud algorithm is sometimes not able to detect clouds over snow-free land and classify these pixels as snow. Cloud shadows can also reduce the estimated SCA value.

Radar waves are partially absorbed in forests. This results in less sensitivity towards wet snow in forests. Researchers in Finland (Luojus et al., 2007) have tested methods to compensate for the local forest stem volume with some success. The current service have not made any attempt to implement forest compensation due to the significantly more complex algorithm needed. In addition, the necessary forest stem volume inventory needed as auxiliary data for such method is currently not available for the areas we cover. Future improvements of the service should, however, focus on this issue.

SMHI observed in 2006 several examples where the snow depletion curve for several drainage areas indicated snowfall in the middle of the melting season. The ability to detect such snowfalls with the snow monitoring service depends somewhat on if it is detected by SAR or optical sensors. If only SAR has coverage during the lifetime of the newly fallen snow, chances are large that it remains undetected since a thin snow cover with little liquid content probably does not reduce the radar backscatter sufficiently to be detected as wet snow.

ESA and EU have through the GMES initiative made SAR data basically free for the GMES services. This will in the next years probably guarantee improved SAR coverage. KSAT is going to improve the operational aspects of the service. Improved experience in running the service and improved software will mean a more reliable service that provide near real time users with high quality data.

The multi-sensor time-series approach has proven to give significantly better coverage in space and time than using a single-sensor approach. The current confidence-based approach has been tested for a few snowmelt seasons and thereby demonstrated to work very well with respect to coverage in space and time. This is the only way of providing close-to-daily snow cover maps throughout the whole snowmelt season. However, there is still a lack of harmonization of the results coming from optical and SAR sensors. The two sensor types observe different geophysical phenomena and, therefore, cannot be expected to give fully consistent results. A new fusion model combining data closer to the physical retrieval process level is currently under development by Norwegian Computing Center and Norut.

CONCLUSION

The MS product from the satellite images has such good quality that they are applicable to compare and to update the HBV-model for a sub basin with large volume errors. Although a fixed constant has to be added to the data from the MS product.

Despite usage of a MS product there could be long periods of time without reliable observation e.g. clouds.

The MS product could be used to indicate overestimated or underestimated amounts of snow in the HBV-model.

An update of the HBV-model with data from the MS product enhances the accuracy of the HBV-model.

Evaluation was made for the spring melting seasons of 2006 and 2007. The results after updating the HBV-model with SCA data were more effective for values during 2007. Most probably due to more favourable weather conditions for satellite images.

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A FLOOD-FORECASTING SYSTEM FOR SKIENSVASSDRAGET, NORWAY

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ABSTRACT

Operation of hydropower reservoir can be a critical element in management of large flood in regulated river systems, and modelling tools for simulating inflow and the effects of operational decisions on downstream water levels is important in flood management. This paper describes a flood modelling system developed for the lower part of the Skien Watercourse (Skiensvassdraget) in Norway. In this watercourse there are several hydropower developments operated by different companies, and data from all of these must be incorporated in order to predict the flood development in the lower part of the river system. The modelling system consists of a hydrological model for inflow prognosis, a reservoir routing module and a linkage to flood zone maps for analysis of potential flooding in critical areas. The local inflow prognosis is updated daily based on meteorological prognosis, and this is combined with predicted inflow from the upstream hydro power systems to give the total inflow to the lower river. The routing and flooding module is then used to investigate impacts of various operational decisions in the hydropower system.

INTRODUCTION

Floods are a serious threat to many communities along the lower reach of the Skienselva river, for example in Notodden, Gvarv, Ulefoss and in Skien. The largest floods are usually caused by a combination of snowmelt and heavy rainfall. Small and medium floods have been reduced during the last decades, due to the building of several reservoirs for hydropower regulation. These reservoirs have a limited capacity, however, and large floods will not be completely controlled by the reservoirs so that considerable flooding may still occur. Since small and medium floods are reduced, the time between flooding will be increased, possibly leading to less awareness about floods and flood protection. The hydropower reservoirs may be used to reduce flooding, but this operation may lead to less optimal use of water for hydro generation and economical losses if reservoirs are kept at a too low level in order to reduce the risk of flood spill from the reservoirs, and thereby reduced flooding in downstream areas.

A flood warning system has been developed for Skien watercourse, by integrating a number of data sources and computer models into one system: Operation plans for upstream reservoirs, flood forecasts for downstream catchments, hydraulics of lakes, rivers and reservoirs and operational characteristics for gates and hydropower plants. Results from different models operated by separate organizations have to be integrated in near real-time, in order to issue forecasts and prepare plans for actions both for reservoir operation, issuing flood warnings and possibly planning rescue and evacuation operations. The system is using FTP, E-mail and Web-based solutions for data transfer and distribution of results.

SYSTEM STRUCTURE

The flood warning system consists of several modules that communicate through file transfer. The layout of the system is shown in Figure 1.

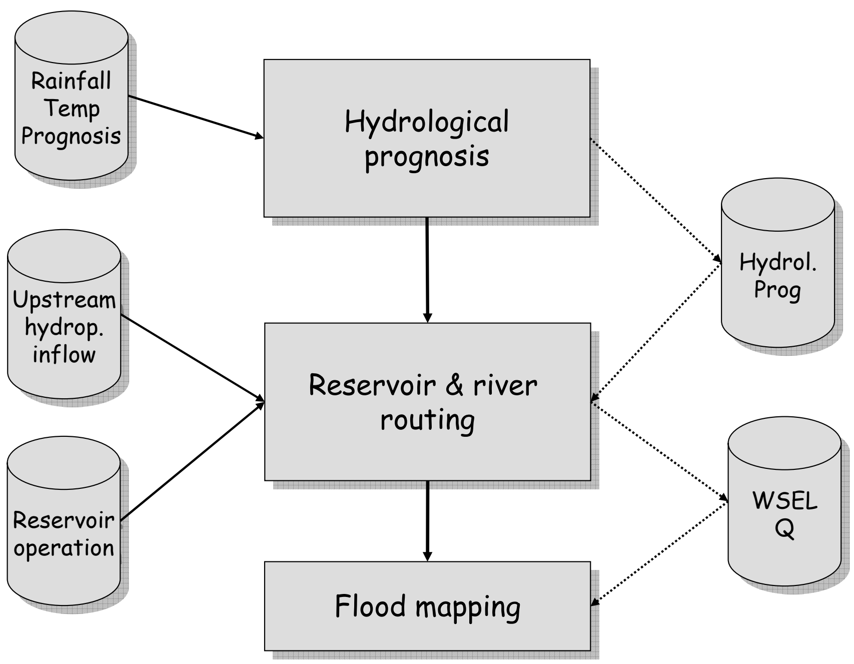

Figure 1. Structure of the Telemark floor warning system. The storage on the left hand side symbolizes external input data to the system, and the right hand side shows the internal data flow.

The hydrological prognosis is generated by a version of the HBV model (Killingtveit and Sælthun, 1995). The model is calibrated on observed data, and an update procedure is implemented in the model to fine tune the observed model just prior to the forecasting period. The forecasting is usually based on 10-day predictions from the meteorological institute, and it is possible to simulate alternate predictions for analysis of variability in the predicted temperature and precipitation.

The routing module is based on an object-oriented toolkit (Alfredsen and Sæther, 2000) which allows a modular development of the structure of the river system and a flexible inclusion of computational methods for routing and analysis. The current setup uses mass-balance routing in both in the reservoirs and in the river reaches based on total releases from each reservoir defined by the user and inflow from local and external catchments.

MODEL SETUP AND OPERATION

System model

The Skien water course is located in the southern part of Norway and has a total catchment area of 10772 km^2 and an annual runoff of 274 m^3/s. The flood-forecasting system covers the area from Tinnsjø to the outlet, a total catcment of about 5440 km^2. The main reservoirs are Tinnsjø and Norsjø. The remainder of the catchment is divided into the western part (Tokke-Vinje hydropower system), the Møsvatn hydropower system and the Mår hydropower system (Fig. 2). The area from Tinnsjøen to the outlet is divided

Figure 2. The catchment of the Skien water course. Map from NVE-Atlas (www.nve.no). Regulated input from 1) Mår, 2) Møsvatn, 3) Vestfeltet, 4) Sundsbarm, 5) Hjartdøla.

into a series of components, and each of them is represented as objects in the main model (Fig. 3).

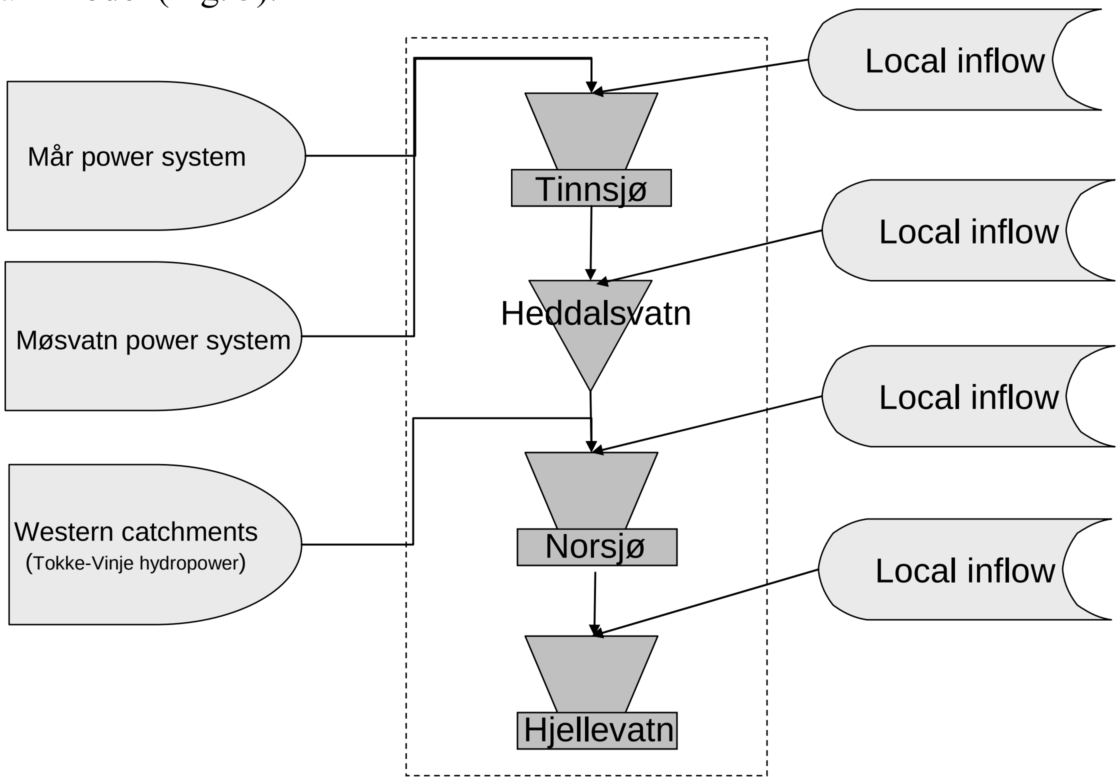

Figure 3. Components in the flood warning system.

Inflow computations

Three catchments were selected within the model area, and the HBV model was calibrated for each of them on historical data. Every morning the meteorological prognosis is downloaded from the meteorological department, data for the selected precipitation and temperature stations are selected and the prognosis input is prepared for the HBV model. The observed discharge for each catchment for the previous day is also collected and the model input is updated.

When the dataset for the prognosis is complete, the model for each catchment will be run until the start of the prognosis period, and if necessary the operator updates the model to ensure that the lead up period to the prognosis fits the observed data. The prognosis is then executed and the inflow prognosis is stored and transferred to the routing part of the flood model.

The inflow from the other local catchments used in the flood computations are computed from the three HBV catchments using a scaling factor based on area and specific runoff.

Data from upstream hydropower systems

Statkraft provides the total inflow prognosis for the Mår and Tokke-Vinje hydropower systems and Hydro provides a prognosis for the Møsvatn hydropower system. These are received by email from the operational centres and imported into the flood routing system. Møsvatn and the Tokke-Vinje system provide a weekly updated prognosis and Mår sends data on a daily basis. At times the prognosis from the external sources does not match the inflows computed from the meteorological prognosis, and they are then extended in the model with a constant value. Normally a five day period with observed data is imported with the prognosis to work as a control period for the simulation.

Reservoir operation and routing

With the future inflow and external input prognosis in place the final step is to run the routing model to generate the water levels for each of the lakes and reservoirs in the system. The user of the system must specify a release plan for each reservoir for the prognosis period and the initial levels must be set for both the reservoirs and the lake. The reservoir levels are imported from observed data in the database operated by the Øst Telemark Regulatory Asscociation (ØTB). The procedure used for the routing computations is to define the starting point for the simulation some days before the start of the prognosis period to get a control of the computation. In the cases where we have a deviation in the water levels between the observed and simulated water levels, the model needs an update to ensure a proper starting point for the prognosis period. The scaled inflow is considered to be the component with the highest uncertainty, and the method employed in the model today is to adjust the scaling factor to get the simulation of the water levels correct.

A special consideration is taken in the routing model for the reach from Heddalsvatn to Norsjø. This is relatively flat, and the water level in Norsjø will influence the outlet capacity of Heddalsvatn. In a previous study the release capacity of Heddalsvatn was computed for various water levels in Norsjø. The current routing model of Heddalsvatn will check the water level of Norsjø and update the release capacity curve dependent on this, thereby ensuring that hydraulic link is kept during the computation.

For a selected number of areas along the reservoirs inundation of built areas is a serious problem during flooding, particularly along tributaries to Norsjø and Heddalsvatn. To visualize this model will in the future provide a dynamic flood zone mapping utility developed by the Norwegian Regulatory Association (NVE). Tributary inflow and reservoir water levels will be transferred automatically to a central computing unit that will perform dynamic routing in the critical reaches, and the resulting inundation maps will be transferred back and made available to the user of the flood warning system through the interface of the program. This will provide an opportunity for real-time visualization of the impacts of high inflow and operational strategies on flooded areas and potential damage in the catchment.

Example of use

The major objective of the development is to provide a tool where reservoir operators can test release plans and find impacts of various strategies during flood conditions. During the latter half of June and first half of July in 2007 the Telemark area experienced a flood situation and the flood management system was tested for a real simulation situation. An area of particular interest was Tinnsjøen and the possibility of managing the water level combining releases from the upstream reservoir in Møsvatn and releases from Tinnsjøen itself. Figure 4 shows development scenarios for Tinnsjøen for various combinations.

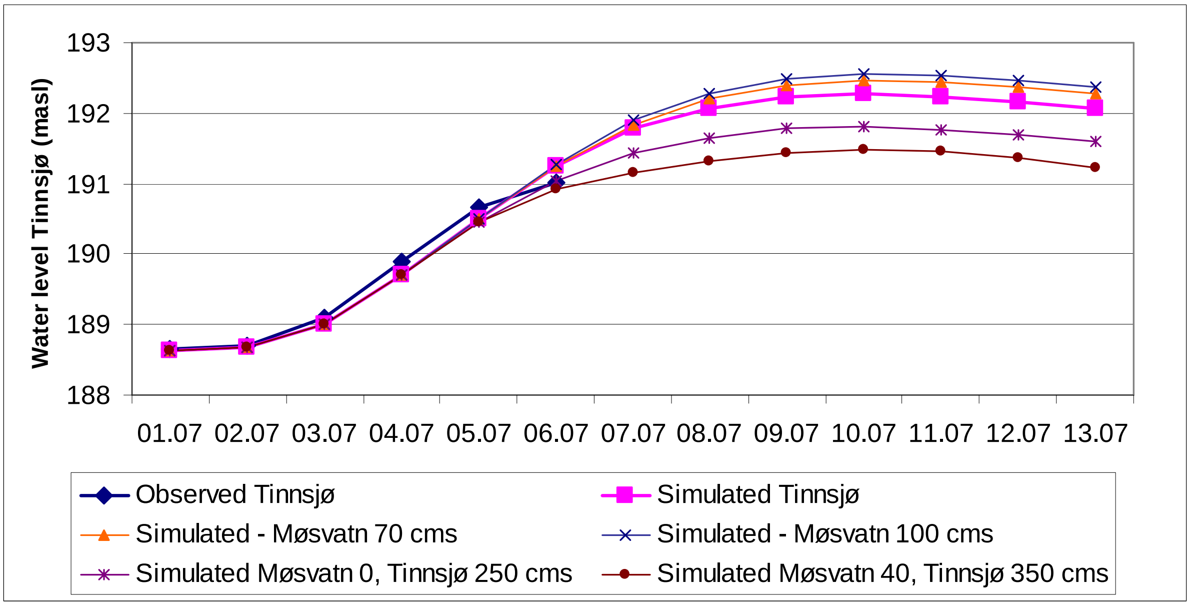

Figure 4. Prognosis on the 6th of June 2007 with different operational strategies. Simulated Tinnsjø is the option with no changes in the current operational strategy.

CONCLUSIONS

A flood warning system for the Skien river system is developed and used for flood management simulations. The model combines data from various distributed sources to provide a basis both for model control and updating and for the future prognosis. The experiences from operational use of the model shows the challenges in synchronizing data sources and getting a seamless transfer of data, but also the potential of computing with distributed data sources.

ACKNOWLDGEMENTS

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SEASONAL FORECAST OF STREAMFLOW OVER SCANDINAVIA: A GCM MULT-MODEL DOWNSCALING

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ABSTRACT

This work investigates the operational predictability of seasonal to inter-annual streamflow over Scandinavia through the use of multi-model ensembles, to test different recalibration methods linking simulated large scale circulation and moisture fields to streamflow, and to test various multi-model ensemble combination schemes. The inherent variability of the atmosphere requires seasonal to inter-annual climate forecasts to be expressed probabilistically, and are made possible through the proper use of General Circulation Model (GCM) ensembles. However, GCMs do not explicitly simulate streamflow, necessitating the statistical link between GCM-forecast fields and streamflow.

INTRODUCTION

The seasonal predictability of streamflow in Scandinavia has emerged over the most recent decade due to the deregulation and privatization of the electricity market in the 1990s. Streamflow is the key information for hydropower production and e.g. in Norway up to 99% of the electricity generation is hydroelectricity (EIA 2004).

The objective of this work is to investigate the seasonal predictability of streamflow over 23 river stations (Fig. 1) in Scandinavia by means of downscaling of a GCM multi-model ensemble. Large scale circulation and moisture fields, as forecasted from the GCM models will be linked to streamflow using Model Output Statistics (MOS).

Two GCM models were chosen for this task: the HadAM3, run by the University of Cape Town, South Africa, and the ECHAM4.5, run at the International Research Institute for Climate Prediction (IRI), Columbia University, USA.

A MOS based on non-linear artificial neural network (NN) is applied to relate winter season (JFM) circulation and moisture fields as forecasted by the GCMs in December, to melting season (MJ) streamflow in the selected river stations (Fig. 1).

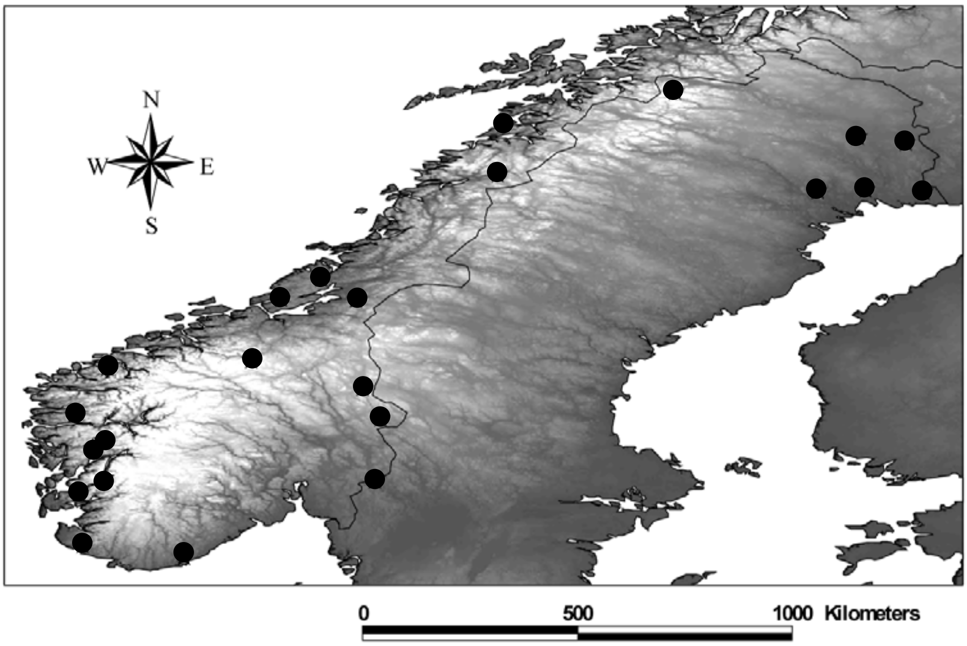

Figure 1. Topography map showing the Scandinavian mountain range, which extends along the Norwegian and Swedish boarder. The gauging stations are marked with stars. Brighter areas are higher in elevation.

SCIENTIFIC AND TECHNOLOGICAL BACKGROUND

The scientific basis for doing seasonal forecasts originates from the observation that slowly evolving sea-surface temperature (SST) anomalies influence seasonal-mean weather conditions (Palmer and Anderson 1994). Therefore, estimation of the evolution of SST anomalies, which are often relatively predictable and subsequently employing them in atmospheric GCMs, potentially provides means of generating forecasts of seasonal-average weather (Graham et al. 2000). But GCMs typically exhibit systematic spatial and temporal errors in their representation of rainfall, particularly on the representation of rainfall at high latitudes (Graham et al. 2000; Goddard and Mason 2002, Peng et al. 2000). Since streamflow is directly affected by rainfall similar problems are expected to be found for streamflow simulations. However, although GCMs do not explicitly simulate streamflow, therefore necessitating the statistical link between GCM-simulated fields and streamflow, it has been shown that deterministic GCM-downscaled streamflow forecasts on a seasonal time scale viable (Landman and Goddard 2002, Nilsson et al. 2007).

The advantage in combining ensemble members of a number of GCMs into a multi-model ensemble is in the fact that GCMs differ in their parameterizations and therefore differ in their performance under different conditions. A number of ensemble combining algorithms exists. The most simple of these is the unweighted combination of ensembles from different models (Graham et al. 2000, Mason and Mimmack 2002).

PRELIMINARY RESULTS

To this moment, only preliminary results are available. They were acquired by Nilsson et al. (2007), using an ECHAM4.5 single-model ensemble and are partially represented here, as an example of how promising results can be.

The predictive skill for the individual stations is expressed in terms of correlation between the downscaled GCM variables and the MJ streamflow and is listed in Table 1. The geographic location of the forecasting skill is presented in Fig. 3.

Table 1. Cross-validated correlations for the NN-based MOS forecasts of MJ streamflow based on GCM ensemble mean predictors. MJ streamflow forecasting skills for the 23 individual Scandinavian streamflow stations are presented. Predictors used are the GCM variables: moisture (m) and zonal wind (zv). The probability value (p-value) corresponds to the level at which the MOS correlations are statistical significant.

Streamflow station	**GCM variable**	**Correlation coefficient**	**p-value**
Flaksvatn	850 hPa m	-0.29	0.09
Gjedlakleiv	850 hPa zv	0.11	0.53
Stordalsvatn	850 hPa m	0.35	0.04
Sandvenvatn	850 hPa m	0.30	0.09
Bulken	850 hPa m	0.34	0.05
Viksvatn	850 hPa zv	0.27	0.11
Krinsvatn	850 hPa zv	0.13	0.44
Øyungen	850 hPa zv	0.11	0.51
Strandå	850 hPa m	0.35	0.04
Femundsenden	850 hPa m	0.29	0.10
Nybergsund	850 hPa m	0.27	0.12
Magnor	850 hPa zv	0.02	0.89
Suldalsoset	850 hPa m	0.11	0.53
Risefoss	850 hPa m	0.19	0.27
Fetvatn	850 hPa zv	0.13	0.46
Myrkdalsvatn	850 hPa m	0.22	0.20
Grunnfoss	850 hPa m	0.13	0.44
Junosuan	850 hPa zv	0.24	0.16
Kallio	850 hPa m	0.33	0.06
Kukkolan	850 hPa zv	0.16	0.36
Räktfors	850 hPa zv	0.14	0.40
Torneträsk	850 hPa m	-0.05	0.77
Ytterholmen	850 hPa zv	0.10	0.58

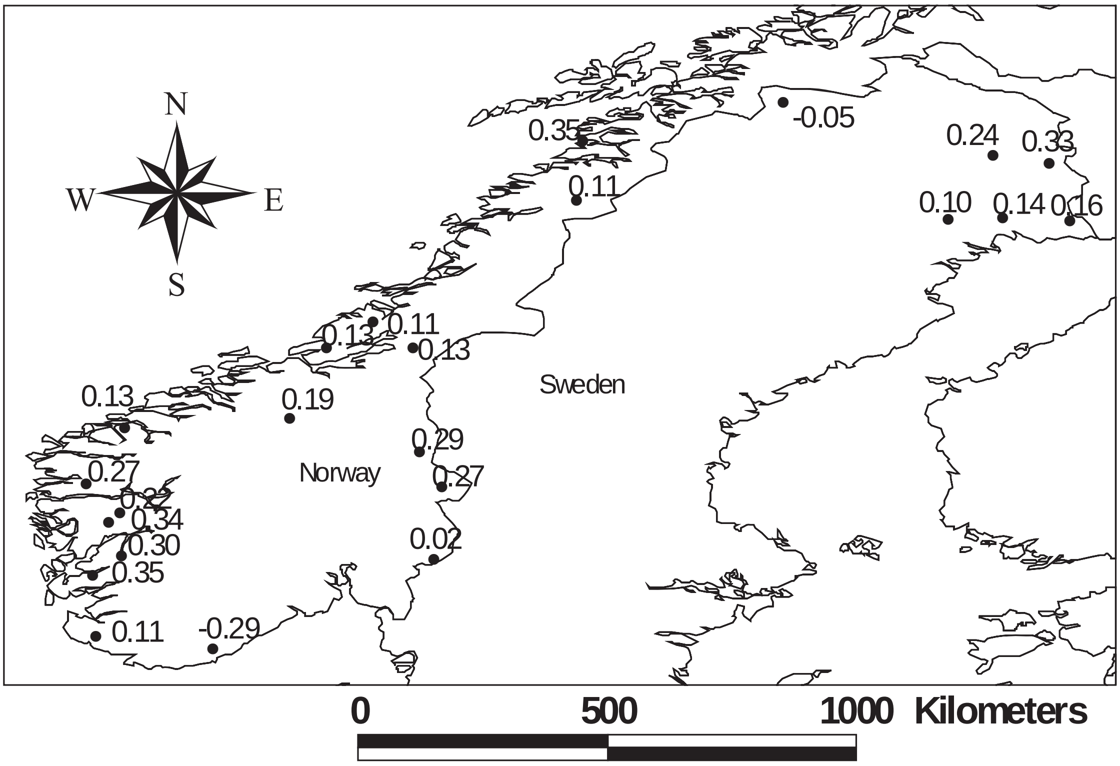

Figure 3. Geographic location of the forecasting skill for the streamflow stations in Scandinavia expressed as cross-validated correlation coefficients.

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The authors would like to thank Patrik Nilsson for valuable data collection and development of software. Trine Fjelstad, NVE (The Norwegian Water Resources and Energy Directorate) and Marcus Flarup, SMHI (Swedish Meteorological and Hydrological Institute), for providing streamflow data. This work was developed under a cooperation supported by SIDA – Swedish Research Links.

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USING GIS TO CALCULATE POTENTIAL FOR SMALL HYDRO POWER PLANTS IN NORWAY

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ABSTRACT

The object of the analyses is to calculate the potential for small hydro power plants. The method was developed in 2003 through a joint cooperation between NVE and a GIS consultant. The method uses national digital datasets prepared or developed at NVE and digital cost functions developed at NVE. In 2003 and 2004 the potential was mapped and the result manually checked. The result was approved by specialists and is presented on an interactive map via internet. Since then the method has been improved and will be tested for selected areas and possibly run for the whole country. As a supplement the developed application gives the user the possibility to define location of one or more intakes and a power plant site and get the calculations of capacity and costs for the specific project back. The new method and the results from the first mapping compared to the new will be presented.

INTRODUCTION

Norway has many small and large hydro power plants. The hydropower potential has from earlier been known through the Master plan for water resources, but this has not included mapping of all possible rivers in Norway. The interactive map shows the result of the calculation of potential for small hydro power plants done in 2004. Every identified potential power plant with its theoretical calculated capacity is located on the map (Fig. 1). This service has been widely used by municipalities, power companies and consultants and caused an increase in applications for building of small hydro power plants.

During the analyses some weaknesses in the method where discovered. In addition some datasets like the cost functions and the power lines needed improvements. At the time the river network were not complete for the coastal areas. We chose to complete the first analysis for the whole country using the same method and same datasets.

Since then the method has been improved and several of the basic datasets have been updated. The method for generating flow direction and flow accumulation has through another project (the Low Flow Index map project) been improved. The distances to roads are calculated as the shortest distance from the power plant to the nearest road when lakes and steep areas are excluded. The power lines with high voltage are excluded, but the distance to power lines are calculated as straight lines.

The new method has been tested for a few basins. When and how many more basins will be tested by the analysis is not yet decided.

The presentation will include a short summary of the first method, the improved method and some results.

THE CONCEPT FOR THE ANALYSIS

Hydro power plants capacity is a function of discharge and head. The minimum capacity in the project was set to 50 kW. The purpose was to find all slopes with a gradient down to 1:25 in all rivers in the river network and calculate the discharge at the intake level and the head. All heads which gave a possible hydro power plant of above 50 kW was stored for further estimations. To calculate the discharge the runoff map from 2002 was used as a weighted grid when the flow accumulation grid was derived from the flow direction grid. The flow accumulation and weighted flow accumulation are generated to present the regulated river system. The result is a grid where each cell value gives you the discharge. For each power plant several parameters are calculated to define the investment costs for each project (NOK/kWh). The parameters in addition to capacity and head are length of the waterway (from top to bottom of head), distance to nearest road and existing power lines and whether the plant is located in a protected area.

All power plants identified in the project where controlled by an expert especially towards existing hydro power projects. Since the power system in Norway is complicated and water is transferred to and from reservoirs and catchments, the regulated flow accumulation grids are not correct in the regulated areas. The results where also compared to planned project to be able to summarize existing, planned and potential power production in the end.

THE NEW METHOD

To identify heads tracing of 3D-rivers from the outlet in the ocean or in a lake to the source are used. Every head with a gradient down to 1:25 was identified and discharge on top of head calculated. If the discharge was too small, the head was not stored and tracing continued from the top of the last head. Consequently the continuous large head which nearly reach to the source of the rivers were excluded because of too little discharge even with a very large head. The new method loops downstream from the top of the head to find the location of intake which gives a project the largest capacity. The next upstream cell in the river is the bottom of the new head.

CONCLUSION

The new method combined with improved cost functions and input datasets gives a better estimate for hydro power potential than in 2004. In a steep river the method seems to create many power plants in a row instead of creating less with larger potential for each. Several tests have been and will be tested to investigate the possibility to optimize the number of power plants created. Comparison with results from the first analysis in 2004 is also on the agenda. The analyses are time consuming, especially the preparation of the regulated flow accumulation grids and the shortest distance to roads. The analyses will be done for several basins during the spring 2008 and these results combined with available personnel resources will decide if the method will be carried out for larger areas.

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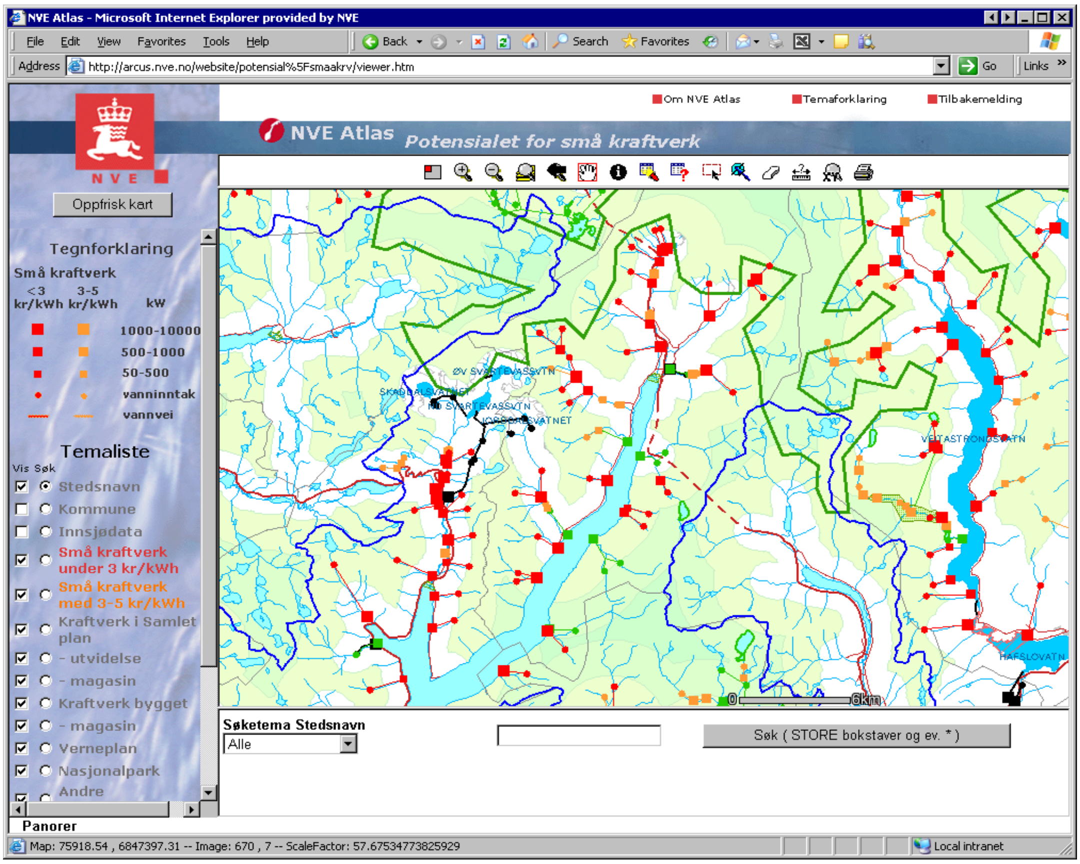

Figure 1. Interactive map showing the results from the analyses in 2004.

SESSION 7: WATER QUALITY

DEVELOPMENT AND TEST OF A NEW SWEDISH WATER QUALITY MODEL FOR SMALL-SCALE AND LARGE-SCALE APPLICATIONS

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ABSTRACT

A new hydrological model for small-scale and large-scale assessments of water resources and water quality has been developed at the SMHI during 2005-2007. The landscape is divided into classes according to differences in soil type, vegetation and altitude. In agricultural lands, the soil is divided into three layers, each with individual computations of soil wetness and nutrient processes. The model simulates water flows and flow and turnover of nitrogen and phosphorus. Nutrients follow the same pathways as water in the model: surface runoff, macropore flow, tile drainage and groundwater outflow from the individual soil layers. Rivers and lakes are described separately with routines for turnover of nutrients in each environment. Model parameters were related to soil type or vegetation and estimated using data mainly from small agricultural basins. The performance of the model and the validity of these parameters are illustrated in the paper by examples of applications obtained by transferring model parameters to two larger basins in southern Sweden; River Rönneå and River Vindån.

BACKGROUND

Spatially distributed assessments of nutrient load in Sweden have been made at the Swedish Meteorological and Hydrological Institute (SMHI) for more than ten years. Different versions of the HBV-NP model (Andersson et al., 2005) have been used (by e.g. Brandt and Ejhed, 2002). This model lacks routines for nutrient turn-over in the root zone and has therefore been coupled to e.g. the SOILN model (Johnsson et al., 1987) and the ICECREAM model (Tattari et al., 2001) in many applications. Such coupling of models with very different structure, scale and degree of detail has been found difficult (e.g. Andersson et al., 2005). The HBV model (Bergström, 1976), upon which HBV-NP is based was originally developed for discharge forecasts. For simulation of nutrient flow and turn-over it is important to distinguish between different flow paths, something that was not accounted for explicitly in the original HBV model. The availability of digital geographical information is furthermore completely different today than 30 years ago when the HBV model was developed. The development of a new hydrological model, primarily intended for water quality applications, therefore began at the SMHI in 2005 (Pers et al., 2006). The model should simulate realistic transit times, flow paths and turn-over of water and nutrients in different environments.

Distributed mapping of water resources, with a high spatial resolution, is one of the requirements from the Water Framework Directive from the European Union. A further aim of the model development was therefore to use information on for instance soil type, vegetation and topography, in order to improve the possibilities for using geographical information as a basis for extrapolating conditions to ungauged basins. The new model was called the HYPE model, a model for HYdrological Predictions for the Environment. Examples of other models developed with similar aims are SWAT (Arnold et al., 2005) and SWIM (Krysanova et al., 2005).

MODEL DEVELOPMENT

The model development ran over three years 2005-2007. The starting point was the experience from applications of the HBV and HBV-NP models, and parts of the HYPE model are based on these models. The plan was to start with large-scale processes, in low spatial resolution, and then gradually increase the detail in both space and processes. The focus during the first year was to build a flexible modelling system and to do annual water balance modelling for all of Sweden (average subbasin size ~400 km^2). During the second year a water quality framework was added, together with routing through rivers and lakes. River Motala Ström was then used as a test basin (subbasins ~40 km^2). Nutrient turn-over processes were added during the last year, together with a regional groundwater flow component. The Vindån basin had been chosen for the final development of the water quality model, and was set-up with an average subbasin size of ~8 km^2. Campaign measurements of discharge, water stage and nutrients were carried out through the project in Vindån to obtain data for spatial evaluation and to emphasize the spatial focus of the model development.

HYPE MODEL DESCRIPTION

The model simulates flows and turnover of water and nutrients. Concentrations in streams and lakes of inorganic (IN) and organic (ON) nitrogen, dissolved (SP) and particulate phosphorous (PP) are simulated. Conservative tracers can also be modelled. Elements follow the water pathways in the model. The landscape is divided into subbasins, according to geographical and climatologic differences, and depending on the spatial resolution with which the results are required. Subbasins are further divided into classes, according to the different combinations of soil type and vegetation in the subbasin. Classes can also be used to describe a distribution in altitude (Fig. 1). The number of classes is flexible. In the applications in this paper, soils have been divided into coarse materials, fine material and till soils. Land-use has been divided into forests, different crop groups in agricultural land, bogs and urban areas, and other open areas. The elevation is specified for each class, to account for elevation effects on snow and evaporation conditions. A maximum of three soil layers can be simulated within each class. Three soil layers are typically used in agricultural land, whereas the heterogeneity of forested till soils can be treated by using a set of classes with only one layer, but with a distribution of soil depths (Fig. 1). A schematic model structure within one class is given in Fig. 2.

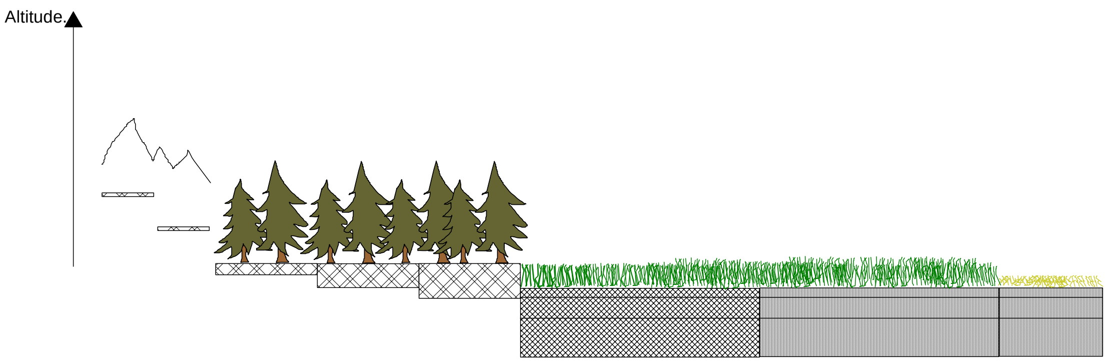

Figure 1. Schematic division of a subbasin into classes according to elevation, soil type and vegetation.

The runoff from all classes forms the local outflow from a subbasin, and is routed through rivers and lakes, together with inflow from subbasins located upstream. A regional groundwater flow between subbasins can be simulated. Model parameters either have regional values, or are coupled to soil type or land-use. Although the model is comparatively simple a detailed description does not fit into this short paper.

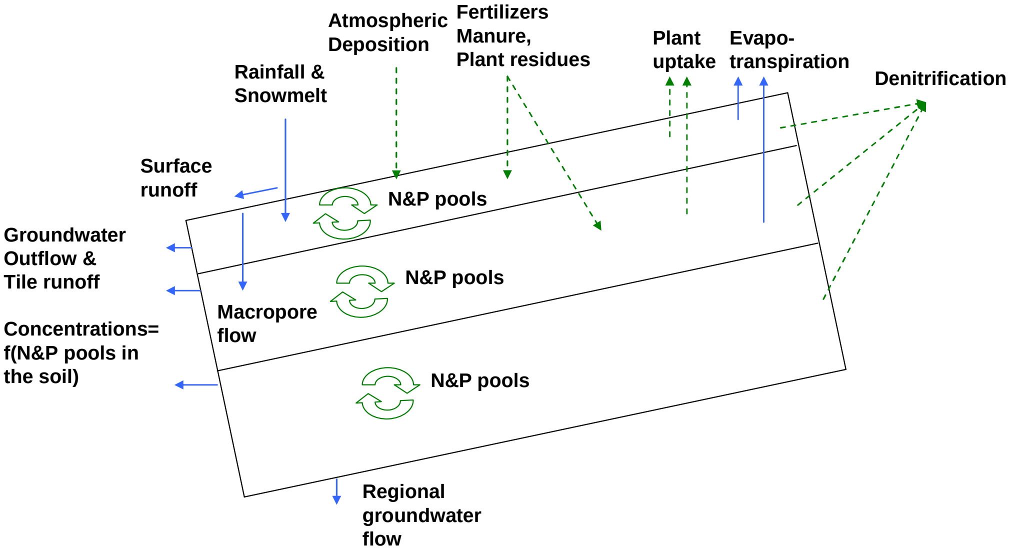

Figure 2. Schematic model structure within a class, i.e. a combination of a soil type and a crop, simulated using three soil layers. Solid and dashed arrows show fluxes of water and elements respectively.

Water

Snow conditions are simulated with a degree-day method, but with a temperature interval rather than a temperature threshold to simulate a gradual transition from snowfall to rainfall with increasing temperature. Rain and snowmelt can either infiltrate, form surface runoff or flow through macropores directly to the groundwater zone. Surface runoff can occur when the infiltration capacity is exceeded, or when the groundwater level reaches the ground surface. The total porosity in the soil is divided into water held below wilting point, plant available water, and drainable water in the largest pores. When the soil wetness exceeds field capacity (wilting point plus plant available water) the excess water percolates to the next layer, provided that there is available space there. Excess water in a layer can either percolate, drain into the stream or drainage tiles, or form regional groundwater flow. A maximum percolation capacity can be set for each layer. The groundwater level is an auxiliary variable, computed as a function of the soil wetness. It is assumed to be located in the lowest non-saturated layer, and is given by the fraction of the largest pore space that is filled by water.

Potential evapotranspiration is calculated from air temperature, with a degree-day coefficient that varies sinusoidally over the year. A given temperature results in a higher evaporation in spring than in autumn. Evaporation only takes place in the two uppermost soil layers, and the evaporation rate decreases exponentially with depth. A simple time delay and damping in rivers is simulated as a combination of a linear channel and a linear reservoir. The delay within a river is estimated using an approximate length of the river and a flow translation velocity. The outflow from lakes follows rating curves, or a simple regulation routine.

Nutrients

Crops are treated as different vegetation classes. To simplify, crops with similar characteristics can be grouped into crop groups such as pasture, autumn crops, spring crops and row crops. Crop husbandry data such as information on amount, timing and type of applied fertilizers are specified by the user along with information on for example sowing and harvest dates.

A number of sources and sinks of phosphorus (P) and nitrogen (N) are simulated (Fig. 2). Plant uptake is a sink determined by crop specific uptake functions. Inorganic and organic fertilisers are sources of N and P to the upper soil layers. Atmospheric deposition and crop residues returned to the soil are other sources of N and P. In addition, denitrification, a sink of nitrogen, is also simulated as a function of soil wetness, soil temperature and concentration of inorganic nitrogen in the soil. Eroded phosphorus from the soil due to heavy rainfall or surface runoff is a source of particulate phosphorus to the river.

Nitrogen and phosphorus in the different soil layers is divided into pools with different turn-over characteristics. Three nitrogen pools are simulated: a slow organic pool, a fast organic pool and a dissolved inorganic pool (IN pool). The concentration of dissolved organic nitrogen is linked to the amount of nitrogen in the fast organic nitrogen pool. For phosphorus, four pools are simulated: a slow organic P pool, a fast organic P pool, a soluble P pool (SP pool) and a pool with P adsorbed to mineral particles (partP pool). Nitrogen and phosphorus in the slow organic pools are transferred into the fast organic pools through a slow degradation process. Likewise, N and P in the fast organic pools are transferred into the IN and SP pools by mineralization. The transformation rates between these pools depend on soil temperature, soil wetness and the pool sizes. Phosphorus in the SP pool is assumed to be in dynamic equilibrium with phosphorus in the partP pool. Nutrient processes in rivers and lakes include sedimentation, resuspension, denitrification, mineralization and primary production.

PARAMETERIZATION AND INPUT DATA

The model was parameterized using hydrological and water quality observations from a large number of sites. Most of the parameters were calibrated manually. The reason for this is that the observations are sparse and highly variable in time, that there are many, interacting parameters and that the process representations are crude simplifications of a complex reality. All this makes it difficult to use automatic calibration. The water balance parameters were mainly estimated by calibrations to most of the unregulated basins in Sweden, smaller than 2000 km^2 (Rodhe at al., 2006). The water quality parameters were mainly calibrated using data from small agricultural basins (described by Kyllmar, 2004). Additional parameter estimation and tests of different parts of the model to observations of e.g. evaporation, snow depth, groundwater levels, lake water levels and ^{18}O were made for a number of basins in different parts of Sweden. The input data necessary to run the model was mainly collected from national data sets.

HYPE MODEL EVALUATIONS

The validity of the model and the parameters obtained above was tested by transferring the model to two independent test sites: Rivers Rönneå and Vindån. The River Rönneå is located in southern Sweden. The area of the drainage basin is approximately ~1900 km^2, here divided into 64 subbasins. The fraction of agricultural land is 31 %. The river outlet is located on the Swedish west coast. The Vindån system is located on the east coast of Sweden, and drains into the Baltic Sea. The basin area is 430 km^2, here divided into 88 subbasins. The fraction of agricultural land is 18 %. No local calibration was made, except for adjustments of lake parameters and soil depths, so these applications can be seen as almost independent evaluations.

Fig. 3 shows examples of streamflow and total nitrogen, TN (=IN+ON) from Rönneå, for two selected sites; the agriculturally dominated basin Heåkra and the mainly forested Klippan basin. Fig. 4 shows the same variables together with total phosphorus, TP, (=SP+PP) from Vindån, compared to campaign measurements gathered in the area. The agreement is reasonable, especially considering the fact that the model parameters were not optimised using these observations. The modelled streamflow in the two Rönneå basins is too attenuated, whereas the streamflow in Kvarnån is surprisingly good. The modelled streamflow in these small subbasins, without lakes, is determined by the division into classes, soil depths, soil layers and runoff parameters. The local conditions in Rönneå might differ from the average behaviour in the basins used in the parameterization above.

The average nutrient levels are simulated rather well at the different sites. The simulated nitrogen concentration in Heåkra has a very different pattern than the one in Klippan. The difference partly depends on how fluctuations in the ground water levels are modelled. At high flow the groundwater level reaches upper layers of the soil and runoff with higher concentrations of nutrients occurs. This is clearly the case in Heåkra (agricultural), but not that evident in Klippan (forested). Great differences in water quality and runoff coefficients, between different soil layers, can result in exaggerated variations in the simulated concentrations in agricultural lands. Forested areas, on the other hand, do not have this feature as only one soil layer is used there. The intensely monitored event in the spring of 2006, at the Vindån outlet to the sea, is captured well by the model, whereas the model missed another event with high nutrient concentrations half a year earlier.

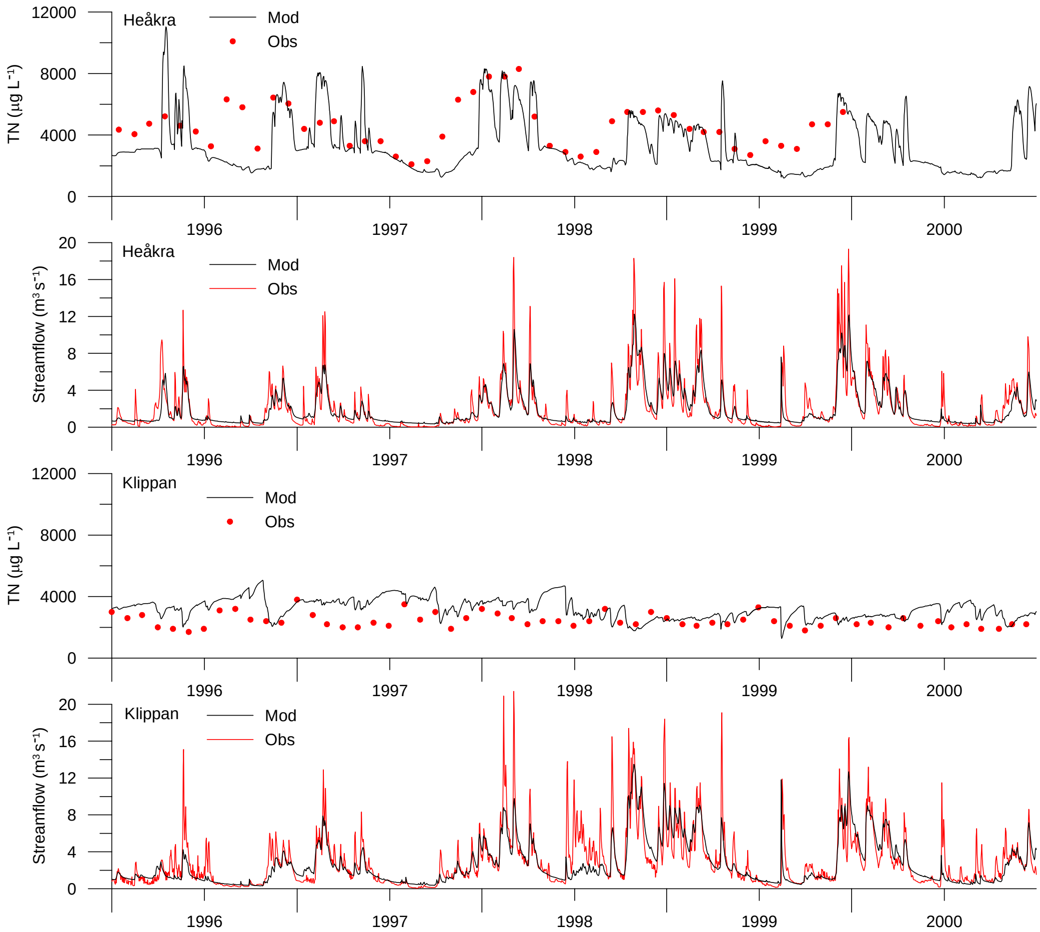

Figure 3. Examples of simulation results of streamflow and total nitrogen for two sites (the mainly agricultural Heåkra and the mainly forested Klippan basins) in the Rönneå River basin.

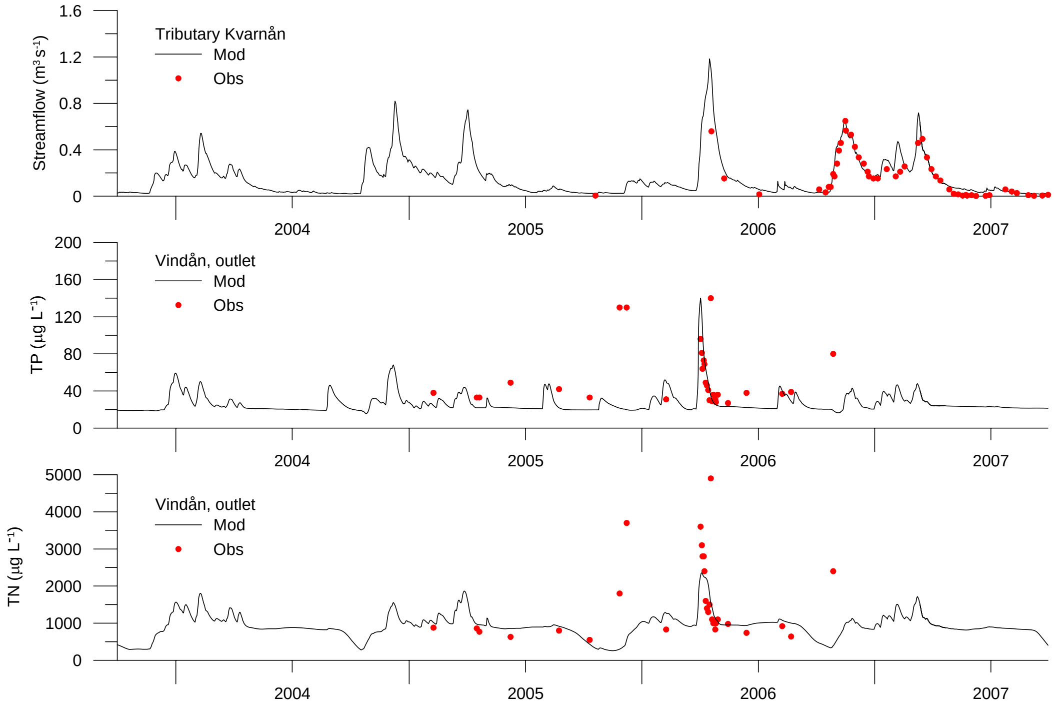

Figure 4. Examples of simulation results compared to campaign measurements from Vindån: streamflow in the tributary Kvarnån (top), total phosphorus (centre) and total nitrogen (bottom) at the outlet of Vindån into the Baltic Sea.

CONCLUSIONS AND FUTURE DEVELOPMENT

A first HYPE model version has been developed, containing simple descriptions of both water flow and coupled nutrient flow and transformation. The philosophy was to start as simple as possible and thereafter refine the model when needed, but at the same time try to maintain a consistent degree of complexity throughout the model. Different parts of the model have been tested in a large number of basins, and the tests in general support the validity of the model concept. The plan is to continue with a high-resolution application for all of Sweden, in a set-up of some 17000 subbasins, corresponding to a spatial resolution of about 25 km^2. It is likely that this application will help us to identify needs for further model improvement. With the large number of model parameters, more work has to be done on the parameterization and the handling of parameter uncertainty. The intention is that the model will be a realistic candidate for scenario analysis, rather than the one and only true model. An ensemble of models (e.g. Viney et al., 2005) should preferably be used if scenario simulations are to be used as the basis for important decisions.

ACKNOWLEDGEMENTS

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POSSIBILITIES TO IMPROVE THE SEDIMENT DEPOSITION IN THE NEMUNAS DELTA

Rimkus Alfonsas and Vaikasas Saulius

ABSTRACT

Sediment deposition in the inundated floodplains of rivers and particularly in their deltas improves the water quality of rivers and their receivers. Naturally, it would be very important to find the means to increase this possibility. The investigation of such possibilities was performed for the Nemunas delta. The influence of factors, which can change the sediment deposition, was studied. The factors are: the increase of water discharge flowing through the valley, growing bushes or wood, building of way banks across the valley and change of grass stage, i.e., of their ability to entrap the sediments. These problems are discussed and the most successful means for the Nemunas delta are proposed in the paper.

Keywords: sediment deposition, water contamination, hydraulics.

INTRODUCTION

In the river deltas, where the floods inundate the large floodplain areas, the flood-water leaves many deposited sediments with bioorganic matter and becomes much clearer. This improves the quality of water getting into the seas. It was estimated that during the period 1950 – 1981 about 250 t of potassium, 950 t of phosphorus and 147000 t of organic matter rich with nitrogen were deposited in the Nemunas delta. It did not get into the Curonian Lagoon and the Baltic Sea. The question arose, if it is possible to increase the sediment deposition in the delta areas even more.

There are two strips in the Nemunas delta (Fig. 1), where the floodwater overflows wide areas and investigation of which for increasing of sediment deposition is expedient. The lower strip is over the way to the city Rusnė. The floods overflow into this strip below the mouth of the river Veržė. The water flows into the upper strip at the hill Rambynas and returns back to the Nemunas together with the flow of the river Gėgė. The upper strip is more effective for sediment deposition than the lower one, as the valley is wide, and during the large floods almost half of the total flood discharge flows here.

Several factors, which can increase or decrease the sediment deposition in the floodplains were investigated. These factors are: the increase of water discharge flowing through the valley, growing of bushes or wood, building of way banks across the valley and change of grass stage, i.e., of their ability to entrap the sediments. It was estimated that the most effective means were to increase the discharge of water overflowing into the valley; consequently the amount of getting sediments and their deposition would increase.

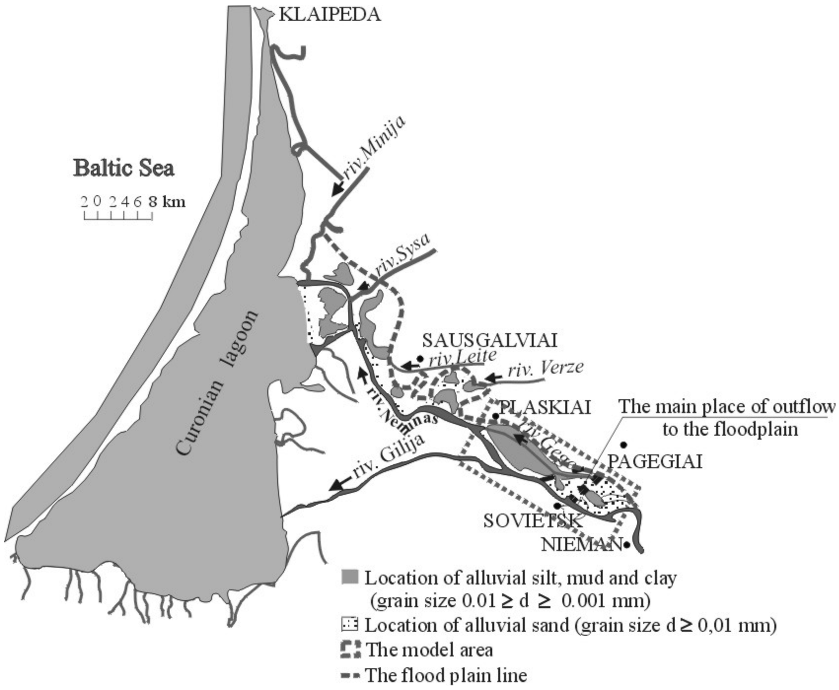

Figure 1. Floodplain of the Nemunas delta.

It is favourable for sediment deposition that the floodplain of delta is overgrown with grass. The other vegetation cannot be grown in the inundated areas as it could be washed. The sediments brought by the water flow between the grasses settle down quickly, as the water velocities between the grasses are low. Calculation of sediment deposition in flooded meadows according to formulas created for riverbed flow showed that the calculated amount of deposited sediments is several times less than the one measured by field investigations (Rimkus et al., 1999; Rimkus et al., 2004; 2007). That is because of grass ability to entrap and retain sediments brought by flow at its bottom. Sediment deposition over the grassland occurs even when the sediment concentration is quite low and in the cases when the flow velocities are high, if they are not yet bent significantly by strong flow. In the riverbeds with sandy bottom, the high flow velocity stops sediment deposition, as their concentration becomes transportable. The sediment deposition in the meadows depends on the state of grass. Luxuriant grasses can entrap the sediments more successfully. Therefore, sediment deposition during the floods will be more intensive, if more grown grasses would be left for winter.

The roadbeds built across the floodplains commonly decrease the sediment deposition in the valleys. They can pond the water flow overflowing into the valley consequently decreasing the discharge of water flowing through the floodplain. Besides the significant backwater areas are formed behind them, as water streams flowing through the bridge orifices widen slowly. Only a little amount of sediments can get and be settled in these backwater areas. The necessary new ways must be traced so that their negative influence would be minimal and that they would not pond the water flow significantly.

The possibilities to increase sediment deposition in the Nemunas delta reducing water flow velocity by growing of bushes or wood were investigated as well. However, it was estimated that it is not effective for grass-covered floodplains.

METHODS OF INVESTIGATION

The efficiency of investigated means for increasing sediment deposition in floodplains was estimated by calculation of deposited sediment amounts for the period 1950–1991, for which the hydrometric data about the sediment concentrations was available. During this time of investigations the periods with high and low floods were observed, then, sediments were accumulated on the bottom of the riverbed from year to year or washed and the main canal became shallower or deeper. The water levels during the floods were accordingly changing also. The discharge of water overflowing into the valley depends on these water levels. Consequently, during these periods the sediment deposition in the valley was also changing accordingly. The average data of sediment deposition was received by calculations for long period.

According to the calculations, during the high floods the riverbed below the places of water overflow in the valley was filled by sediments quite fully, as the flow velocity decreased there significantly, and the flow was not able to bring the sediments further. Such were the floods during 1951, 1958 and 1979. Water overflow into the valley and sediment deposition were then increased highly. During the sinking of flood and after that the accumulated sediment layer in this strip was quickly washed out and spread below. The water flow remained normal.

Sediment deposition calculations were performed for 4 sediment fractions found by the investigations. Their particle diameters were 0.005, 0.01, 0.02 and 0.1 mm. Those were the sediment particles from clay to fine sand. According to the investigations, the concentration of these sediment fractions fluctuated in large diapason – from 3 to 100 mg/l. They were accidental values, which depended on the conditions of ground washing from water catchment's fields during the melt of snow or during the storm rains. The really visible dependence of the concentration on the water discharge was not found. Therefore, the concentration close to the average one and equal to 20 mg/l was chosen for the calculations thus, more consideration was taken to the influence of flood size; the influence of accidental sediment concentration fluctuations was eliminated.

Sediment deposition intensity depends on the flood size. During the low floods, when small water discharge flows through the valley, all sediments brought into the valley are settled. With the growing of floods discharges a certain part of sediments is carried to the end of investigated valley interval and returned to the riverbed. For estimation of this process investigations were continued for a long time period.

Sediment deposition in the Nemunas valley was calculated applying our hydraulic-mathematical model "DELTA" created for the study of the Nemunas delta (Rimkus et al., 2004, 2007). For these investigations the model was supplemented for better estimation of peculiarities of being investigated variants. The known mathematical models (MIKE 21 1995) were not applicable for our work because they are not adapted for sediment deposition calculations in the flooded meadows, for which the special formulae are to be applied. The ability of grasses to entrap the sediment had already been noticed earlier (Bafield et all. 1979, Thornton et all, 1997, C. Deletic, 2001), however, sedimentation process in grassed food plains was not investigated properly yet.

The formula for calculation of sediment deposition in the grass-covered floodplain is created with estimation of grass ability to entrap the sediments. Because of the low flow velocity between the grasses, the sediment deposition in them becomes similar to the deposition in still water. It is proportional to the fall velocity of sediment particles and to the sediment concentration between the grasses, which is formed by concentration in the flow at the grass layer. Therefore, the sediment deposition into the unit of bottom area can be expressed as follows:

$$D = k_{cor} w C_b , \qquad (1)$$

where w – the fall velocity of sediment particles; C_b – sediment concentration at the flow bottom, i.e. at the surface of grass layer; k_{cor} – correction coefficient depending on the state of grasses (for the luxuriant grass it is greater).

The fall velocity of sediment particles depends mostly on their diameter. Sediment concentration in the flow is commonly expressed by the average concentration $\overline{C}$; therefore, it is necessary to estimate their ratio $F = \overline{C} / C_b$. Then formula (1) changes as follows:

$$D = k_{cor} w \overline{C} / F \qquad (2)$$

The following formula was derived for the calculation of ratio F:

$$F=\left(\frac{a}{h-a}\right)^{z}\left[\int_{a}^{h}\left(\frac{h-y}{y}\right)^{z} v_{y}dy\right]\cdot\frac{1}{\int_{a}^{h} v_{y}dy}, \quad z=\frac{w}{\beta k u_{*}}. \tag{3}$$

where h – water depth; y – distance of investigated point from the bottom: v_y – water velocity at the distance y from the bottom, a=0.3 h_{gr}; h_{gr} – thickness of grass layer; k=0.4 – Van Karman number; z – Rouse number; β – ratio of sediment and momentum diffusion coefficients, u_* – shear velocity.

Sediment deposition calculations were performed according to these formulae. Sediment deposition on the riverbed covered by sand formations occurs in a different way. It depends on the transportable concentration of the main canal stream. Sediment deposition begins when the sediment concentration becomes greater than the transportable one. In the case of deposition in the grass the concept of transportable concentration is not applicable, as grass entraps the sediments at any flow velocity. Consequently the evaluation of special formulae was needed.

INFLUENCE OF INCREASE OF WATER DISCHARGE OVERFLOWING IN THE VALLEY

It was estimated that for increasing of sediment deposition in the upper strip of the Nemunas delta, the most effective means were to increase water discharge overflowing into the valley. For this aim it would be useful to widen and deepen the place of natural overflow at the Pagėgiai settlement (Fig. 1). The natural overflow here was especially large in the case of ice hummock at the bridge of Tilžė town. The excavated channel here would increase water overflow and sediment deposition in the valley quite significantly. It was found that the widening of this overflow place is effective, because the water through the excavated channel flows into the lake Užlenkė, from which it spreads into the whole valley. But the deepening of the other wide overflow place below the railway is not so effective.

The attempt to widen the other existing nearly overflow places, e.g., the inflow into Malūnkalnis or Marižiogis, was also unsuccessful, as water flows further through narrow beds into the valley, which limits the conductivity. It is so, because the widening only of inflow from the Nemunas bed is not effective.

Attention to the possibility of channel excavation in this place was paid during the investigations for selection of the optimal trace of designed road round Tilžė town. It would be convenient to take the ground for the road dykes from the designed channel. Consequently, not only the negative influence of new roadbed for which the optimal trace was found would be avoided; conductivity of the valley would be increased as well. For the building of road dykes it would be necessary to use the ground from the channel with the width equal to 120 m and with the depth equal to 2 m.

The channel was modelled with various measurements of its cross section and the amount of settled sediments in the valley was estimated. Variants with several width and depth values were calculated. The results of calculations, i.e. the average amounts of sediments during one year are presented in Fig. 2.

As one can see, increasing the channel width up to 50-100 m results in the growth of sediment deposition proportionally to it. With further growth of the channel width the growth of sediment deposition is slower.

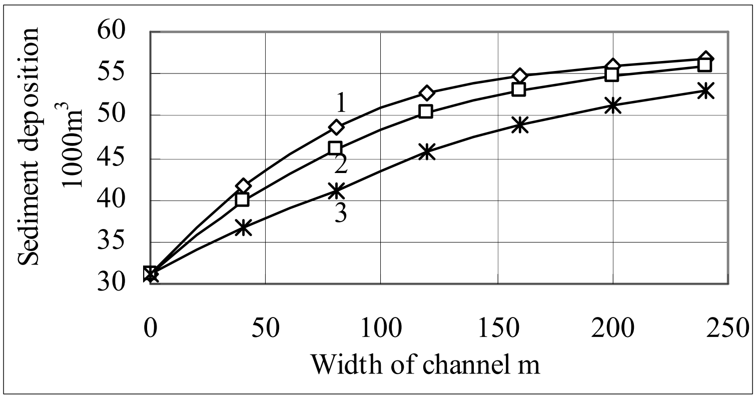

Figure 2. Dependence of average amount of sediments settled during one year on width of channel, when depth of channel is: 1 – 3.0 m, 2 – 2.5 m, 3 – 2.0 m.

When the channel depth is 2.0 m and the width – 150 m, the arrangement of the channel increases the deposition by 53% and the widening up to 240 m – 71%. The channel with the depth of 2.5 m increases the sediment deposition by 70% and 85% accordingly. Deepening of the channel to 3.0 m increases the sediment deposition less. However, deepening of the channel increases his cross-section more than the widening, therefore, its deepening to 3.0 m ensures the desirable sediment deposition with the less volume of excavated ground.

If it were desirable to increase sediment deposition by 50%, (according to graphs in Fig. 2 from 31100 to 46700 m^3) then from these graphs we find that, when the channel depth is 3, 2.5 or 3.0 m, it would be necessary to have 85, 119 and 181 m width of the channel accordingly. The ground volume that needs to be excavated from the channel would be 212000, 298000 and 452000 m^3 in this case. As one can see, the minimum volume is received when the channel depth is 3.0 m. It is somewhat greater for the depth of 2.5 m and still much greater, if the chosen depth is equal to 2.0 m. These dependences are shown in Fig. 4.

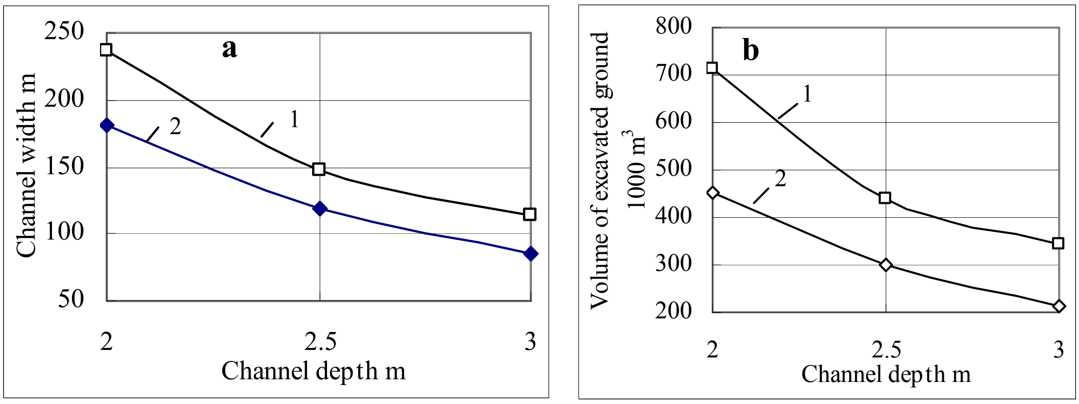

Figure 3. The necessary channel width (graphs a) and the ground volumes, necessary to excavate from the channel, (graphs b) dependences on the channel depth, when the desirable increase of sediment deposition in the valley after arrangement of channel is: 1 – 70% 2 – 50%.

If the desirable increase of sediment deposition was 70%, then the necessary width of the channel would be 114, 147 and 237 m^3 accordingly and the ground volumes being excavated from the channel – 312000, 441000 and 711000 m^3. As one can see, increasing of sediment deposition required much greater excavated ground volumes. The most acceptable is a deeper channel. For the shallow channel greater excavated volumes are necessary, therefore, shallow channels are less acceptable. But still deeper channels could be often flooded during summer and autumn floods, which is not useful for the exploitation of meadows in the channel area.

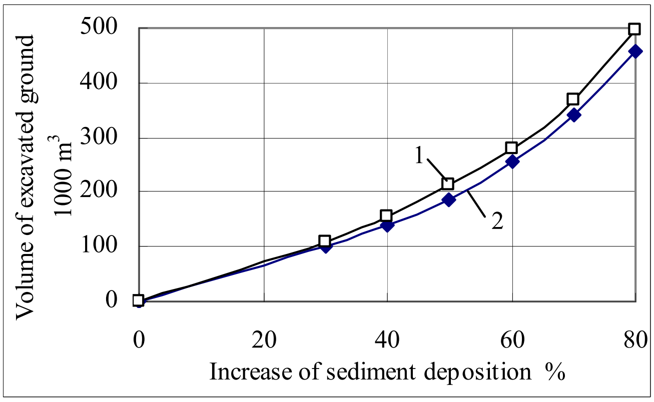

Figure 4. Dependence of ground excavated from 1 meter of channel length on the desirable increase of sediment deposition in the valley: 1 – when channel depth is 2.5 m; 2 – when channel depth is 3.0 m

Fig. 4 presents the dependence of the ground volumes required to be excavated to have the desirable increase of sediment deposition. As one can see, the necessary excavating growth is more intensive when the desirable sediment deposition is increased to 70-80%. Therefore, the most rational increasing of sediment deposition will be up to 50-70%. Choosing of the variant will depend on available financing and on the possibility to apply the excavated ground usefully. Naturally, it would be the most economic, if the excavated ground was used for certain needs, as for building of new roads or protective dykes. Then the direct expenses would be necessary only for the arrangement of meadows for protection of the channel from washing by water flow. These needs can appear with the time, therefore, at the beginning the channel can be made narrower and be widened, when new needs appear.

Deepening of water overflow place below the railway bridge can also increase the water overflow into the valley to some extent. The natural width of this overflow is about 800 m. The increase of sediment deposition was calculated after its deepening by 1 m. It could be useful after deepening of water overflow in Panemunė. However, the additional sediment deposition increase according to the calculations was about 10% only. That is because of less favourable conditions in the valley for further flow widening. In addition, this would supply the shorter strip of the valley with water, what would decrease its deepening effect. The ground volume necessary to excavate would be 2 times greater than in Panemunė. Consequently, deepening of this overflow place will surely be unacceptable.

The grass sowing on the bottom and slopes of the channel is the most necessary for the safeguarding from washing by water flow. The calculated average flow velocities, developing in the channel, are shown in Fig. 5.

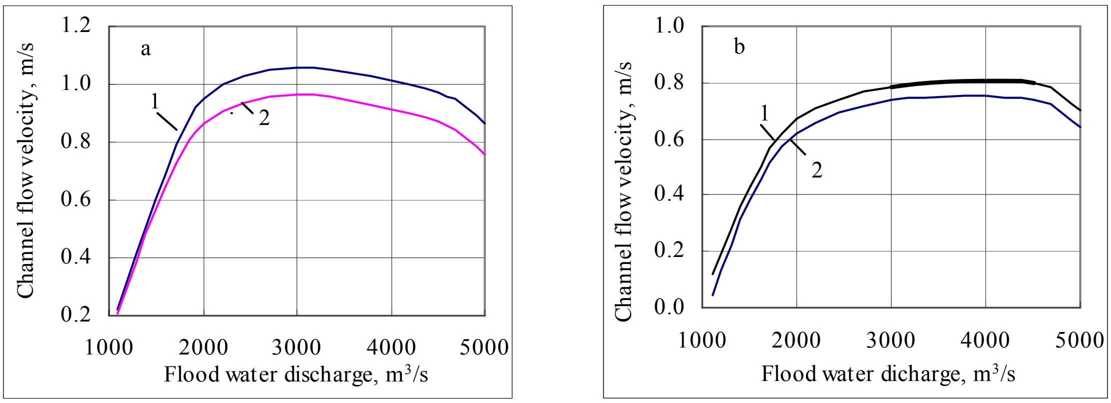

Figure 5. Water velocities developing in the channel, when its depth is: a – 3 m; b – 2.5 m and when the width of channel is: 1 – 100 m, 2 – 160 m.

When the flood is low and little water discharges flow through the channel, the flow velocities are low. With the increase of floods they increase as well. However, during large floods, when water levels are very high, the cannel is dammed and the flow velocities begin to decrease there.

The maximum flow velocities in the channel develop, when the floodwater discharge is 2500 – 4000 m^3/s. They reach about 1 m/s. Such velocities are permissible, when the channel bottom is cowered by grass. The velocities are higher in deeper channels, and some decrease with the increase of their width.

INFLUENCE OF TREE GROWING AND ROAD DYKES BUILDING

Bushes and woods reduce velocity of the flow in the valley. Decreasing of flow velocities in the riverbed commonly increases sediment deposition. However, in the valleys overgrown with grass this means is not effective, as the water flow in the valleys is slow, grasses are not bent and may entrap sediment irrespectively to the flow velocity. In this case, if the water depth is increased by flow deceleration too much, it can pond the water inflow into the valley and decrease sediment flow rate deposited. That is shown by the calculation data placed in Fig. 7.

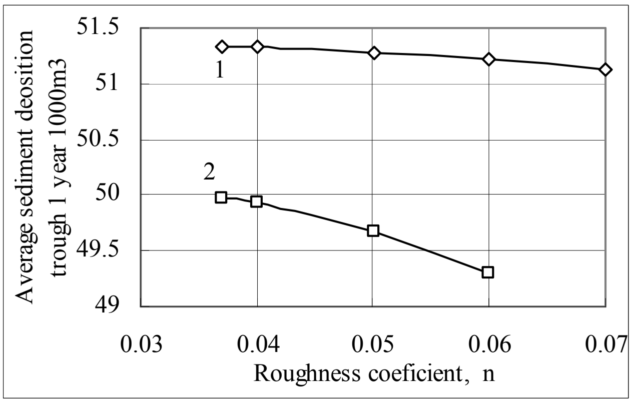

Figure 6. Influence of the reserve road dyke existence and growing of bush or wood strips in the valley on sediment deposition in the valley, when: 1 – the reserve road dyke is absent; 2 – the dyke exists.

The railway and highway banks are traced through the Nemunas delta. It is built also the reserve road dyke, which is not necessary now. The influence of bushes and wood growing was calculated in the cases, when the reserve road dyke exists or is dug up. As one can see from Fig. 6, the deposition of sediments increases after the dyke removal by nearly 2%. It is not a large change, however, the dyke could be removed.

The dykes of railway and highway decrease sediment deposition more significantly (about 30%), as they are not far from the main water overflow in the valley and pond it. It should be noted, that the excavation of the channel in Panemunė compensates this negative influence and still increases the conductivity of the valley.

Growing of bushes or wood in the strips of the valley, when the reserve road dyke exists, increases the pond of flow even more and decreases sediment deposition. When this road is absent, bushes do not decrease sediment deposition, if the hydraulic roughness coefficient of the valley strip is not increased more than 0.050. However, a further increase of roughness begins to pond the inflow of water and decreases sediment deposition. Therefore, growing of bushes and trees in small areas do not decrease sediment deposition.

CONCLUSIONS

Sediment deposition in the valley of the river Nemunas can be increased by excavation of a channel through the place of natural water overflow to the valley at the settlement of Panemunė. The optimal depth of this channel is 2.5 – 3.0 m. The necessary width of the channel will depend on the desirable increase of sediment deposition and can reach 150 – 170 m.

A possibility to increase sediment deposition will depend on available funding and on a possibility to use excavated ground for certain objects, e.g., for building of new roads or protecting dykes.

Growing of bushes or wood in the strips of the floodplain does not increase sediment deposition. The deposition could be even decreased, if they were too thick and could pond the inflow of water into the valley.

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THE HOME WATER MODELLING SYSTEM INTRODUCED IN DENMARK

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ABSTRACT

The HOME Water modeling system is developed by the Swedish Meteorological and Hydrological Institute (SMHI) and able to simulate water quality parameters in water bodies, e.g. nitrogen and phosphorous concentrations, mass transport and the corresponding ecological status in the affected water bodies. The model system is an effective and useful tool in implementing the Water Framework Directive requirements in the Swedish water planning and administration. The HOME water model system has been introduced in Denmark in 2008 and tested in the Nivå catchment area and coastal zone of the Nivå Bugt in order to customize the functionalities to Danish conditions and context. Furthermore, the model has been refined with environmental economic applications facilitating estimates for cost-effective interventions and related impact on the ecological status of the water bodies. This paper contains a brief description of the test of the HOME to Danish conditions.

DESCRIPTION OF NIVÅ

The Nivå catchment area is located at Zeeland. The coastal area of Nivå Bugt interacts with the Øresund (the Sound). The catchment area is 183.5 km^2. The run off is roughly divided into the main rivers of the *Nivå* and the *Usserød Å* draining the northern and the southern part, respectively (see figure 1). The northern part is characterized by forest and agriculture land use patterns while the southern part is mainly urbanised having numerous outlets from storm water drains and a major wastewater treatment plant. The major lake *Sjælsø* is used for water abstraction and located in the southern part. Furthermore two minor lakes are located in the area (Little and Great Donse Dam). The main catchment area and the Nivå Bugt have been divided into 17 sub catchments and 4 sub basins in the model set up (see figure 2).

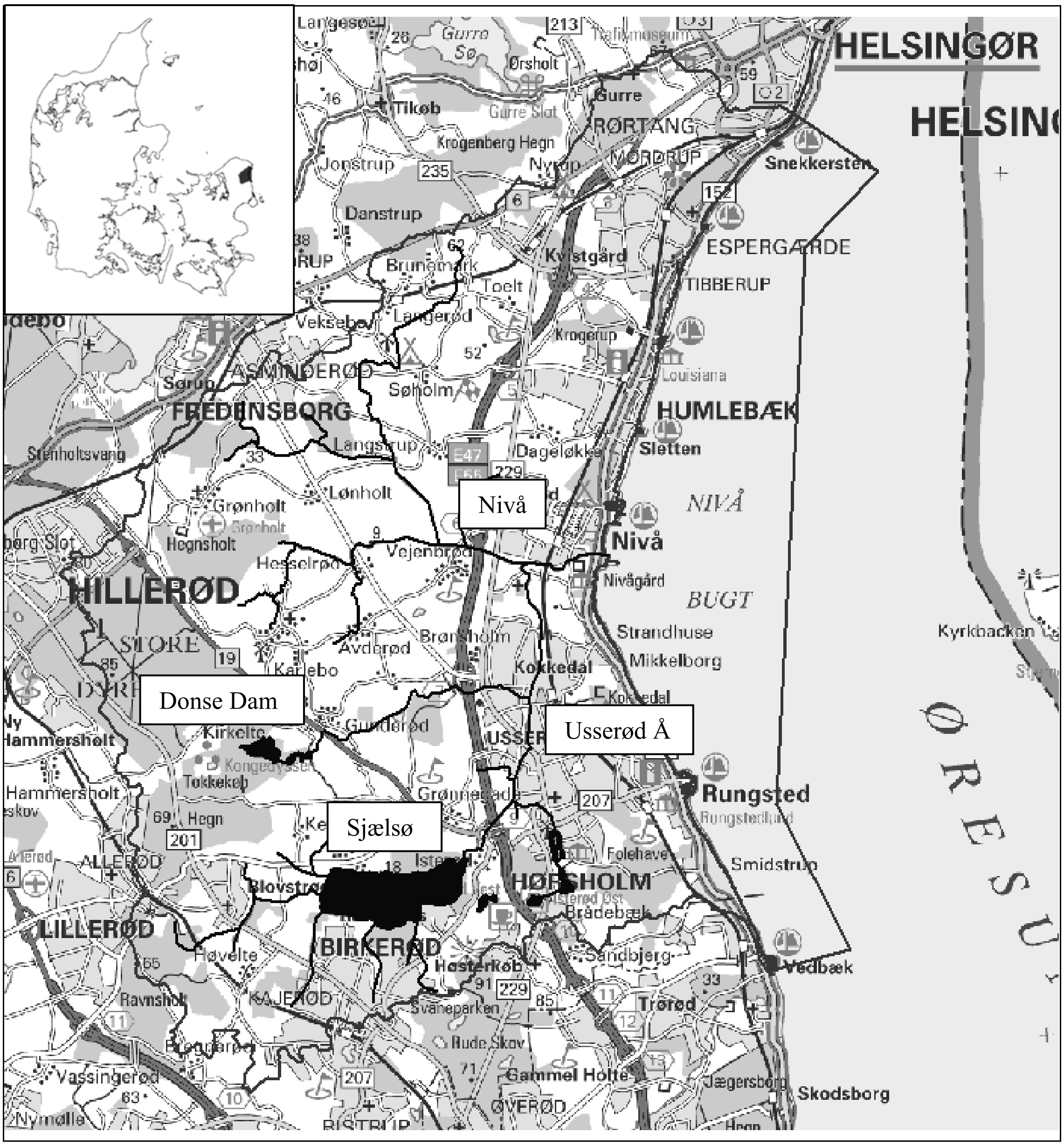

Figure 1. Nivå catchment and bay.

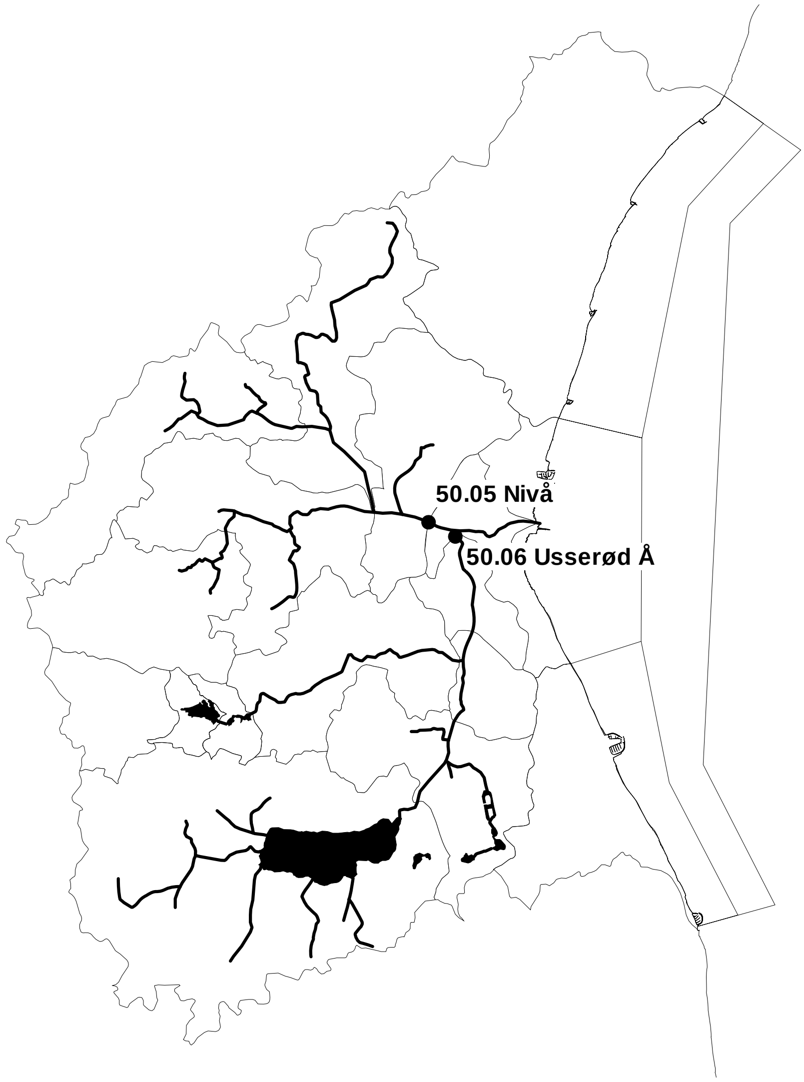

Figure 2. Sub catchments/basins and gauging stations.

THE MODEL SYSTEM

The HOME Water model includes the HBV-NP model, Pers 2007, and a biogeochemical coastal zone model, Marmefelt 1999. The HBV-NP model calculates the net load of nitrogen and phosphorous to the sea on a daily basis, which is used as input to the coastal zone model. The coastal model simulates the redistribution of nutrients between confined coastal water bodies. The coastal zone model also interacts with a large-scale open sea biogeochemical model simulating nutrient exchange between the open sea and the coastal zone.

Input data and sources of information

The majority of data required for the model set up is available from open data sources, e.g.

- GIS data: Catchments, rivers, lakes, coastal boundaries and bathymetry
- Land use from AIS (Area Information System)

- Air temperature on daily basis for each sub catchment, DMI
- Precipitation on daily basis for each sub catchment, DMI
- Climatic data for the coastal zone model, SMHI
- Atmospheric deposition of nitrogen and phosphor, SMHI
- Crops on fields from Plantedirektoratet 2002
- Diffuse root zone leakage concentration, SMHI
- Nutrient loads from treatment plants, storm water and rural households from municipalities wastewater plans 2004

Calibration

The hydrological parameters and retention processes are calibrated using the HBV-NP model, Pers 2007, starting with the hydrological parameters and continuing with parameters describing the retention of nutrients in the groundwater zone. In the Nivå catchment area two gauging stations are used for measuring flow and water quality, one in Nivå and one in Usserød Å. The groundwater and river retention has been calibrated using the Nivå conditions considering that no sink in terms of lakes and wetlands are present in this part. Then the calibrated parameters were extrapolated to the entire catchment area. Next, parameters describing the retention of nutrients in rivers and lakes were calibrated in Usserød Å catchment. The measured hydrological parameters and the nutrients variability fits very well to the simulated variation – see figure 3. Especially nitrogen has been calibrated well, with an explanation of more than 88% and 70% of the measured daily variation in run off and nitrogen respectively.

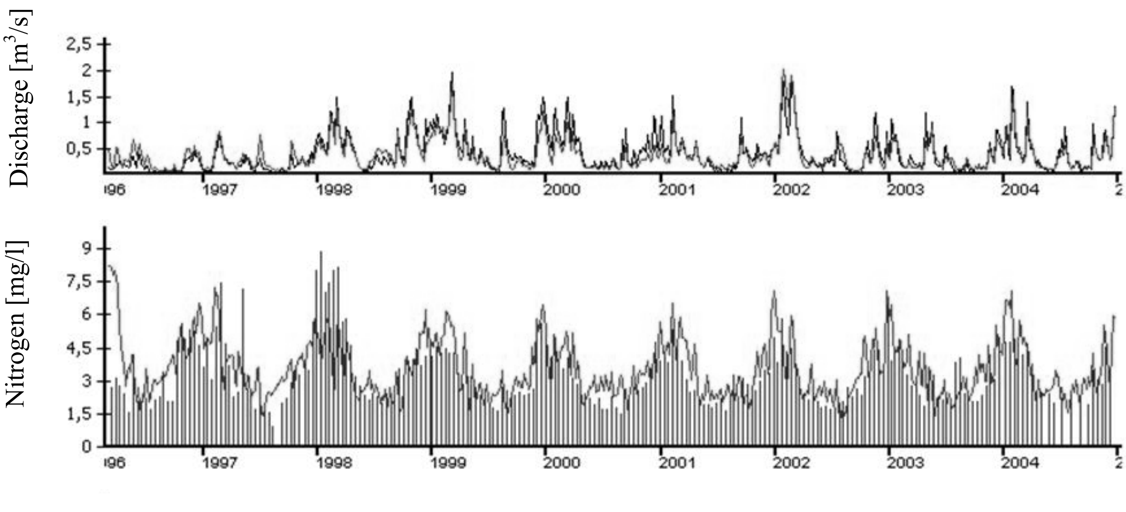

Figure 3. Measured (black) and simulated (grey and columns) discharge and nitrogen concentration in Nivå.

Also the phosphorus concentration was calibrated, see figure 4.

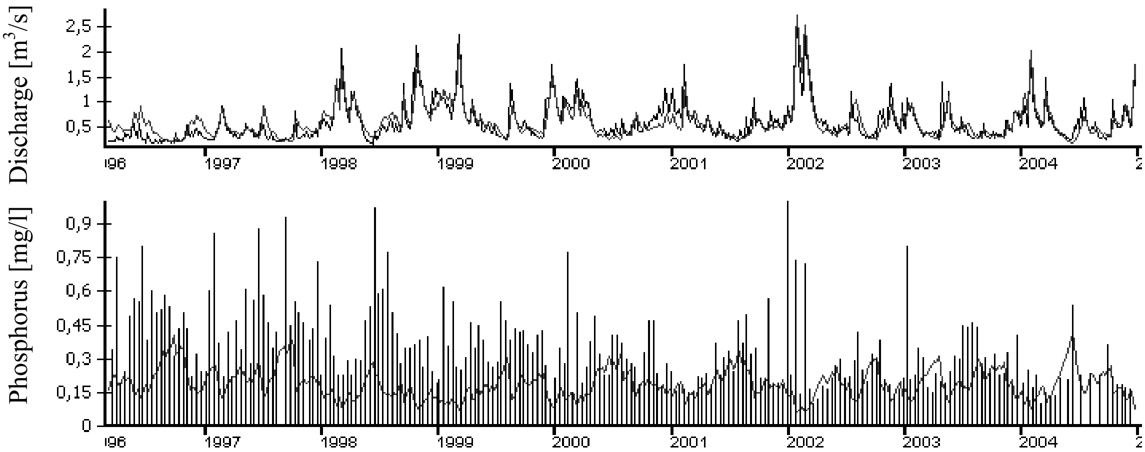

Figure 4. Measured (black) and simulated (grey and columns) discharge and phosphorus concentration in Usserød Å.

Coastal water bodies receiving water and nutrient loads from the inland areas as well as the exchange from the open sea are described using the HBV-NP model, Pers 2007. The exchange of water and nutrients between the coastal water bodies is determined by meteorological conditions and the cross-sectional area between adjacent water bodies. The physical processes within the coastal zone are described by the model PROBE, whereas biogeochemical processes are described by the model SCOBI, Marmefelt 1999. Also the coastal zone models have been calibrated according to the measurement with a very good result.

RESULTS

Subsequently, the calibrated models have been used to simulate several scenarios of impacts from interventions in the catchment area from the most extreme situation with 'Background conditions without any human impacts', Baseline 2015 (all planned and agreed wastewater investments have been accomplished) and a suite of additional interventions e.g.

- Increased coverage of forestry and decreased agriculture rotation
- Wetlands established
- Green fallow

The scenarios have been chosen to evaluate the effect of typical intervention means according to the Danish conditions.

Users log on to the HOME Water modelling system using a regular PC connected to the internet (https://home-vatten.smhi.se/homevatten/home.do). A username and password is required. The user then selects the geographical area where s/he would like to analyse the interventions from a list of pre-selected areas. Following the area selection, two different views are offered:

“Scenario definition” and “Simulations”. The first view is used to make changes in input data, to design an alternative intervention programme, prior to running a scenario simulation, whereas the second view is used to start simulations and to explore the results of earlier simulations. Both the loads and the ecological status can be explored, and the environmental economy impact can be explored in designing the most cost-effective programme as required in the WFD in the near future.

Figure 5 and 6 show a screen dump of the HOME presentation features. The nitrogen loads to Nivå Bay and the resulting ecological status according the Swedish limits and normal condition. The Danish limits will be described according to the depth limits of the eel grass (*Zostera marina*) and nitrogen concentration in the coastal area.

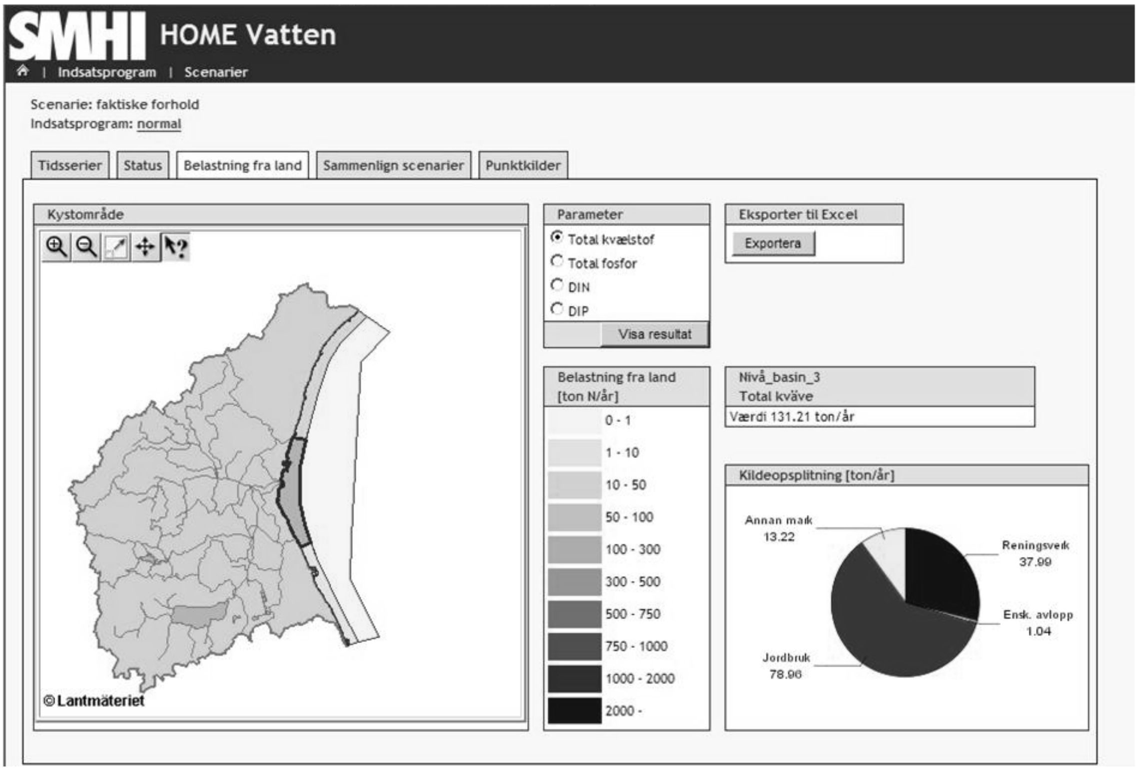

Figure 5. Screen dump from HOME (example is in Swedish). The net annual average load of total nitrogen to Nivå Bay sub basins is shown to the left in tonne N/year. The load from land is 131.21 tonne N/year to the middle sub-basin. Source chart of loads is shown to the right.

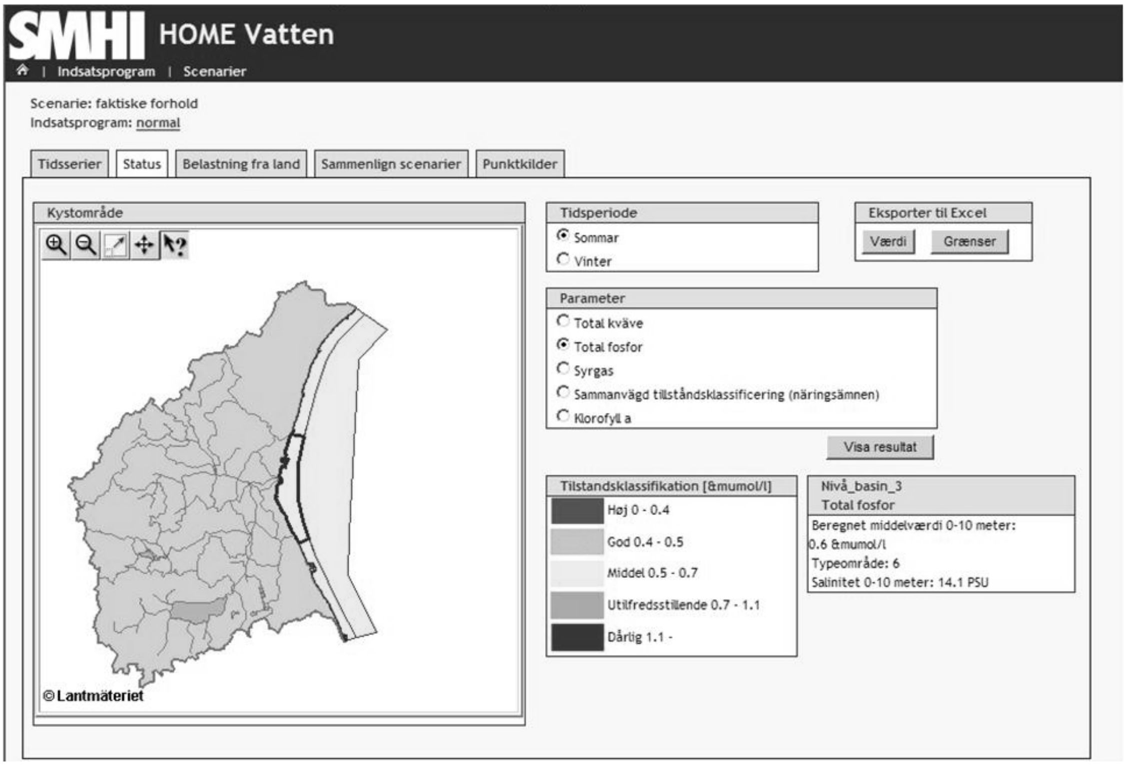

Figure 6. Screen dump from HOME (example in Swedish). Ecological status of Nivå Bay (middle part of the bay marked with full line) according to the Swedish limits referring to summer condition and phosphorus is shown to the left. The limits of high, good, mean, poor and bad condition are shown to the right in combination with the calculated condition.

Figure 7 shows the simulated scenarios and the total nitrogen loads to Nivå Bay. The figure indicates that the load without antropogene activity was about 25% of the load by normal conditions (today) with respect to nitrogen. Scenario 3 forests, 4 green fallow and 5 wetlands, reduce the nitrogen load according to normal.

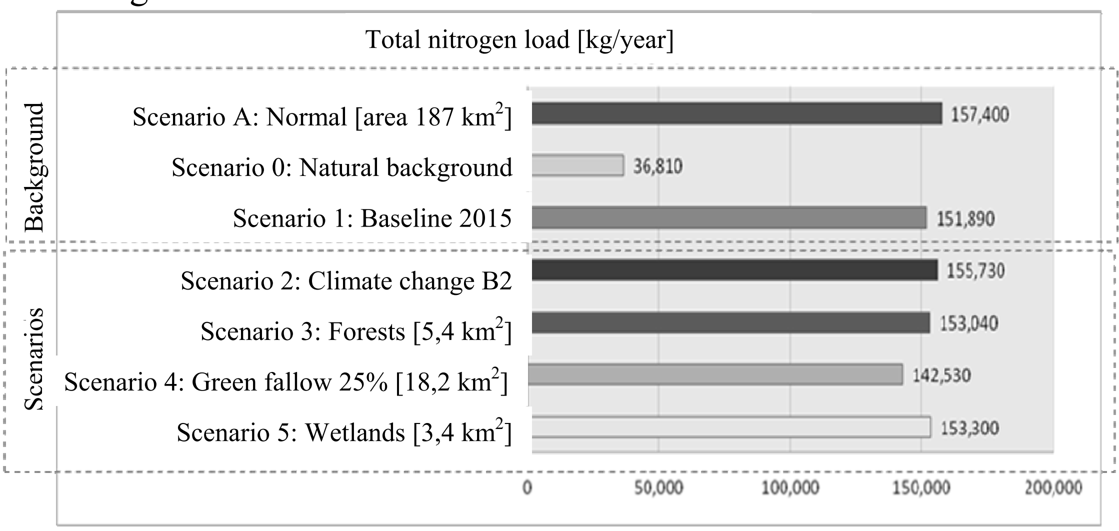

Figure 7. Nitrogen loads to Nivå Bay, in total.

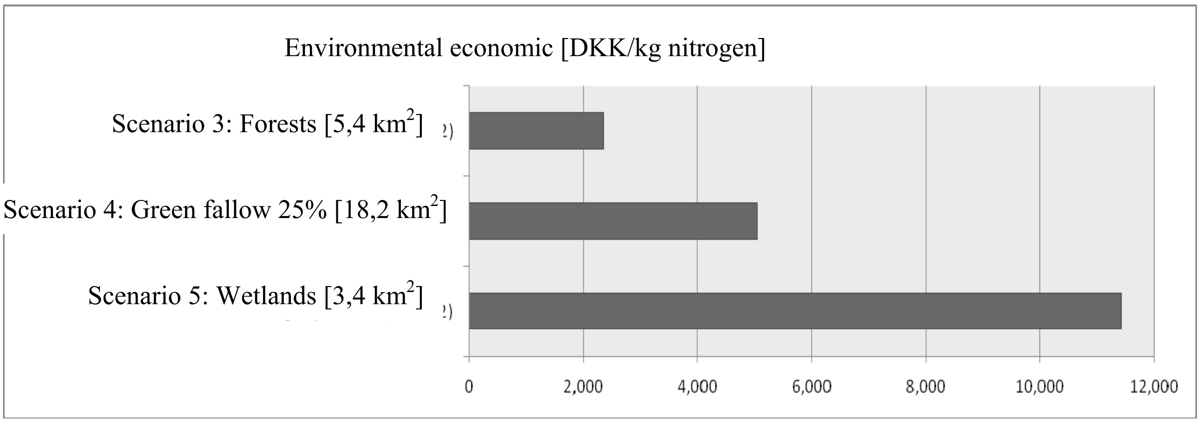

Figure 8. Environmental economic impact of various interventions.

Figure 8 shows the environmental economic impact where the cost effectiveness of interventions is indicated. The figure shows that it is most cost-efficient to raise forests and most expensive to make wetlands.

DISCUSSION AND CONCLUSIONS

The HOME Water model system was found capable of simulating the Danish conditions related to the hydrology and nutrient cycle. Especially nitrogen was simulated very well in the natural catchment Nivå, see figure 3. The phosphorus cycle, especially in the urban catchment of Usserød Å was more dynamic and difficult to simulate in the model. Figure 4 shows the phosphorus calibration of Usserød Å catchment. It should be noted that the input data only represent the 2004 situation. A decreasing trend in recent years in phosphorous load is likely which influence the calibration result.

The HOME Water system offers multiple tools for analyzing the nutrient status of both inland and coastal water bodies, set up intervention programmes and simulate several scenarios within a short time (several years can be simulated in 3-4 minutes, both inland and coastal waters). Users can access the system from a regular PC via a web interface, thus the system fulfil the WFD intention to involve end-users in the process to set up remedies to improve the ecological conditions.

The overall conclusion is that HOME Water is very useful in a Danish context to simulate conditions in the water and nutrient cycle for several scenarios describing intervention programmes.

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MORE BANG FOR THE BUCK?
IDENTIFYING COST-EFFICIENT WATER QUALITY REMEDIES USING THE HOME WATER MODELLING SYSTEM

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ABSTRACT

Member states within the European Union have been committed by the Water Framework Directive to classify all inland and coastal water bodies according to their ecological status. In Sweden alone, the number of water bodies now surpasses 17 000, making classification based on field measurements difficult and expensive. An alternative approach is to use models for estimating ecological status. The HOME Water modelling system has been developed by the Swedish Meteorological and Hydrological Institute to simulate some of the water quality parameters that dictate ecological status, especially nitrogen and phosphorous transport. Users access the system through a web interface, which offers several tools to examine the fate and transport of nutrient loads from inland to coastal water bodies. The user can also define different scenarios, e.g. land use changes or changes in point source pollutant loads, and simulate the outcome of these scenarios to identify cost-efficient remedies. The HOME Water modelling system is also an effective tool for communicating water quality related problems to the general public, and to visualize how remedial measures taken by different polluters each can contribute to the fulfilments of water quality goals.

Keywords: Water quality model, ecological status, nitrogen, phosphorous, scenarios, cost-efficient remedies.

INTRODUCTION

How can we identify the most cost-efficient means of improving water quality? This question has received increased attention by water authorities in EU member states since the ratification of the Water Framework Directive.

Many water bodies already fail to meet the classification standards of an ecologically good status, or risk a deteriorating water quality in the near future. This study presents the development of a tool for water quality managers which can be used to classify inland and coastal water bodies according to their nutrient levels, and also to study the impact of different scenarios. At present, the development of the system focuses on merging tools from environmental economics with the nutrient transport models in order to optimize cost-efficient remedies.

The HOME (Hydrology, Oceanography and Meteorology for the Environment) Water modelling system is a system of coupled water quality models that has been developed by the SMHI (Swedish Meteorological and Hydrological Institute). Nutrient levels in inland fresh water systems are modelled using the HBV-NP model (Pers, 2007), and nutrient levels in coastal areas are modelled using the coastal zone model (Marmefelt et al., 1999). Personnel at SMHI set up, calibrate and maintain the models, and users access the system through an interactive web interface (Fig. 1). The philosophy is to make complex models available to users who lack experience or resources for setting up, calibrating and maintaining models, but still need direct access to models in their daily work. The interactive web-interface has been developed through a continuous dialogue with managers at water authorities in Sweden in order to meet current needs and priorities.

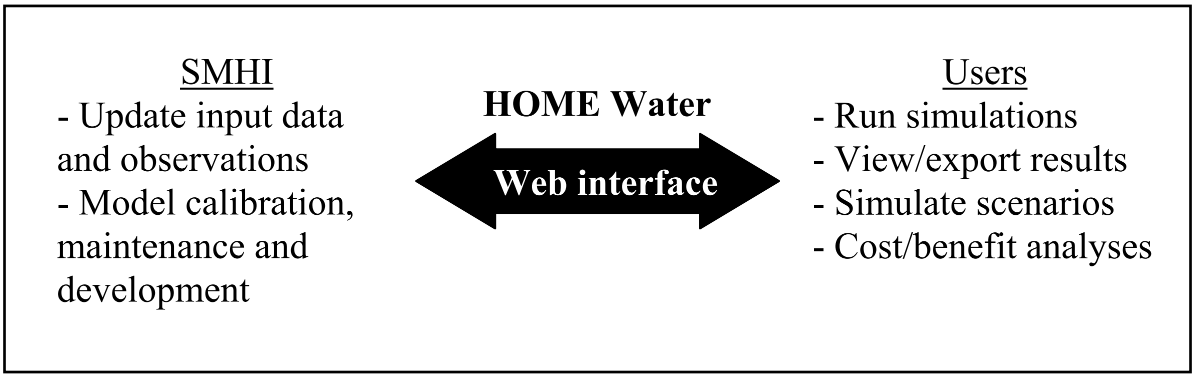

Figure 1. Conceptual overview of the HOME Water modelling system. Services provided by the SMHI are listed on the left side and functions offered to users through the web interface are listed on the right side.

In the following section we will give a brief description of the different models included by the HOME Water modelling system and the input data required to run the system at the national scale in Sweden. Next, we provide some examples of using the interactive web interface from the Östergötland region in Sweden. Finally, we discuss the merits of the present system and outline areas of future development, including the adaptation of the HOME Water system to methods in environmental economics to identify cost-efficient means of reducing nutrient levels.

METHODS

The HOME Water models include the HBV-NP model, which is an adaptation of the HBV hydrologic model for simulating nutrient transport and retention in fresh waters (Pers, 2007), and a biogeochemical coastal zone model (Marmefelt et al., 1999). The HBV-NP model calculates the net load of nitrogen and phosphorous to the sea on a daily time-step, which is then used as input to the coastal zone model to simulate the redistribution of nutrients between coastal water bodies. The coastal zone model also interacts with a large-scale open sea biogeochemical model to simulate nutrient exchange between the open sea and the coast.

Input data

Climatic data used to drive the HBV-NP model is provided through the PTHBV database, which is a daily interpolated 4*4 km grid of precipitation and temperature measurements for all of Sweden. Climatic data for the coastal zone model is supplied by a larger-scale meteorological database with a grid resolution of 1*1° but a time-step of 3 hours.

The MATCH (Multiscale Atmospheric Transport and CHemistry model) atmospheric model is used to calculate the monthly atmospheric deposition of nitrogen, but the model itself is not implemented in the HOME Water system. The atmospheric deposition of phosphorous is estimated from measurements. The diffuse soil leakage concentration has been estimated for different land-uses from field measurements (e.g., for forested areas) and by the use of field-scale models SOILNDB for nitrogen and ICECREAM for phosphorus. These models calculate average leakage concentrations for different combination of crops and management practices for arable land. Other input data include nutrient loads from soil erosion, stormwater systems, rural households, industries, and wastewater treatment plants.

Calibration

Both hydrology and retention processes must be calibrated within the HBV-NP model. During the HELCOM PLC5 (Pollution Load Compilation) mission in 2007, the model was set up and calibrated for 1200 subbasins in Sweden (see Brandt et al., 2008; Brandt, Ejhed and Rapp, 2008). First, the parameters describing the retention of nutrients in the groundwater zone were calibrated first using observations from small catchments without lakes distributed around the country. The calibrated parameters were then regionalized to cover all of Sweden. Next, parameters describing the retention of nutrients in rivers and lakes were calibrated and regionalized using observations from larger subbasins with lakes. The results were verified using river mouth observations which had not been used in the calibration process. To sum up the results from the validation, the simulated annual discharge deviated from interpolated observed discharge by +1%, the total annual net transport of nitrogen to the coast deviated from the interpolated measurements by -3%, and the total annual net transport of phosphorous to the coast deviated from the interpolated measurements by -25% (Brandt and Ejhed, 2008).

Coastal water bodies receive water and nutrients both from inland areas, as described by the HBV-NP model, and also from the open sea, as described by the coastal zone model. The exchange of water and nutrients between coastal water bodies is determined by climatic forcing and by the cross-sectional area between adjacent water bodies. The physical processes within the coastal zone model are described by the model PROBE, wheras biogeochemical processes are described by the model SCOBI (Marmefelt et al., 1999).

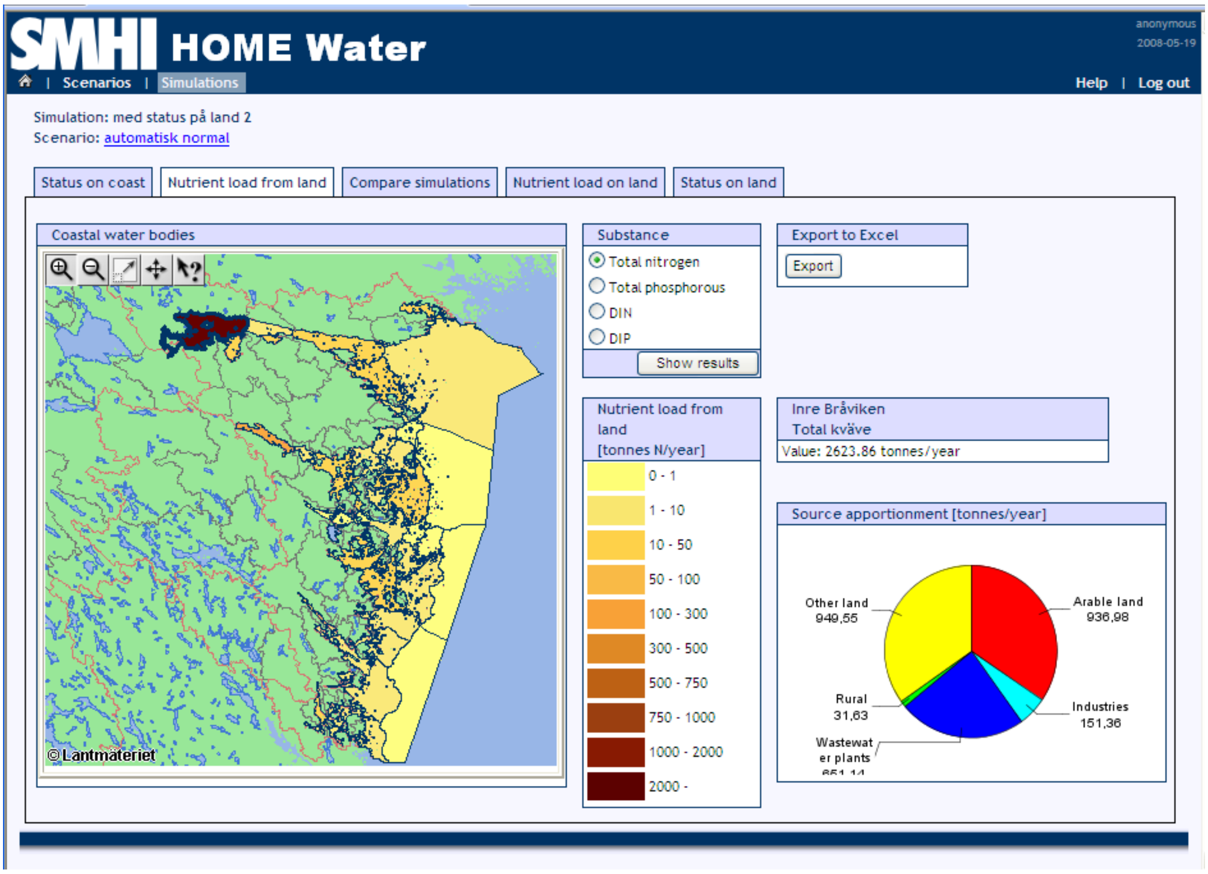

Figure 2. Example view from the HOME Water web interface showing the net annual average load of total nitrogen to water bodies along the coast of Östergötland, together with the source apportionment for one selected coastal water body.

RESULTS

Users log on to the HOME Water modelling system using a regular PC connected to the internet (https://home-vatten.smhi.se/homevatten/home.do). A username and password is required. The user then selects the geographical area where s/he would like to work with from a list of available areas.

Following the area selection, two different views are offered: “Scenarios” and “Simulations”. The first view is used to make changes in input data prior to running a simulation, whereas the second view is used to start simulations and to explore the results of earlier simulations. Two simulations have already been modelled from the start: a “normal” simulation and a “background” simulation (estimating natural conditions without anthropogenic loads). The planning of remedial measures often start with a detailed analysis and comparison of these two conditions.

Improving water quality along the coast of Östergötland

The coast of Östergötland in southeastern Sweden is divided into 45 coastal water bodies within the coastal zone model. The land area that drains along this coast is divided into 133 subbasins within the HBV-NP model, and this area is dominated by the Motala Ström watershed (15 480 km^2) which drains into the coastal water body Inre Bråviken (selected in Fig. 2). In order to demonstrate the capability of the HOME Water system to simulate scenarios the example discussed below focuses on nitrogen transport, but similar functions exist for phosphorous transport.

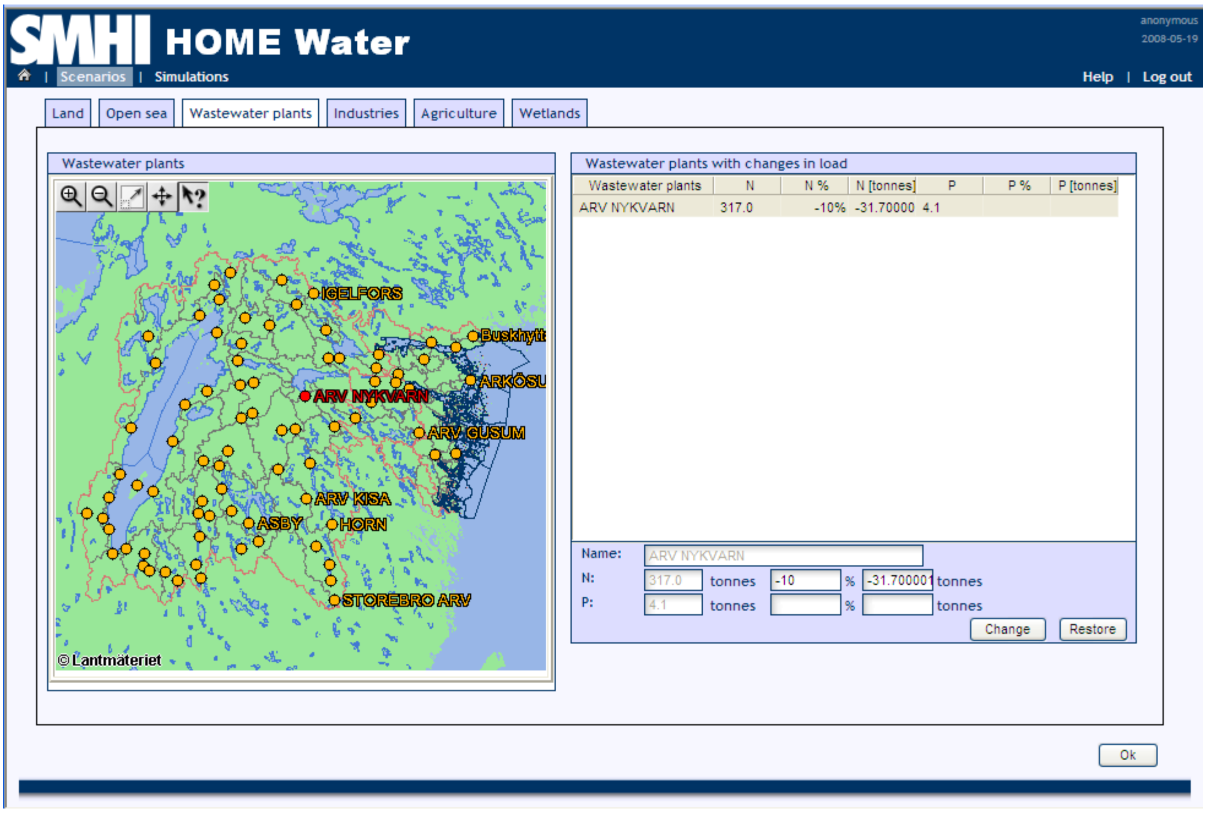

Figure 3. Example view illustrating how users can define scenarios by, e.g., changing the gross load of nitrogen from specific wastewater treatment plants.

According to results in the “Simulations” view, the annual average net load of total nitrogen from land to Inre Bråviken is 2 623.86 tons/year (Fig. 2). The source apportionment of this load is illustrated in a pie diagram, which shows that the diffuse leakage from arable and other land dominates the net load (Fig. 2). Point sources, such as wastewater treatment plants and industries also contribute substantial amounts of nitrogen to the coast. The impacts of reducing point source loads can easily be evaluated within the system. For instance, the gross load from any wastewater treatment plant can be altered in the "Scenarios" view (Fig. 3). A reduction of 10% of the annual gross load at two large wastewater treatment plants, Nykvarn and Slottshagen, yields a 1.3% reduction of the annual average net load to Inre Bråviken. Simularly, various measures to reduce the diffuse leakage from arable land may also be evaluated. A scenario in which winter catch-crops are used on 50% of the arable land in Östgötaslätten, the most productive arable region in the area, yields a 3.3% reduction of the annual net load to Inre Bråviken. With both remedies in place, the net nitrogen load from land is reduced by 4.6%.

Identifying cost-efficient measures

Users of the system may provide a cost range for each defined measure prior to simulation. This may be, for instance, a range in cost for reducing the gross load of nitrogen from a specific wastewater treatment plant by 10%. Following simulation, the system calculates the change in net load (as compared to a defined reference simulation), as well as the cost-efficiency for the measures in the scenario. The cost-efficiency is defined as the ratio between the total cost of the measures in a scenario and the change in net nutrient load. Several simulations, each involving different measures, may be compared at the same time in order to identify the most cost-efficient measures. Results may show, for instance, that a proposed constructed wetland becomes less cost-effective when another remedy is implemented further upstream. The reason is that the retention of nutrients in a wetland is reduced when the input of nutrients from upstream is reduced.

DISCUSSION AND CONCLUSIONS

The HOME Water system offers multiple tools for simulating and analyzing the nutrient status of inland and coastal water bodies. Users can access the system from a regular PC via a web interface, thus avoiding the cost of maintaining models on individual computers. Different scenarios can be defined, simulated and analysed. New scenario building functions are being implemented through continuous dialogues between SMHI and users at water authorities. The challenge of this work has been to allow maximum flexibility but at the same time "fool-proof" and simple for users. At present, the system is being developed to include tools of environmental economics which will enable users to identify the most cost-efficient remedial measures to improve nutrient levels (see Arheimer et al., 2005).

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SELF-PURIFICATION PROCESS AND RETENTION OF NITROGEN IN FLOODPLAINS OF RIVER NEMUNAS

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ABSTRACT

Submerged floodplain of the Lowland of the River Nemunas (605 km ^{2}) preserves the natural retention threshold for pollutants in water of the main canal and the Curonian Lagoon as well as improves farming conditions in the inundated meadows of the valley. It increases sedimentation and nitrogen retention capacity of the River Nemunas catchment's (97,860 km^2). It was established that about 40% of the fine suspended sediments (silt and clay as well as "wash load") can be retained and deposited in the flooded meadows of the Delta. Man-controlled inundation (summer type polders) of floodplains in the Nemunas delta may reduce its runoff nitrogen load by 21 kg km^{-2} per flood event. Subsequently, nitrogen concentration was decreasing by about 8 % causing self-purification process in the flooded area. Nitrogen retention depends on the velocities of the flood current and was mostly observed in the zones of stagnate water. This is due to low flow velocities and long retention times necessary for sedimentation and denitrifying processes favour this processes.

Keywords: floodplains, sediment deposition, nitrogen retention.

INTRODUCTION

Large rivers are conduits for nutrients and sediments from continents to the sea, but the swamp areas and wetlands can enhance denitrification and are valuable both for wildlife conservation and nutrient retention (Wissel et all., 2005).

The River Nemunas (97,860 km^2) is the fourth largest river basin that enters the Baltic Sea (via the Curonian Lagoon). 48% of the river is situated in Lithuania, and it drains more than 47% of the country. The river has 600 km^2 of floodplains in the delta. The density of the hydrographical network of the Nemunas basin in Lithuania equals 1.10 km km^{-2}, and 82% of this network is regulated or converted into drainage channels. Being maintained as water receivers from drained lands and covering the greatest part of the river basin, channels collect the 40% of pollutants from all diffused sources (Zalakevicius, 2000).

The annual runoff of the Nemunas approaches 22.1×10^9 m^3. The total annual dissolved inorganic N (DIN) discharge from the Nemunas basin into the Baltic Sea ranged between 16.2-42.7 (on average 26.9) $\times10^6$ kg over the last decade (Annals, 1993-2002). This discharge is in line with the river runoff inorganic N load of 167-436 (on average – 275) kg km^{-2} yr^{-1}.

Due to significant pollution from agriculture, the River Nemunas basin has been identified as a hot spot in the Baltic Sea basin (HELCOM, 1993). The costs of reducing inputs of pollutants from land sources into the sea were estimated to be billions of ECU. However, none of the Contracting Parties achieved the overall target adopted by the HELCOM Ministerial Declaration of 1988 to reduce the nutrient load to the Baltic Sea by 50% before 1995 (Šileika, 2000; Ollikainen *et al*., 2001; Sileika *et al*., 2003). Moreover, the nitrate nitrogen (NO_3-N) load into Lithuanian rivers from agricultural basins even increased (Šileika, 2000; Sileika *et al*., 2003).

It took a long time to recognise that an interaction between a river and its valley is of great importance to the ecological functioning of the river (Hynes, 1975). River valley restoration may contribute much to the river functioning and have an immediate effect on it (Iversen *et al*., 2000). A special effect on water purification and pollutant removal can be determined in wetlands possessing a large filtering and pollutant retaining capacity (Leonardson *et al*., 1994; Lars *et al*., 2000). During flood events when water overflows the riverbanks, certain hydrological conditions characteristic to floodplain wetlands may also occur and last sometimes for several months in inundated river valleys.

Investigations in the floodplain of the Nemunas delta with a range of summer polders (with dykes protecting against summer flooding) and winter polders (never flooded) revealed that the content of nutrients was higher in the soils of flooded polders than that in non-flooded ones (Malisauskas *et al*., 2001). This fact suggests the possibility to retain nutrients from floodwater in summer polder soils.

The objective of the study was to assess the potential of man-controlled flooding of the Nemunas delta to improve the water quality by reducing the N concentration and load of the River Nemunas into the Baltic Sea.

MATERIALS AND METHODS

The investigations were carried out in the Lithuanian part of the Nemunas basin in 1994-2002 (Fig. 1, 2). Two methods were applied: 1) field studies of

N concentrations in the River Nemunas inundated delta, and 2) modelling of the flood dynamics in the river delta valley.
To assess the affect of inundation on NO_3-N retention, the investigations were carried out during spring floods in the Nemunas delta in 1994, 1996, and 1999. At the same time, the turbidity of floodwater was studied.

Figure 1. Nemunas catchment.

Maximum floodplain discharges were in chronological order: 2100 (probability of 10%), 1300, and 910 $m^3 s^{-1}$.

Using bottle-type point-integrated samplers and a survey boat, 234 water samples were taken from the whole flooded area of the delta (Fig. 2). NO_3-N concentrations were determined by the above-mentioned method. For turbidity and suspended sediment fractions to be assessed, a turbidity optical measurer in combination with water samples for data calibration was used (Rimkus *et al*., 2003a; Rimkus *et al*., 2003b).

To quantify the NO_3-N load reduction when water flows via the flooded delta valley, the flow velocity and water delay in the valley needed to be assessed. As flooding conditions were complicated, flow velocity dynamics in the valley were simulated physically (hydraulic model scales 1:600 and 1:50) and mathematically by solving Saint-Venant and mass-balance equations (Vaikasas *et al*., 2003a, 2003b).

The quasi-2-D hydrodynamic model (Rimkus *et al.,* 1999) for sediment and pollutant transport along with the empirical equation (1) (Vaikasas *et al.,* 2003) evaluating NO_3-N concentration decrease in floodwater were used to quantify the retention of NO_3-N in floodplains:

$$C_t=C_0e^{-kt} \quad (1)$$

where C_t – NO_3-N concentration after water detention time t in inundated valley; C_0 – initial NO_3-N concentration in floodwater; k – empirical coefficient based on data from 1994, 1996 and 1999.

For model calibration, the field data as well as data of previous experiments with hydraulic (physical) flow models were used (Vaikasas, 2001).

The calculations were performed for the inundated 23-km upper section of the delta valley (Fig. 2). Since year 2003 detailed GIS database of the delta area was developed (Ascila et all, 2003), that enabled to develop 1D and 2D hydrodynamic models, produce maps of inundated areas (Fig 2) and get other useful information. As input data for hydraulic model we used hydrological data of Smalininkai (Annals, 1993-2002).

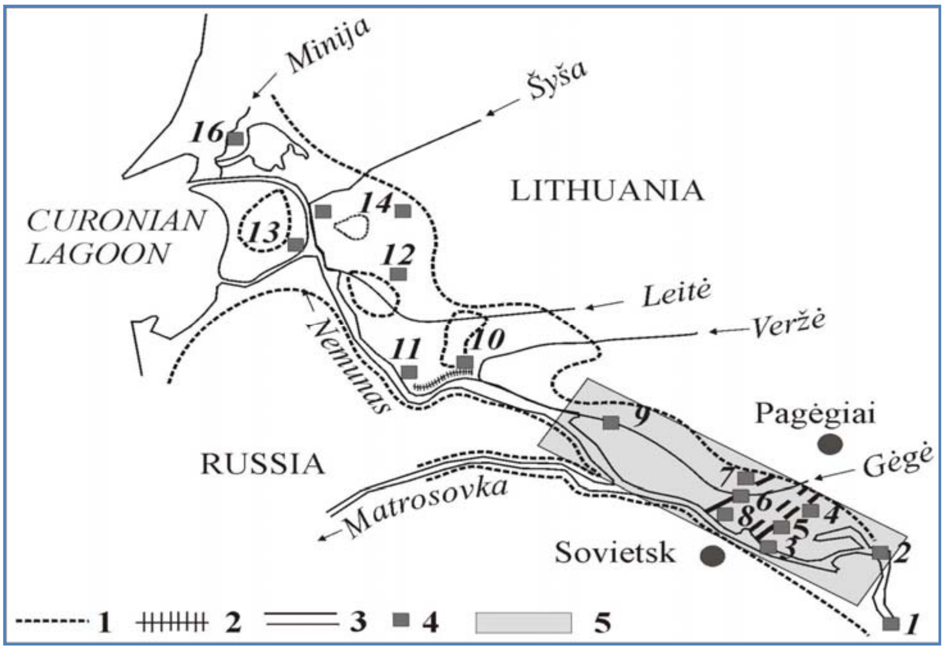

Figure 2. The River Nemunas delta (400 km^2): 1 – line of flooding; 2 – unflooded embankment; 3 – causeway; 4 – sampling spot; 5 – section of valley where modelling was completed. The sampling spots 1–3, 11, 13 and 15 – close to the main river canal; 4–8 – in valley stream zones; 9, 10 12 14 and 16 – in stagnant water zones.

RESULTS

The data analysis of floodwater turbidity and NO_3-N concentrations revealed that a special distribution of these floodwater characteristics occurred in the flooded Nemunas delta, depending on the distribution of flow velocities and water retention time in the floodplain (Table 1).

NO_3-N concentration as well as turbidity values were less in the zones of stagnant water. The NO_3-N concentrations dropped as the water flowed from the valley flooding spot as far as the river outfall into the Curonian Lagoon (from 3.0 to 1.7 mg l^{-1}). The reduction of NO_3-N depended on the delay of floodwater in the valley (Fig. 3).

In fact, water that was part of a more intensive flood was more polluted in the delta, since NO_3-N reduction appeared to be slower during larger flood events. This is also indicated by an increasing k value (0.007, 0.016 and 0.029) when the range of years (1994, 1996 and 1999) follows the decrease in abundance of water in the flood events (Table 2).

Table 1. Water turbidity and NO_3-N concentrations in the Nemunas delta during the spring flood in 1994.

Samplingspot No (Fig. 2)	Location with respect to stream	Turbidity (mg l^{-1})	NO_3-N (mg l^{-1})
1	R	40.00	3.0
2	R	18.00	3.00
3	R	10.00	2.30
11	R	6.40	2.50
13	R	6.00	4.20
15	R	5.40	2.50
4	V	8.40	2.50
5	V	7.40	3.10
6	V	6.00	2.50
7	V	7.60	2.50
8	V	6.60	2.50
9	S	3.40	2.00
10	S	7.00	2.00
12	S	7.00	2.30
14	S	4.40	3.00
16	S	6.00	1.70

Note: R – river main canal; V – valley stream zones; S – stagnant water zones.

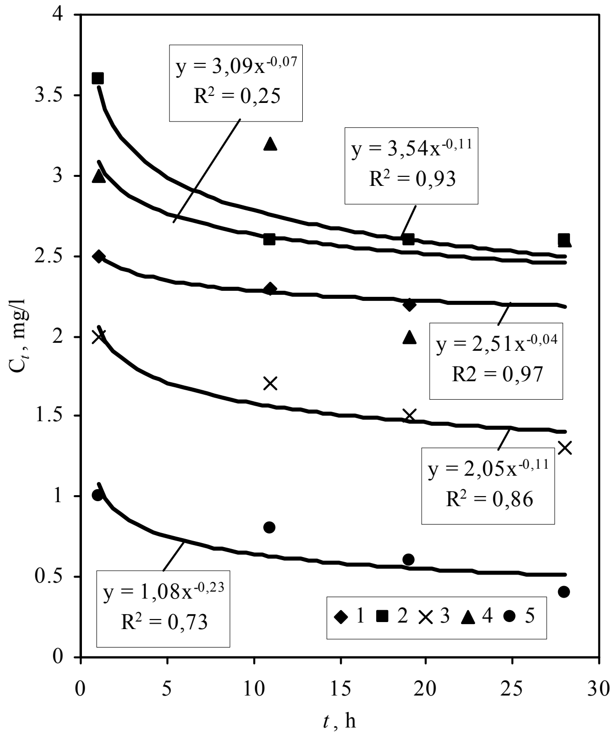

Figure 3. Dependence of NO_3-N concentrations (C_t, mg l^{-1}) on water delay (t, h) in the delta: 1, 2, 3, 4 and 5 – the years 1994, 1995, 1996, 1998 and 1999 respectively. Because of low floods in 1995 and 1998, water samples were taken close to the main river canal (in the junction canals), where concentrations were usually higher than in the delta.

Table 2. NO_3-N concentrations (C_t, mg l^{-1}) measured in the spots at variable distances from the Nemunas outfall, water delay time (t,d) and empirical coefficient (k) calculated according to Equation (1).

Distance from out-Fall, km	Years											
	1994				1996				1999			
	Q_{max}	C_t	t	k	Q_{max}	C_t	t	k	Q_{max}	C_t	t	k
106	2100	2.5	0	–	1300	2.0	0	–	910	1.0	0	–
73		2.3	10	0.008		1.7	12	0.016		0.8	13	0.017
45		2.2	18	0.006		1.5	30	0.016		0.6	22	0.032
5		–	–	–		1.3	29	0.016		0.4	33	0.037
Mean				0.007				0.016				0.029
Note: Q_{max} – maximum valley discharge, m^3 s^{-1}.												

The spring flood event of 1994 was modelled. The maximum discharge of the Nemunas in the inundated valley reached 2100 m^3 s^{-1} and the initial NO_3-N concentrations varied arising from varying discharges from 0.53 to 3.00 mg l^{-1}. The smaller the discharge enters the valley, the slower the flow velocity occurs causing longer water residence time there. At the same time, floodwater residence time was shorter in the valley when higher water levels occurred. This determined water-resident-time-dependent intensity of the decrease in NO_3-N concentrations in flooded valley (Table 3). However, an absolute decrease in NO_3-N concentrations was rather constant (on average 0.45 mg l^{-1}). The contamination level appeared to have no effect on the relative decrease in concentrations.

Table 3. Decrease in NO_3-N concentrations during the flood event of 1994. The results were obtained by simulating an actual flood event in the 23-km upper section of the Nemunas delta valley.

Floodwater level altitude	Discharge of valley flow	Water residence time in the valley	Initial NO_3-N concentration	NO_3-N concentration decrease	
(m)	(m^3 s^{-1})	(d)	(mg l^{-1})	(%)	(mg l^{-1})
8.57	2100	18.35	3.00	14	0.41
8.50	2000	19.36	2.50	18	0.46
8.25	1583	22.03	1.35	40	0.54
8.00	1188	23.66	0.85	55	0.47
7.75	813	24.57	0.65	66	0.43
7.50	484	26.62	0.55	76	0.42
7.25	250	29.04	0.53	83	0.44
				Mean:	0.45

The concentration decrease rate shows the intensity of self-purification processes occurring in the course of water flow via the inundated valley. In the case of the simulated section of the Nemunas delta, about 2.1×10^6 kg of NO_3-N may have been retained during the spring flood of 1994 (Table 4).

Table 4. Retention of NO_3-N due to floodwater self-purification when flowing via the inundated 23-km upper section of the Nemunas delta in the spring flood event of 1994.

Valley discharge (m^3 s^{-1})		Discharge duration	NO_3-N retention
Fluctuation interval	Average in the interval	(h)	($\times10^6$ kg)
100-250	177.5	408	0.11
250-484	376.1	528	0.30
484-813	629.1	324	0.32
813-1188	988.8	180	0.30
1188-1583	1368.6	204	0.54
1583-2000	1776.5	150	0.44
2000-2100	2047.0	24	0.07
		Total:	2.08

DISCUSSIONS

The process of NO_3-N removal from river water is rather complicated and depends not just only on water detention time in a flooded valley. It is determined by many conditions: climatic, topographical, hydrological, the physical and chemical characteristics of floodwater etc. N removal rate depends e.g. on water temperature and N loading rate (Weisner *et al.*, 1994) as well as on facultative anaerobic bacteria (Tiedje, 1988). Little NO_3 reduction occurred in low-oxygen-demand floodwater, while denitrification might be favoured in stagnant areas where water detention time greatly exceeded the water delay in active flow zones (Reddy *et al.*, 1980; Stober *et al.*, 1997). As anoxic conditions are preferable for denitrification, N removal potential ought to increase when it is transported to the underlying anoxic water column layers and bottom sediment. In this respect the inundated floodplains are similar to wetlands.

The lower flood events occurred, the less average flow velocities were in inundated delta. Because of lowered velocities, the water delay in the delta increased. This caused a decrease of flow turbulence, an augmentation of suspended matter settling, and shifts in temperature conditions. These changes might favour denitrifying bacteria. Therefore, NO_3-N concentrations in water flowing through the Nemunas inundated floodplains decreased.

The amount of NO_3-N retained in the Nemunas inundated delta floodplains (2.1×10^6 kg per flood event) was obtained from the simulated section only. Consequently, the retained total amount of NO_3-N should be larger for the whole delta floodplains. Nevertheless, even such an amount is rather significant indicating a decrease in discharged NO_3-N load to the Baltic Sea from the Nemunas basin of about 21 kg km^{-2} per flood event.

When the River Nemunas floods the delta, a large amount of suspended matter settles there. This amount averaged 1.2-1.5 $\times10^6$ kg km^{-2} yr^{-1} containing fine clay and silt particles, and organic matter (about 12,000 kg km^{-2} yr^{-1}) during 1950-1991. Thus, over this 41-year period, along with sediments, the delta floodplain soils were naturally fertilised with 0.25×10^6 kg of potassium, 0.95×10^6 kg of phosphorus, and 38×10^6 kg of calcium (Vaikasas, 2001). Consequently, flooding of the River Nemunas delta floodplains contributes to the retention of contaminants that otherwise would settle in the Curonian Lagoon. On the other hand, it helps to improve floodplain natural meadows to some extent.

On the whole, the River Nemunas is classified as moderately polluted. Inorganic N mean yearly concentrations in the lower reaches of the river fluctuate between 1.0-1.9 mg l^{-1} (Cetkauskaite *et al.*, 2001; Annals, 1993-2002). Since DIN concentrations in drainage channel water were at least four times as high as in the River Nemunas, assessing the effect of floodplain inundation on the reduction of N load showed the importance to address all measures and ways of preventing pollution, stimulating and maintaining self-purification processes of stream water from a river basin perspective. Larger flooded territories in the valley give room for more variation of flow velocities and for stagnant water zones that enhance nutrient retention. In this respect the management of polder dykes (both summer and winter) could be adjusted to control the water flow dynamics in inundated floodplains. N retention in the delta floodplains could be enhanced by maintaining of the summer polder drainage systems in order to lower the soil water level, and to augment soil saturation capacity before flooding. An extension of the floodplain area is impossible if the main channel of the river is not embanked. In the case of the Nemunas delta floodplains, the possibility to extend the floodplain area might be considered (first of all in the political sphere) as the Nemunas delta in Kaliningrad Region is protected from any flooding by high winter dykes (Malisauskas *et al.*, 2001).

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INFLUENCE OF CLIMATE ON RUNOFF OF PESTICIDES

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ABSTRACT

Changes in climatic conditions affect concentrations and total losses of pesticides in runoff from agricultural fields. Measurements on runoff of pesticides with different mobility characteristics have been performed at three agricultural fields in SE-Norway. Volume proportional samples of both surface and drainage runoff have been collected at an annual bases for three years (2001-02, 2002-03 and 2005-06). At an annual scale, accumulated losses of pesticides in drainage runoff might be significant, especially for mobile pesticides. Predictions of environmental concentrations of pesticides have been performed from one of the fields, based on simulations with the MACRO model. Here, the drainage runoff of the mobile pesticide metalaxyl has been simulated for three different years with different climatic conditions. Generally, simulated values agreed well with measured values for annual losses of the pesticide, where climatic events of importance for the runoff of the pesticide were well accounted for.

INTRODUCTION

Regardless of water solubility or affinity for solid surfaces, pesticides that are applied at agricultural fields are frequently found in brooks and rivers (e.g. Ludvigsen and Lode, 2005). Concentrations and total losses of pesticides are, however, heavily dependent on climatic conditions. Especially, precipitation events shortly after application and melting-freezing episodes during winter are of great concern with respect to runoff of pesticides (Riise et al., 2006). The transport of pesticides occurs both through surface and drainage runoff, depending on soil and climate conditions. Concerning annual fluxes of pesticides, a significant part might pass through the drainage water (Riise et al., 2004).

At three agricultural fields in SE-Norway, primary data on runoff of pesticides with different mobility characteristics (bentazone, metalaxyl, propiconazole) have been collected, at a plot scale, for several years. Volume proportional samples have been taken from both surface and drainage runoff at the edge of the fields, to calculate annual fluxes. In addition, the pesticide losses to drainage from one of the sites have been simulated with MACRO, a dual permeability model (Jarvis, 1991). The aim of the study has been to improve the knowledge on factors contributing to the loss of pesticides from fields with different soil characteristics under different climatic conditions.

MATERIAL AND METHODS

Field experiments: Pesticides were applied in the beginning of June at three agricultural plots in SE-Norway (Askim, Bjørnebekk and Askim) the following years: 2001, 2002 and 2005. KBr was applied at the same time as the pesticides. Runoff measurements were performed from 1. June – 31. May.

Two of the sites - Bjørnebekk and Syverud – are located at Ås and one site at Askim, 30 km east of Ås. The soils at all sites have a clay content greater than 20 %; and are characterized as loam/silt loam to silty clay loams (Tab. 1). Two sites, Bjørnebekk and Askim, are artificially levelled. Surface runoff was measured at all sites, while drainage runoff was measured at Syverud and Askim only. Surface runoff was collected by a plastic half pipe at the end of the plots. Volume proportional samples were taken by using tilting buckets which added a small volume of water to a collecting can every second tilt. A further description of the experimental sites and setup can be found in Lundekvam (2007). In general, all plots were subject to either harrowing or ploughing both during spring and autumn. For the season 2005/2006 one plot with no tillage during autumn was also included (Fig. 3). The plots were fertilized and sown (spring barley) in spring.

Climate: Precipitation, air temperature and snow depth were measured at the agrometeorological field station (http://www.umb.no/imt/fagklim/metdata) at Ås, and soil frost depth is estimated from measurements with soil moisture resistance blocks at the Soil Water Monitoring Station at Ås (Hervé Colleuille, NVE pers.comm.).

Table 1. Soil properties of the agricultural plots at Askim, Bjørnebekk and Syverud.

	Askim	Bjørnebekk	Syverud
Soil type	Silty clay loam	Silty clay loam	Loam/silt loam
Plot area (m^2)	324	178	402
Slope	13	13	13
Organic C (%)	1,1	1,0	3,0
Dry bulk density	1,40	1,52	1,22
Pore volume (%)	40,7	44,1	54,4
Drainable pores at -10 kPa (%)	5	6	16

Pesticides: Runoff of the following pesticides have been studied; bentazone (Basagran-87 % a.i.), metalaxyl (Ridomil MZ – 7,5 % a.i), and propiconazole (Tilt – 62,5% a.i). Important characteristics of the pesticides are given in Tab. 2.

Table 2. Partitioning coefficients (K_d and K_{oc}) and degradation rate ($T_{1/2}$) for selected pesticides estimated in Norwegian soils.

	Bentazone	Metalaxyl	Propiconazole
K_d (cm^3/g)	0,38-0,81***	0,34-0,84*	17-26*
K_{oc}	24-60***	17-45*	791-1536*
$T_{½}$ (days)	> 84**	38-546*	144-389*

*Norske scenarier II 2005-2006, **Torstensen and Lode (2001) and ***unpublished data

RESULTS AND DISCUSSION

Climate

Period 1 (2001-2002) had the highest annual air temperature, 6.7 °C (normal 5.3 °C), with only two months with mean temperatures below 0°C. The monthly air temperatures are usually below zero for 3-4 months at Ås (Fig. 1). The first winter 2001-02 (Period 1) had deepest average frost depth, longest period with soil frost, lowest number of days with snow cover and highest number of days with soil frost (Tab. 3 and Fig. 2). The two other winter periods (Period 2 and 3) were colder, but the longer and deeper snow cover these years reduced the soil frost depth compared to 2001-02 (Fig. 2).

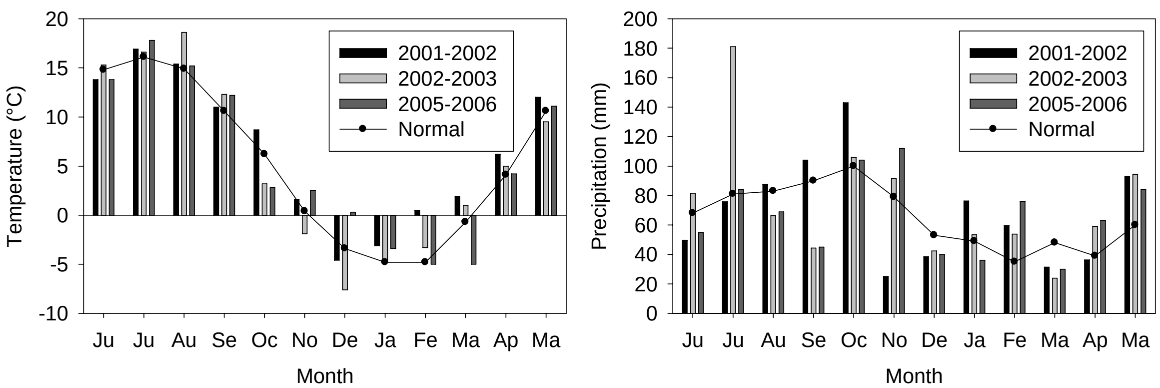

Figure 1. Ås, Norway - monthly average temperature (°C) and precipitation (mm) for June - May for Period 1 (2001-2002), Period 2 (2002-2003), Period 3 (2005-2006) and the normal period (1961-1990).

Table 3. Winter climate at Ås during Period 1, 2 and 3 (1. June - 31. May).

Year	Frost (days)	∑Temp. <0°C	Snow cover (days)	Avg. snow depth (cm)	Soil frost (days)	Avg. frost depth (cm)
2001-02	74	-286	55	5	82	-18
2002-03	105	-581	131	21	50	-8
2005-06	107	-505	123	29	66	-12

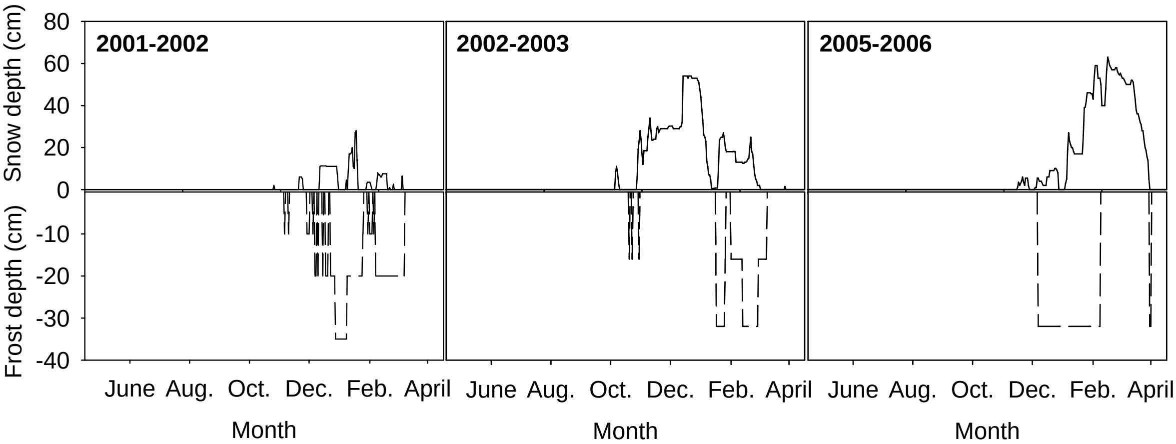

Figure 2. Snow depth (m) at the agrometeorological field station at the University of Life Sciences, Ås and soil frost depth (m) estimated from measurements with soil moisture resistance blocks at the Soil Water Monitoring Station, Ås (H. Colleuille pers.comm).

The annual precipitation was close to normal (785 mm) for all three periods; with largest deviation in total sum (+125 mm) for period 2 (2002-03). Both June and especially July 2002 (Period 2) had precipitation above the normal values Usually, the rainfall intensity for individual storms at Ås is in the range 1 to 4 mm/h, but in July 2002 (Period 2), 80 mm/h for one hour was observed (Lundekvam, 2007). Such rainfall events are rare at Ås and eventually occur in connection with thunderstorms.

Loss of pesticides different years

Generally, there were higher losses of pesticides from the more erodible soils at Askim and Bjørnebekk compared to Syverud. High content of soil organic carbon, high aggregate stability and high infiltration capacity contributed to lower losses of particles and thereby pesticides at Syverud. An exception was, however, some extreme rainfall events in the summer of 2002 which resulted in very high losses from all fields (Fig. 3). Pesticides are generally more sensitive to runoff shortly after application and the extreme events in the summer of 2002 was the main reason for the high losses. In addition measurements of snow cover and soil frost indicates that the snow melting in 2002-03 occurred on frozen soil, which contributed to high surface runoff. More than 3 % of applied bentazone was lost through runoff at Askim in Period 2, which is a very high number. Lowest runoff of pesticides occurred in 2001-02 (Period 1).

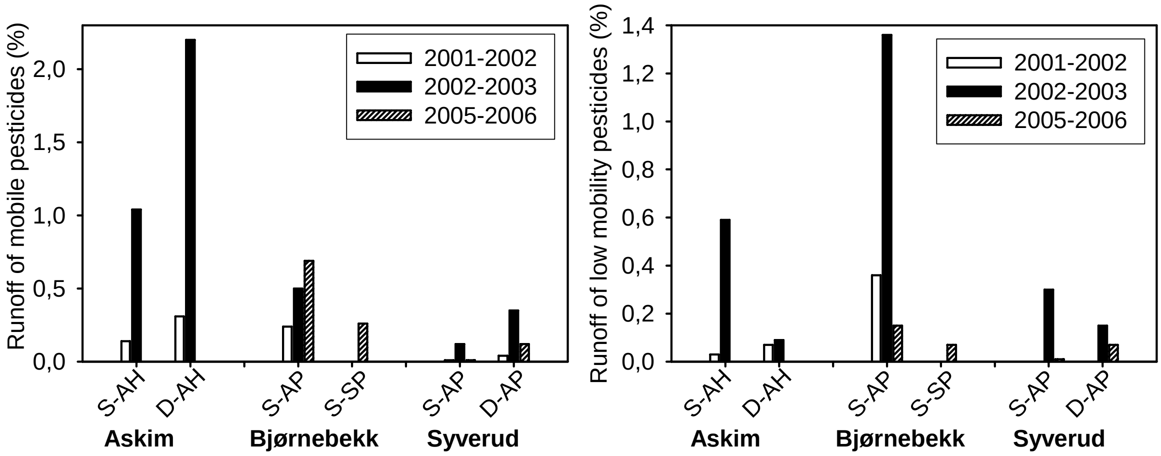

Figure 3. Loss of mobile (bentazone in 2001-03 and Metalaxyl in 2005-06) and less mobile pesticides (propiconazole all years) through surface and drainage runoff from three agricultural fields (Askim, Bjørnebekk and Syverud). S=surface runoff, D=drainage runoff, AH=autumn harrowing, AP=autumn ploughing and SP=spring ploughing.

While, the low mobility pesticide, in general, was most susceptible to surface runoff, drainage losses dominated for the mobile pesticides, which is in accordance with the mobility concept. However, significant amounts of both the mobile and less mobile pesticides were observed in the drainage water, which probably was due to bypass flows in the soil.

A more detailed runoff pattern is given for one of the sites – Askim for 2001-02 (Period 1), showing peak concentrations of pesticides in both surface and drainage runoffs early in the season, and thereafter a rapid decrease (Fig. 4). The peaks for the mobile pesticide appeared very early, prior to the peaks for both bromide and the less mobile pesticide. This transport behaviour can be attributed to a size- or anion exclusion effect, which increases the mobility of the compounds through the soil. Enhanced concentrations were also observed during freezing/thawing episodes during the winter. Although the levels are low, pesticides are measured a long time after their application, showing that their persistence is high.

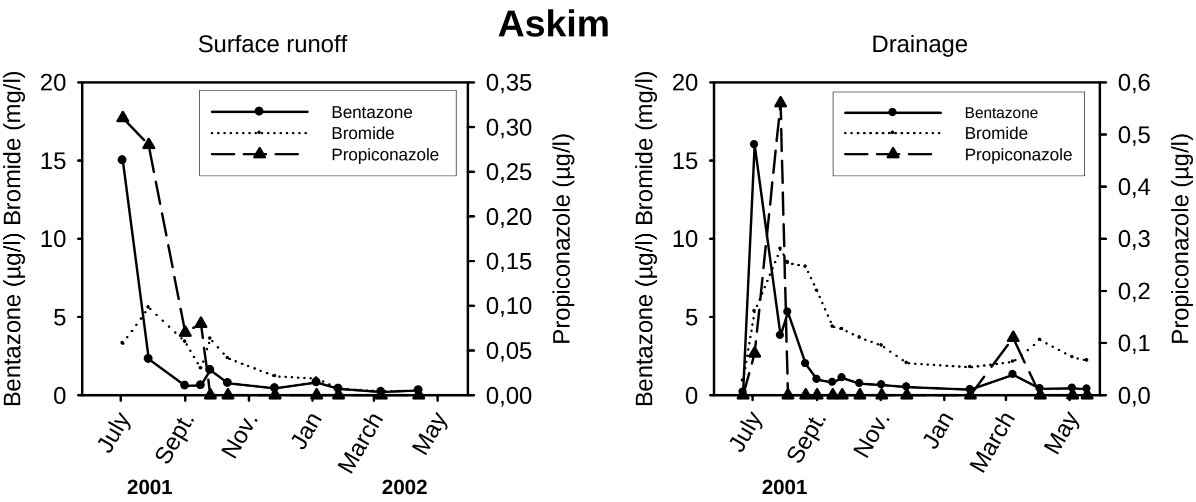

Figure 4. Runoff of mobile (bentazone) and less mobile (propiconazole) pesticides through surface and drainage water in 2001-2002 at Askim. Bromide was used as a tracer for the transport of water.

Mobile pesticide – measurements and simulations

Major fluxes of water pass through the drainage system (Figs. 6 and 7), which also is shown to be an important transport pathway for pesticides, and especially mobile pesticides. Losses of pesticides show large differences between years. Here, the runoff of the mobile pesticide metalaxyl, is compared for different years through model simulation at the site Syverud. The MACRO-model (Jarvis 1991) was parameterized for the period April 2005 to the end of June 2006 against measurements (pesticide, bromide and runoff) at Syverud. As the site is the location for a proposed national Norwegian scenario, the FOCUS-guidelines for the parameterisation of the MACRO-model are followed. Here a short description of the parameterisation of the model is given. A more detailed description can be found in Eklo et. al (2008).

The soil water retention curves for different depth are shown in Fig. 5. The simulation was performed as a two-domain flow with the limit between domains set at -5 cm H_2O suction and with a saturated conductivity of the micro pores equal to 0.4 mm/hour. The critical potential for plant water uptake was set to -1.9 m H_2O. The half-life of Metalaxyl in the plough layer was according to laboratory measurements 38 days (T=20°C, optimum water content) and the distribution coefficient (K_d) equal to 0.56 cm^3/g. The decomposition rate was reduced according to FOCUS-guidelines (FOCUS 2000), a 50% reduction (compared to plough layer half life) for 40-60 cm depth, 70% reduction at 60 to 100 cm depth and no decomposition below 100 cm depth.

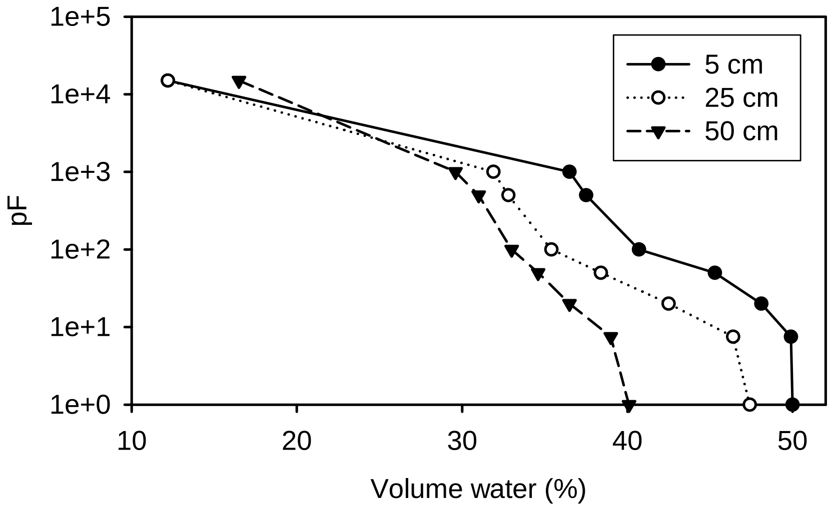

Figure 5. Soil water retention curves at different depths (cm) for Syverud.

The model was parameterized against data of drainage flow and the best fit, found by trial and error, are shown in Fig. 6. The agreement between measured and simulated drainage are quite good. The largest deviations are found around the peaks of the measured drainage fluxes. The simulated peaks correspond in time, but underestimate the drainage compared to measured values. Since daily climatic data is used in the simulation, a better time resolution in precipitation data could probably give a better fit to the measured peak values.

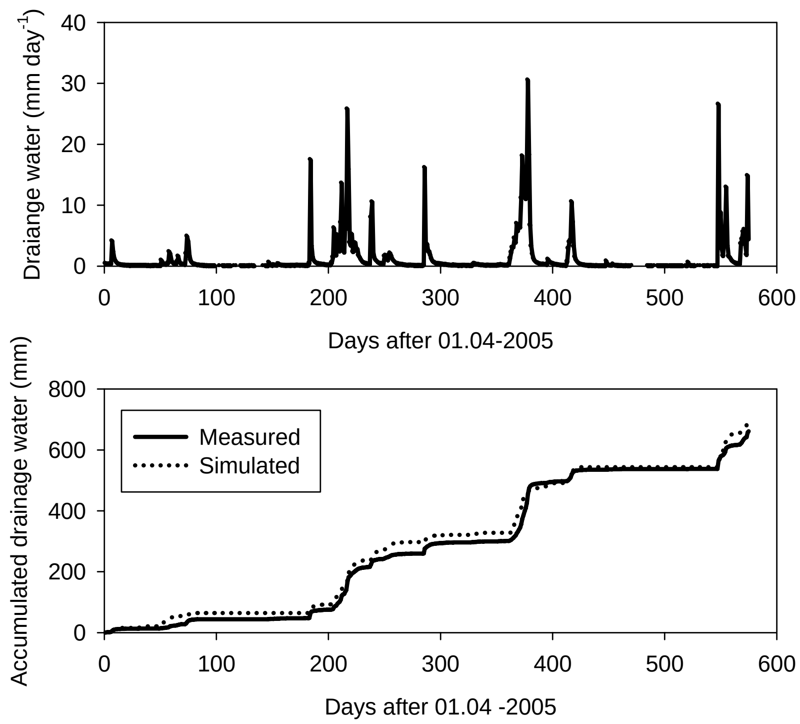

Figure 6: Measured and simulated values for runoff of drainage water.

(mm day^{-1}). Results are given as daily (a) and accumulated values (b).

The measurements of metalaxyl in the drainage water showed an earlier breakthrough than the simulations, the same pattern as for bromide (results not shown). At an annual scale (Fig. 7), simulated fluxes of metalaxyl, applied at an amount of 25 mg/m^2 each year, are in agreement with the results shown in Fig. 3, where total loss of pesticides clearly dominated in 2002-03 (Period 2).

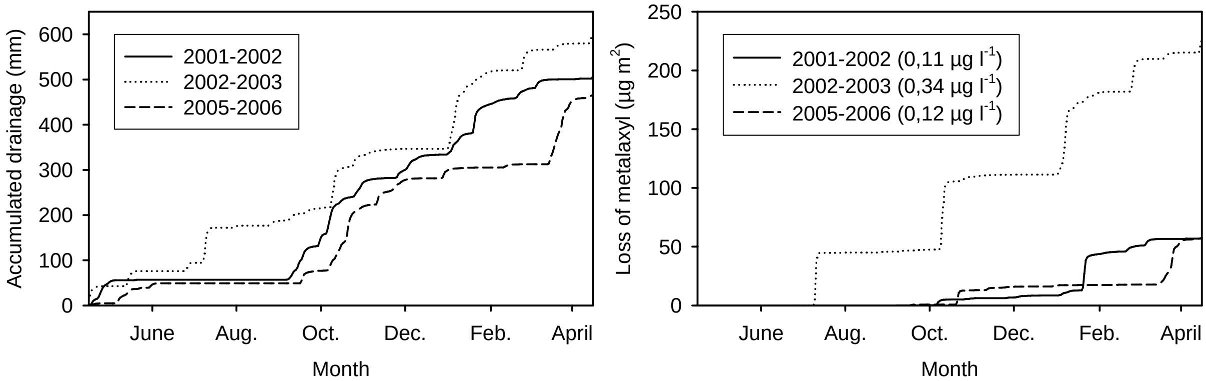

Figure 7. Simulated fluxes of drainage (mm)) and metalaksyl (µg m^{-2}) for Period 1 (2001-02), Period 2 (2002-03) and Period 3 (2005-06). Average concentration of metalaxyl is given in parentheses.

For the period with the highest loss of pesticides, 2002-03, simulated values of metalaxyl (Fig. 7) showed that half of the amount were lost before the end of October, first peak 24th – 25th July and the second peak between 23rd to 25th October. The third episode in January 2003, corresponds with the snow melting episode. Thus, climatic events that promote runoff of pesticides are very well simulated based on an annual loss of pesticides (Fig. 7). See also Fig. 8 for simulated concentration of metalaxyl related to time. From this, it can be seen that climatic conditions of special importance for runoff of pesticides are:

- heavy showers or wet soil (high precipitation) in the growing season
- high amounts of precipitation in the autumn that leads to high leaching
- snow melting episodes during winter, where the distribution between surface and drainage runoff depends on soil frost conditions

The runoff of pesticides was far less for Period 1 and 3. In 2001-02 (Period 1) most of the losses were related to a snow melting episode in February 2003. It was a mild winter with sporadic occurrence of soil frost and little snow cover (Fig. 2), and at Syverud most of the water losses occurred through the drainage pipes.

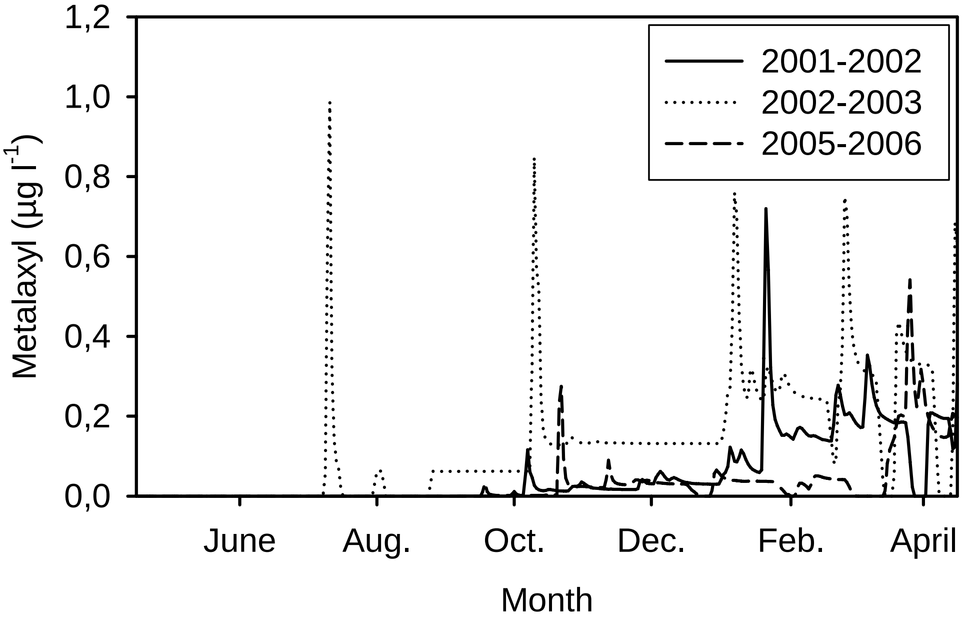

Figure 8. Simulated concentration of a mobile pesticide (Metalaxyl) in drainage water (ug l^{-1}) for three different periods (1/5 to 30/4).

For Period 3 (2005-06), accumulated runoff of metalaxyl prior to the snow melting, was, simulated very well. During the snow melting period in April 2006, however, the simulations indicated higher losses of metalaxyl than actual measured. In addition, the simulation indicated later runoff of metalaxyl than the measurements. On the other hand, simulation of the water transport through the drainage system, fitted well, even though the model failed to simulate the precise time for runoff of metalaxyl. Simulated loss of metalaxyl through the drainage runoff was, therefore, overestimated according to the actual measurements at an annual scale in 2005-06. Preliminary analysis indicates that the degradation rate of metalaxyl, which is used in the model, could be too slow, especially as a function of depth. But turned the other way around, pesticides abandoned for several years are still found in water samples from groundwater and rivers, an observation which is in agreement with the simulated values. Although at low concentration, leaching of persistent pesticides may continue for a long period of time.

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MODELLING PHOSPHORUS TRANSPORT AND RETENTION FROM SWEDEN WITH THE HBV-NP MODEL

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ABSTRACT

The eutrophication of the Baltic Sea, the Öresund, the Kattegatt and the Skagerrak has increased during the last 50 years. National and international action plans have been decided upon and efforts have been made to reduce the eutrophication, although the situation has not improved. We must have knowledge about the sources and processes in rivers and lakes to find efficient ways to reduce the load. The SMED (the Swedish Environmental Emission Data) consortium has developed a system for calculating the nitrogen and phosphorus transport from the sources to the sea. The latest calculation was made for HELCOM PLC5 (Pollution Load Compilation 5). This article presents the HBV-NP approach and focuses on phosphorus model results, such as retention in the freshwater system and the net transport to the seas. Daily simulations are made for Sweden, divided into approximately 1100 subbasins, with calibration/validation against measured time series at about 500 sites. On average, 30 % of the annual gross load of phosphorus is lost during transport, but temporal and spatial variations are large.

INTRODUCTION

The eutrophication of the Baltic Sea, the Öresund, the Kattegatt and the Skagerrak has increased during the last 50 years. Reliable data on nutrient transport into the seas and apportionment of land-based sources are essential to quantify the riverine contribution and to find effective measures. Therefore, large efforts have been made to quantify nutrient losses from both point and non-point sources, retention and transformation in inland water and transport to the sea. Originally, the latest Swedish calculations made by SMED (the Swedish Environmental Emission Data) aimed to meet the demand of the Helsinki Commission (HELCOM) for the Pollution Load Compilation 5

(PLC5), but national quantifications have also been based on these calculations. The SMED consortium consists of the Swedish University of Agricultural Sciences (SLU), the Swedish Environmental Research Institute (IVL), the Statistics Sweden (SCB) and the Swedish Meteorological and Hydrological Institute (SMHI). The Swedish Environmental Protection Agency (SEPA) has commissioned the calculations and parts of the development.

The calculations of nitrogen (N) in PLC5 have been performed in about the same way as in PLC4 and earlier national calculations (Brandt and Ejhed, 2002; Bergstrand et al., 2002; Arheimer and Brandt, 1998), but with extended data to include recent years and changed calculation methods. For phosphorus (P) new methods for calculation of leakage from arable land have been developed and implemented, as well as for retention and transport to the sea. This article will focus on the calculation of P retention in the HBV-NP model, the input data to the model and the model results. A more complete description of input data, calculations of gross and net load to the seas surrounding Sweden and source apportionment of both nitrogen and phosphorus can be found in Brandt et al. (2008).

The development of a phosphorus module to the HBV model started in a Swedish research project named VASTRA with focus on finding effective, workable solutions to the problems relating to eutrophication (Andersson et al., 2005; Arheimer et al., 2005). The diffuse soil leakage is handled in the HBV-NP model by assigning concentrations to water from different land-uses. Nutrient concentrations for different combination of crops and management practices for arable land are achieved by using the field-scale models SOILNDB for nitrogen and ICECREAM for phosphorus. Nutrient loads from soil erosion, rural households, industries, and wastewater treatment plants are also considered. The model includes functions for biogeochemical processes in river and lakes, and simulates daily concentrations and transport of N and P. The River Rönne å (1 897 km^2) was used for this first application.

The concept was tested and made operational in the River Motala Ström (15 480 km^2) (Brandt et al., 2004). The ICECREAMDB model and system for arable land was further developed by the Swedish University of Agricultural Sciences (SLU), the user interface between ICECREAMDB and HBV-NP model was made suitable for national and regional applications, and the sensitivity of different factors in the ICECREAM model was studied in a SMED-project (Johnsson et al., 2006).

METHODOLOGY

The HBV-NP model is a dynamic mass balance model with a daily time step. Applications include assessment of N and P transport, retention, source apportionment, separation of antropogenic loads from background levels, and scenario analyses. The spatial distribution is handled by division of catchment into coupled subbasins. Within a subbasin different land-uses and elevations are separated based on the area fractions. Functionally, each subbasin is divided into unsaturated zones and streamflow generation zones. The nutrient load for each subbasin is computed by summarizing the diffuse leakage from all land-use classes, atmospheric deposition on water, emission from wastewater treatment plants, industries, rural households and from stormwater in urban areas. The phosphorus model simulates the fractions of soluble reactive phosphorus (SRP) and particulate phosphorus (PP), but the sum, total phosphorus (totP), is also computed.

Different biogeochemical processes affect the nutrients on their way to the sea. In the P model transformation is assumed to occur in the rivers and in the lakes. The assigned P-concentrations for different land-uses in PLC5 are given at the river and already include transformation and retention in the soil and groundwater.

Three processes of P transformation in rivers are considered: biological production including adhesion of SRP to soil particles, sedimentation/ resuspension of PP and exchange of SRP with river bed.

The retention and release of P in lakes is described in the model by up to four transformation equations in the following way:

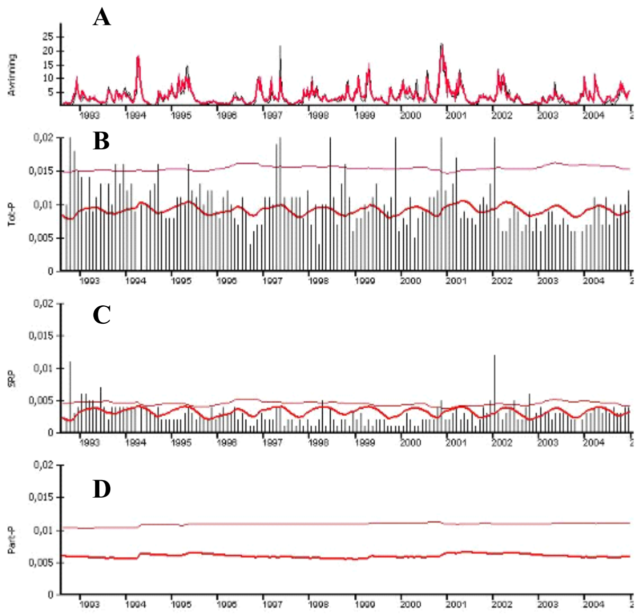
*Retention/release= parameter*concentration*lake area*function(temperature)*

A lake can have retention of SRP or release of SRP from sediments. This is modelled with the same equation differing only in the sign of the calibration parameter. Sedimentation of PP is not depending on temperature and thus the temperature-function is excluded. Further description of the model can be found in Andersson et al. (2005) and in Pers (2007).

In the national model set up for the whole Sweden we calibrated SRP retention or release and sedimentation or resuspension of PP in lakes. A transformation between SRP and PP in rivers was also simulated by the model and gave temporary increases and decreases in concentrations, but no long-term retention or supply.

The lake calibration was made for selected subbasins (with measurements), where model parameter sets were tested until the best fit was found between simulated and measured concentrations. In Figure 1 an example of a P calibration at a site is given. The calibration was made stepwise. First SRP was calibrated with one free parameter (Fig. 1C), then PP was calibrated with the sedimentation parameter. If measurements of PP was lacking (as in Fig. 1D), this parameter was calibrated by looking at totP concentration instead

(Fig. 1B). This parameter set was tested for the whole river, changed if its was needed to get better fit at other sites and tested again so that the simulated concentrations fit to the measured concentrations at all calibrated measurements sites in the river as good as possible. Finally, a resulting parameter set for the whole river or part of it was chosen. However, some basins with lakes got their own parameter setting, when the common parameter set didn't work and they strongly influenced the downstream concentrations. Also lakes where we could suspect from experience a bottom release or a low retention got their own parameter sets.



A: runoff (m^3/s); simulated (thick line) and measured (thin line)

B: total phosphorus concentration (mg/l); measured (bar), simulated without retention (thin line) and with retention (thick line)

C: soluble reactive phosphorus concentration (mg/l); measured (bar), simulated without retention (thin line) and with retention (thick line)

D: particulate phosphorus concentration (mg/l); simulated without retention (thin line) and with retention (thick line) (no measurements)

Figure 1. Example of calibration of P at Kringlan (area 294 km2) in the River Arbogaån. Time period shown is 1992-2004.

DATABASE

The database and calculations cover the whole Sweden. Parts of the River Klarälven and the River Torneälven that belong to Norway and Finland respectively are also included. The total land area (including islands) is divided into nearly 1100 subbasins for which load and retention are simulated. Time series from little more than half of the available measurement sites with nutrient concentrations (totally around 525 sites) are used for calibration and the rest for validation.

Table 1 summarises the input information for the calculations. The database is based on national available data, which has been refined and adapted to the subbasin scale within SMED. In the HBV-NP model set up point sources are estimated for the year 2005 and leakage from arable land represent the arable management for year 2005. The calculations thus represent the nutrient loads for the last years, but flow has been normalised (period 1985-2004) to remove year to year fluctuations due to natural climate variations. Calibration is focused on the last 10 years.

Table 1. Input information for the phosphorus model.

Input data	Quantity	Background information
Hydrography:		
Main river basins (> 200 km^2) + basins along the coast	119 + 113	Nearly 1100 subbasins
Runoff	1100	Daily simulations (1985-2004) from HBV
Land-uses (km^2):		
Forest, clearcut areas, mountain, mire, arable land, water, other open land, urban area		Arable land is further divided into 22 agricultural regions, 10 soil types, 15 crops
Concentrations for leakage from land-uses (SRP, PP, totP) (mg/l):		
Forest, clearcut areas, mountain, mire, other open land, urban area		For 3 forest regions (monthly means), 4 open regions (annual means) (Uggla and Westling, 2003; Löfgren and Olsson, 1990)
Arable land		Annual mean[1)] for each combination of agricultural region (22), soil type (10), crop (15), slope-class (3) and P-HCl-class (3) based on ICECREAMDB
Atmospheric deposition on water (kg/km^2 lake area and year)		Annual mean (based on measurements)
Point sources:		
Wastewater treatment plants (kg/year)	1330	Summarized per subbasin
Industries (kg/year)	137	Summarized per subbasin
Other sources:		
Rural households (kg/year) per subbasin		Estimated based on statistics (person, type of sanitation, estimated emission from different type of sanitation (Ryegård et al., 2007)
Storm water from urban areas (kg/ year) per subbasin		Estimated based on runoff, land-use in urban areas and estimated emission from different land-use (Ryegårds et al., 2006)

1) time-independent leakage are used due to the differences in modelled runoff between the detailed vertical soil model ICECREAM and the HBV runoff model for larger areas

RESULTS AND DISCUSSION

Both runoff and P concentrations in the water are regionally calibrated, that means that model parameters are searched that describe the best fit for all subbasins in a region or in a river catchment. The parameter settings is then assumed to be robust enough to describe the runoff and concentrations from unmeasured basins, although a single subbasin may show better results if it was calibrated separately.

Each main river was calibrated and validated against measured concentrations if available. Figure 2 illustrates measured and simulated concentrations after calibration in the River Helge å (4 749 km^2) in southern Sweden at five sites. Totally there are eleven sites with measurements in the river. The model is calibrated at five sites (Almån and Outlet of Möckeln in Fig. 2). Hörlinge, Vramsån and Torsebro krv (in Fig. 2) are three of the six validation sites. Upstream of Lake Möckeln (outlet of Lake Möckeln in Fig. 2) in the northern part of the catchment the phosphorus concentration is low due to forest being the dominating land-use and retention in the lake, while the concentration is high in the southern part of the river with a lot of arable land (Almaån and Vramsån). The large Lake Möckeln also has a smoothing effect on runoff and concentrations.

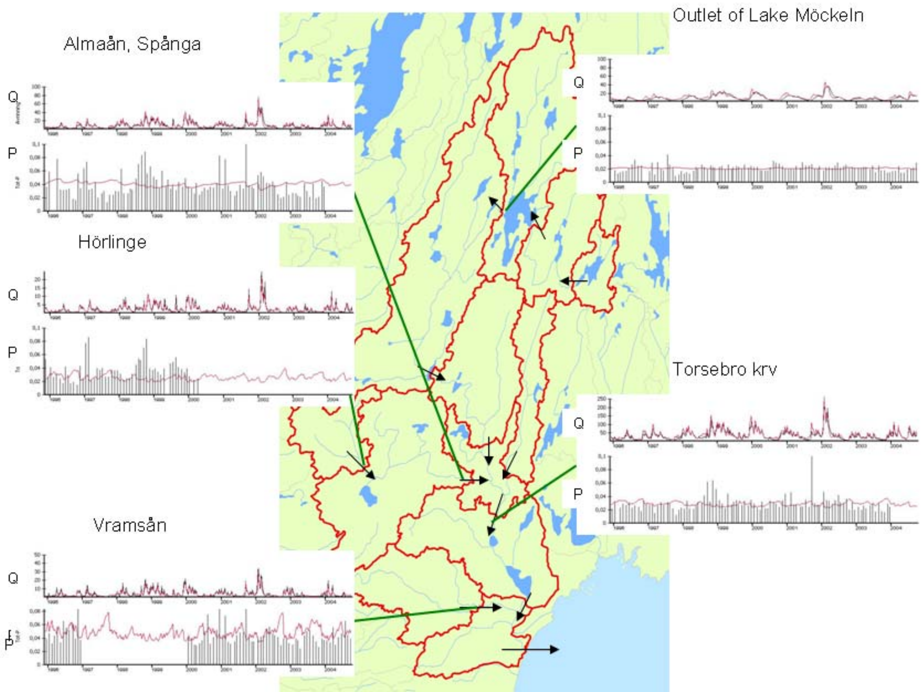


Figure 2. Simulated and measured runoff and totP concentrations in the River Helge å. Upper diagram show runoff (m^3/s), lower diagram totP, where bars are measured and line simulated concentration (with retention) (mg/l).

The total phosphorus gross load (into inland water and on islands) from Sweden (including the Norwegian part of the Klarälven and the Finish part of the Torneälven) is estimated to around 5 000 tonnes/year, while the corresponding net phosphorus transport to the sea is estimated to nearly 3 600 tonnes/year (period 1985-2004). The average phosphorus reduction is about 30 %, but there is a wide spatial variation in phosphorus reduction (Fig. 3).

Since the lakes normally are efficient phosphorus traps, the load from areas upstream of large lake systems (such as Lake Vänern, Lake Vättern and Lake Mälaren) are greatly reduced. The zone near the coast with few lakes and short residence time show little or no load reduction. The reduction in the northern part of Sweden is also lower due to low P concentrations in water.

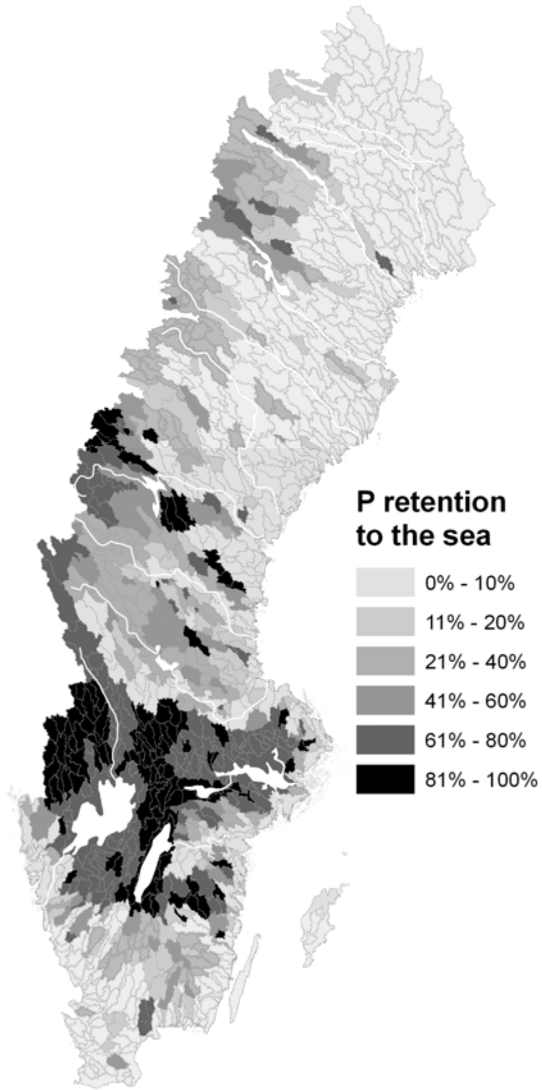


Figure 3. Retention of phosphorus load to the sea.

The simulated runoff, phosphorus concentration and transport have been compared to measurements in areas ranging from small subbasins (2 km^2) up to large river basins (50 000 km^2). In general, the dynamics and mean value of water runoff and phosphorus concentrations correspond fairly well with the measured time-series in the rivers. Of course, in small subbasin dominated by arable land and without lakes the simulated concentrations show little dynamic due to use of mean annual leakage concentrations for arable land leakage, but for larger basins with mixed land uses and with lakes the correspondence in seasonal dynamic is better.

The model performances of long term mean runoff (1985-2004) were compared at 50 runoff stations at river mouths. The simulated runoff is 1 % higher than measured, but for an individual site the difference can be more than 20 %, especially in the south of Sweden with many small rivers.

Figure 4 is a comparison between phosphorus transports calculated based on national measurements at the river's outlet and simulated phosphorous transport (period 1985-2004). For load calculated from measurements, daily runoff is available, but concentrations are measured once per month and interpolated.

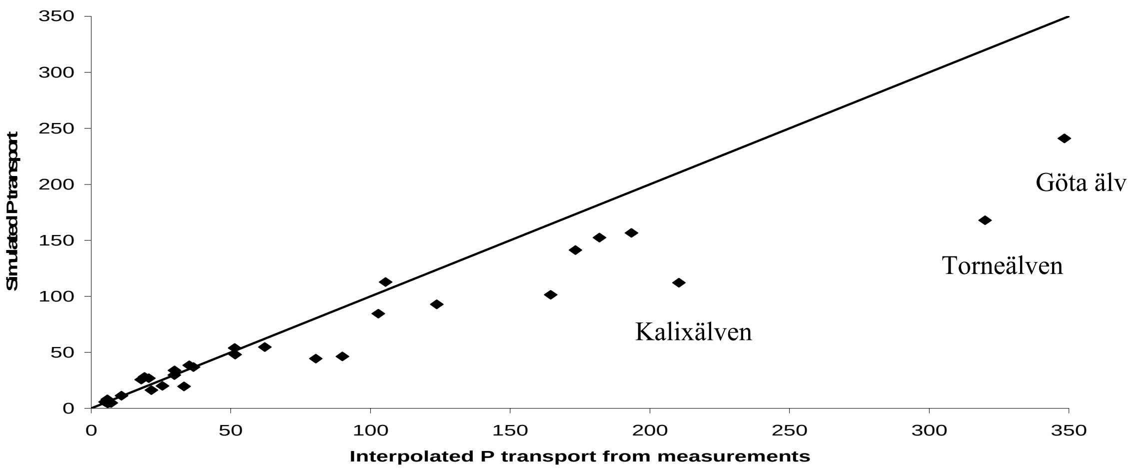


Figure 4. Comparison between interpolated totP transport (in tonnes/year) from measurements and simulated totP transport.

A study of results from each river shows that there are different reasons for the underestimation of the simulated P load in the larger rivers (Fig. 4). In the largest river, Göta älv, the simulated and measured concentrations and transport agree fairly well at the outlet of the Lake Vänern, while simulated P concentrations are too low near the outlet to the sea. All sources in the basin have been analysed. In an ongoing study we are evaluating the potential sources of phosphorus from river bank erosion between Lake Vänern and the last measurement site. The preliminary results from this study show that the contribution of phosphorus from erosion must be very large to get a good agreement between measured and simulated concentrations.

The simulated transports in nearly all northern large rivers (corresponding to totally 14 dots in Fig. 4, for example Kalixälven, Torneälven) are also lower than interpolated from measurements. This seems to depend on high peaks in concentration at the start of spring floods, which we don't capture with the current model (Fig. 5). The high peaks could depend on increased soil leakage at rapid raising ground water table. A project has started to study these matters further.

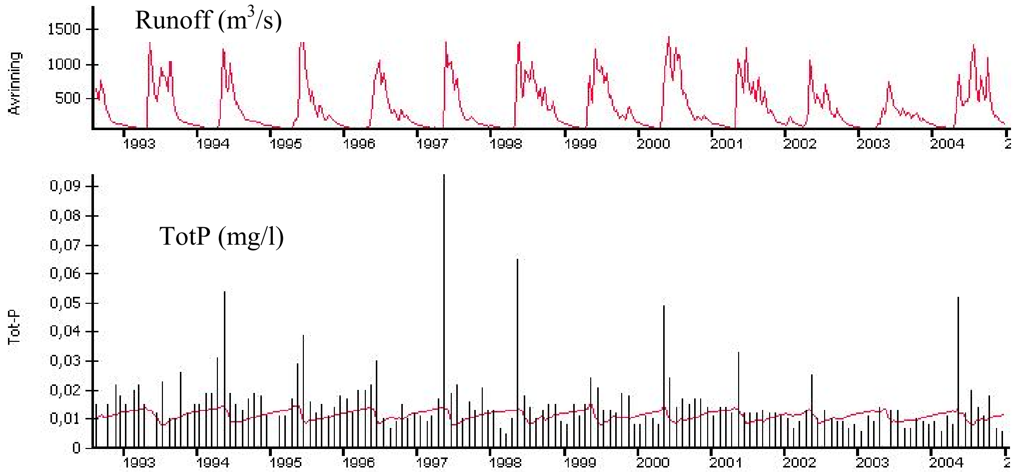


Figure 5. Simulated runoff, measured (bar) and simulated (line) totP concentration at the outlet of the River Kalixälven.

Another reason for the difference is that we in some of the rivers have calibrated on regional measured concentrations, which can differ from the national measured concentrations at the river outlet due to chemical analyses in different laboratories.

In rivers where measurements show trends of decreasing or increasing concentrations, primary the last few years of the period were used in the calibration. Trends or changing base levels can depend on actions against eutrophication, change of laboratories or other causes. In such situations it isn't correct to compare measured transport with simulated transport interpolated for the whole flow normalised period of 20 years (find at least for one station in Fig. 4).

In our comparisons we have also noted that P arable leakage seems to be too high in many regions and this will be subject to further analysis by the SMED consortium.

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LARGE SCALE PHOSPHORUS LOAD MODELLING IN FINLAND

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ABSTRACT

The Watershed Simulation and Forecasting System (WSFS) of the Finnish Environment Institute (SYKE) simulates the hydrological cycle for the whole land area of Finland (Vehviläinen & Huttunen 2002). The phosphorus load model (WSFS-P) has been developed as a part of WSFS. The WSFS-P phosphorus load model can be classified as conceptual nutrient transport model laying between the physically based nutrient transport models and simple source apportionment assessment tools. The phosphorus transport is based on the simplified conceptual method and calibration is used to estimate the parameters describing the phosphorus transport. WSFS-P is applied to the whole territory of Finland and model calibration for all river catchments are completed now.

INTRODUCTION

Several different modelling tools varying in their complexity and data requirements have been developed during the past decades to assess nutrient losses (e.g. Kronvagn et al., 1995; Arheimer and Brandt, 1998). In Finland, a few different process-oriented nutrient transport models (e.g. ICECREAM, SWAT, INCA, COUP) varying in scale and complexity have been tested for different tasks at selected river basins. The more simplified tools, such as VEPS (Tattari & Linjama, 2004) which calculates potential annual nutrient load for all 3rd level sub catchments have been utilized county-wide during the first phase of Water Framework Directive (WFD) work to locate the river basins which are potentially susceptible to risk of eutrophication. Generally speaking, the existing model variability, both process-oriented and more simple ones, are needed to point out the uncertainties in modelling results, but at the same time there is a high demand for an operational nutrient transport model which is easily applied country-wide for WFD work.

More accurate nutrient load estimates are needed in order to distinguish the effects accomplished by different water protection measures. Riverine loads, often misleadingly called measured loads, which base on daily water level measurements and on sporadic nutrient concentration measurements, are typically used to estimate the total load to the Baltic Sea. Depending on the load calculation method and on the frequency of concentration data the load estimate includes inevitably erroneousness.

The operationally used, country-wide Watershed Simulation and Forecasting System (WSFS) is currently used in Finland for simulation of hydrological cycle and for real-time flood forecasting (Vehviläinen & Huttunen 2002). It consists of hydrological model which is originally based on the HBV-model (Bergström 1976), simple river routing scheme, water balance and regulation model of lakes, automatic model calibration system, automatic data collection system, data assimilation and automatic model updating, forecasting procedure, public www-pages. Recently developed WSFS-P phosphorus loads model can be classified as conceptual nutrient transport model laying between the physically based nutrient transport models and the simple source apportionment assessment tools such as VEPS. The phosphorus transport is based on the simplified conceptual method and calibration is used to estimate the parameters describing the phosphorus transport. The lake retention processes are also included in the calculation.

The WSFS-P model has now been calibrated country-wide, but results has not been checked for all river catchments yet. The objective of this study is to point out the strengths and weaknesses of the model and to present study cases for some selected small and large river basins.

MODEL DESCRIPTION

Total phosphorus load model is incorporated directly into the WSFS as separate subroutines. The phosphorus load model consists of three parts: phosphorus transport from land areas, phosphorus transport and retention in rivers and phosphorus balance in lakes. The model unit for the phosphorus transport from land areas is 3rd level subcatchment, but if there are small lakes (surface area bigger than 1 ha) in the 3rd level subcatchment, then the model unit is small lake's catchment. There are 4 types of load simulated within each subcatchment - load from agricultural fields, load from non-agricultural territory, load from scattered settlement and point load.

Total phosphorus transport modelling from land area is based on the assumption that the main dynamic variable governing the phosphorus transport is runoff. Total phosphorus concentration has straight relationship with daily simulated runoff from each subcatchment. This assumption is based on the well-documented increase in particulate P loss with increasing erosion (Sharpley, 2007) and erosion is subsequently increasing depending on runoff depth. There are now two versions of the model with slightly different phosphorus concentration/runoff relationship – one is used in the operational model applied for the territory of Finland (1) and other is the development version for testing new ideas (2,3). The total concentration from the subcatchment is then calculated as the weighted average depending on the percentage of the different land use class.

$$c_x = \frac{r_1 \times c_{1,x} + r_2 \times c_{2,x} + r_3 \times c_{3,x} + r_4 \times c_{4,x} + r_5 \times c_{5,x}}{r} \tag{1}$$

Runoff is divided into 5 classes - r_1 stands for class 1, 0-1 mm/day, r_2 stands for class 2, 1-3 mm/day, r_3 stands for class 3, 3-6 mm/day, r_4 stands for class 4, 6-10 mm/day, r_5 stands for class 5, > 10 mm/day, c_x – daily total phosphorus concentration for each runoff class for either of two land use classes (agricultural land or non-agricultural land) (µg/l), $c_{1,x}$, $c_{2,x}$, $c_{3,x}$, $c_{4,x}$, $c_{5,x}$ – calibrated parameters which represents phosphorus concentration. In addition, year is divided into four seasons, each season has separate parameter set both for agricultural and non-agricultural areas. Seasons are decided based on snow covered area (winter) and temperature sums (summer) and vegetation season.

$$c_x = \frac{c_{fastflow,x} \times r_{fastflow} + c_{baseflow,x} \times r_{baseflow}}{r} \tag{2}$$

$$c_{fastflow,x} = x_{SCA} \times x_{plough} \times \frac{r_{fastflow}^{d}}{r_{\max,sim}} \times c_{\max,x} \tag{3}$$

c_x – daily total phosphorus concentration for each runoff class for either of two land use classes (agricultural land or non-agricultural land) (µg/l), $r_{fastflow}$ – daily simulated fast flow (subsurface runoff), mm, $r_{baseflow}$ – daily simulated base flow (groundwater flow), mm, $r_{max,sim}$ – simulated mean maximum fast flow (subsurface runoff) of 1990-2007, r – total daily simulated runoff, mm, $c_{baseflow}=c_{min}$ – base flow concentration, calibrated parameter, x_{SCA}, xplough, d, – calibrated parameters.

Phosphorus transport and retention through river is simulated in the similar way as the runoff routing through river. For each 3rd level subcatchment the river length and width is estimated. Rivers are divided into about 1 km long river stretches. Each river stretch is then simulated as a reservoir, respectively the inflow, volume and outflow of the each river stretch is simulated. The phosphorus concentration is then simulated taking into account the simulated volumes of the river reaches.

Lake hydrology in WSFS is simulated by water balance model. Water balance components, e.g. daily inflow, lake evaporation, lake precipitation and the daily volume of the lake are simulated, current water level is estimated depending on the lake's volume, the outflow from the lake is calculated according to the functional relationship between outflow and water level in the lake. Lake phosphorus balance is simulated according to the mass balance equation:

$$\frac{dm}{dt} = I(t) - Q_{out}c - \partial_{sed}Vc + rA \tag{4}$$

Mass balance differential equation is solved by using the Euler's method. Variables following - m is the mass of total phosphorus (M), t is the time (T), I(t) is the inflow loading to the lake ($M\ T^{-1}$), Q_{out} c is the outflow load from the lake ($M\ T^{-1}$), $\sigma_{sed}Vc$ is the sedimentation ($M\ T^{-1}$), rA is the internal load ($M\ T^{-1}$), σ_{sed} – is the sedimentation rate (T^{-1}), V – volume of the lake (L^3), A – is the surface area of the lake (L^2) and r – release rate of phosphorus from the sediment ($M\ L^{-2}\ T^{-1}$).

It is not an easy task to estimate the sedimentation coefficient varying both in time and from lake to lake mainly depending on the residence time, but not only. At the moment daily sedimentation coefficient constant in time is estimated by calibration for each lake separately (limits for σ_{day} is from 0.002 to 0.003). The limits for the sedimentation coefficient is estimated based on statistical equation suggested by Canfield and Bachmann (1981) for estimation annual sedimentation coefficient. Certainly sedimentation coefficient should be made dynamically changing in time depending on the daily inflowing load. Internal load component was added to the mass balance equation, because we had difficulties to simulate the concentration pattern within the year in eutrophic lakes where internal load is an important source of load during the summer months.

Calibration

Model parameters are estimated by automatic calibration, which minimizes the difference between observed and simulated concentrations in rivers and lakes and loads. River catchment is divided into calibration areas depending on the availability of the observation data. The main difference between calibration of hydrological part of the WSFS and phosphorus load model is that the water quality observations are not daily and most probably the highest peaks of the maximum concentrations/loads are missed due to the infrequent observations Lack of daily data series makes the calibration less efficient. There are two main features of the calibration what should be emphasized:

(1) all observation points located at the same calibration area are taken into account for the optimization criteria estimation:

+ the water quality observations with frequent measurements are very scattered over the catchment, therefore there is a need to use all available observations in the calibration even if the are very infrequent (few times per year),

− various number of observations at different points makes the calibration procedure to calibrate the parameters based on the observations at the more frequently observed points.

(2) due to the fact that the different type of observations are taken into account in the optimization criteria it is necessary to estimate the appropriate weights for each type of observations to reach the best possible coincidence between simulated and observed concentrations and loads. Appropriate weight values are tested on some experimental catchments and then applied to other catchments in automatic calibration.

APPLICATION TO FINNISH TERRITORY

Phosphorus load model has been applied now to the whole territory of Finland, 74 river catchments and also coastal areas. Most of the catchments has been calibrated, except the largest river catchments in Finland are still under calibration (Vuoksi 52 700 km^2, Kymijoki 37 150 km^2, Kokemäenjoki 27 000 km^2, Kemijoki 49 400 km^2, Paatsjoki 14 500 km^2). The results for calibrated catchments must be checked before further use and in this study the checking is done for Archipelago Sea river catchments – 9 river catchments and coastal area with total catchment of 6336 km^2, Karvianjoki catchment 3438 km^2 and Iisalmen water course catchment 5583 km^2.

Working on the country-wide scale requires us to be able to simulate wide variety of catchments differing in many ways – hydrological conditions, geomorphologic conditions, land use conditions, phosphorus loading conditions, catchment retention conditions. The know-how to do it has been building up during developing the model on different catchments.

Catchments in Southern Finland

We started with agricultural clayey soil catchment without lakes where phosphorus runoff was mainly governed by erosion processes and our concentration/runoff linear relationship worked well. Similar conditions are in southern part of Finland – agricultural catchments on mineral soils, less amount of lakes. We can state that the developed model gives quite good results for this kind of catchments.

We have compared simulated annual loads for Archipelago Sea catchments with HELCOM estimates which are estimated by mean monthly method by multiplying mean monthly discharge and mean monthly concentration. On the long run results seem to be quite close for both methods – for Aurajoki (874 km^2) mean annual phosphorus load by WSFS-P is 61 t/year and HELCOM data is 55 t/year (Figure 1), for Paimionjoki (1088 km^2) mean annual phosphorus load by WSFS-P is 68 t/year and HELCOM data is 71 t/year.

When we look at the daily simulation of the loads (Figure 2), model gives quite satisfactory results at the average load levels (R^2=0.90 for phosphorus load simulation), but when simulating extremes, like during December 2006 (observed phosphorus concentration 1100 μ/l), daily simulations underestimate the phosphorus daily loads. Advantage of the model is that it simulates daily values depending on daily runoff, but by the mean monthly method some daily load peaks can be missed, because of not observing the concentration at that particular day.

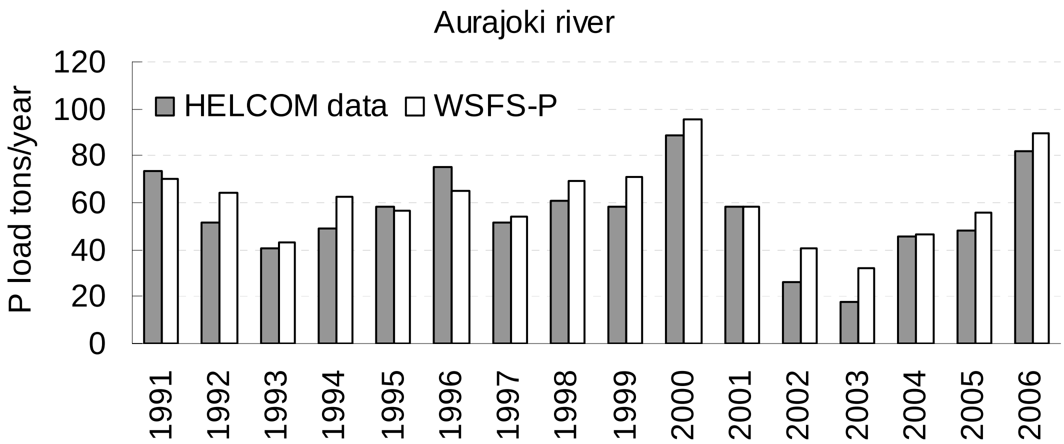

Figure 1. Comparison of HELCOM data and WSFS-P annual phosphorus loads for Aurajoki river (1991-2006).

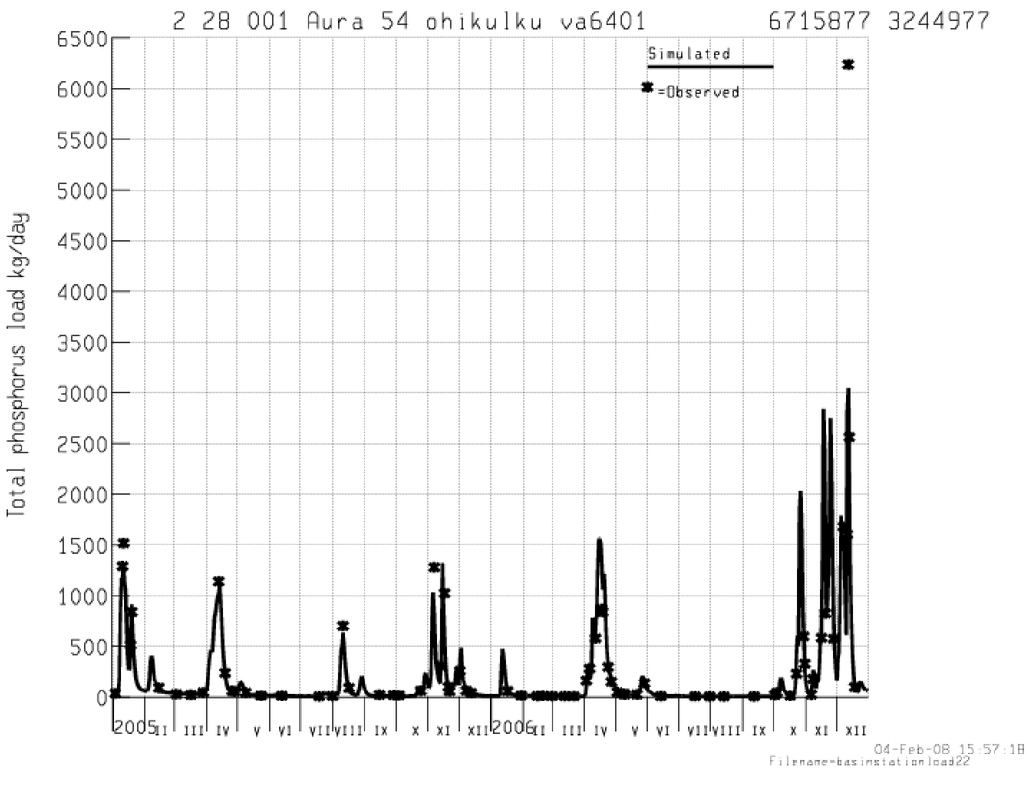

Figure 2. Daily simulated and observed phosphorus loads at Aurajoki river.

Forested catchments with lakes

Moving north to the Central Finland and Western coast the river catchment types change, there are much less agricultural areas, peat soil amount in catchment can be high and the number of lakes increases. In peat soil dominated, forested catchments with less agriculture concentration/runoff relationship is not linear any more, but becomes logarithmic. Soil erosion carrying P during runoff events is still the main phosphorus transporting mechanism from land areas, but the variation of concentrations during high flow periods and low flow periods are considerably smaller than in agricultural catchments dominated by mineral soil. Runoff from grass or forest land carries little sediment (Sharpley and Rekolainen, 1997) and therefore phosphorus concentrations during high flow is relatively low. On the other hand P concentrations in water percolating through the soil profile is high in peaty soils due to the low adsorption affinity and capacity for P, due to the predominantly negative charged surfaces and the complexing of Al and Fe by organic matter (Sharpley and Rekolainen, 1997). In presence of lakes more smooth concentration pattern in streams can certainly be explained by retention effect of lakes on both runoff retention and nutrient retention.

High phosphorus concentrations during low flow periods can be explained by several sources: for river reaches with point source outlets and scattered settlement the ratio of effluent flow to river flow is higher during low flow periods. High phosphorus concentrations during low flow period are observed also in the small rivers and brooks without point source and scattered settlement, it might be that geochemical processes in the soil saturated zone itself, possibly in brook sediments, cause release of dissolved reactive phosphorus (Lazzarotto, 2004). Increased concentrations during low flows are especially to be noted in the peat land drainage areas and peat mining areas (Sallantaus, 1985, Klove, 2001). On the catchment scale high concentrations during the low flow periods might be caused by combination of all three above mentioned sources depending on the soils, land use and point source/scattered settlement availability. Model has been adjusted to simulate catchments with high amount of peat soils by dividing phosphorus transport into two parts – transport by fast flow and transport by base flow (equations 2,3). In-stream processes still need to be added to the phosphorus load model.

Its much more challenging to simulate phosphorus concentrations where there is little variation (Figure 3). Anyhow we manage to simulate the mean concentration level, but daily variation is not so well simulated in this case due to several reasons – this point is located downstream of the regulated lake, at the end of Karvianjoki catchment. Simulating the concentration pattern in this point means integrating all model parts - catchment, river and lake simulation at the daily time step. However, phosphorus load simulation result is always better, for this particular point R^2=0.83.

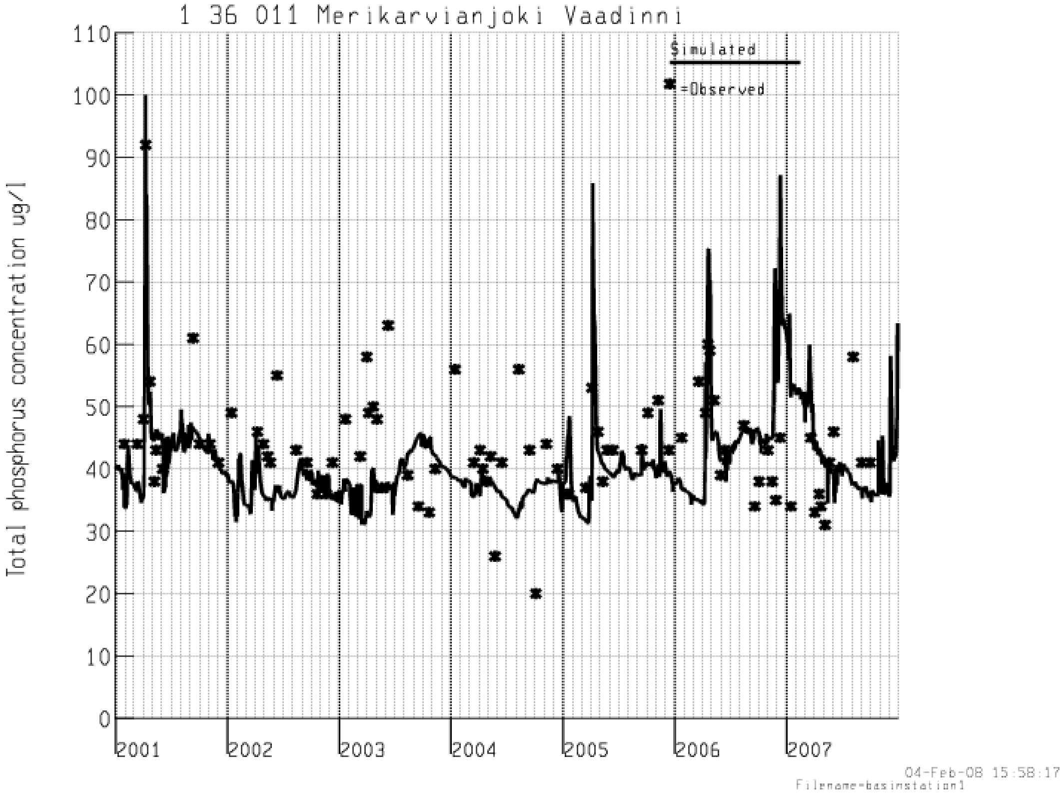

Figure 3. Daily simulated and observed phosphorus concentrations at Merikarvianjoki - Vaadinniemi river point.

When we look at the daily load simulation (Figure 3), our model gives quite satisfactory results at the average load levels, but when simulating extremes, like during December 2006 (observed phosphorus concentration 1100 μ/l), daily simulations underestimate the daily phosphorus loads. Advantage of the model is that it simulates daily values depending on daily runoff, but by the mean monthly method some daily load peaks can be missed, because no observations are made at that particular day.

DISCUSSION AND CONCLUSIONS

Phosphorus concentration sampling frequency is typically quite poor and hence not enough data is available for proper model calibration. Therefore, it is difficult to argue whether the simulated concentrations are right or wrong. During the low flow periods provided measurement frequency is good, the concentration levels during low flow periods can be identified, but very often peaks during high flow are missed. Currently automatic measurement techniques of the nutrient and sediment concentrations are being adopted which will lead to more accurate load estimates and will further help in getting better process descriptions into the model.

This study clearly demonstrates that different geographical regions require different aspects into model.

Automatic model calibration system produces huge amount of output data country-wide. It is essential that the modeling results are closely checked before further use.

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IMPACT OF WATERSHED CHARACTERISTICS AND CLIMATE CHANGE ON AQUATIC CHEMISTRY IN RIVERS OF LATVIA

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ABSTRACT

The aim of this study is to describe relationships between catchment characteristics, climate and aquatic chemistry to determine factors controlling runoff of dissolved substances, spatial and long-term variability of water chemical composition, and possible impacts of pollution sources. Long-term variability of river discharge should be considered as one of the major driving processes influencing water chemical composition and loads of dissolved substances. However, anthropogenic activities can change loads of dissolved substances, especially nutrients. Our study showed a positive correlation between the coverage of agricultural land within the river subbasins and concentrations of N_{tot} ($r = 0.61$) as well as P_{tot} ($r = 0.42$). Between coverage of forests and concentrations of N_{tot} and P_{tot} there was a negative correlation ($r = -0.56$ and $r = -0.40$, respectively). Water quality, especially regarding nutrient concentrations for the study period are influenced both by intensity of natural processes and human loading. These factors affect nutrient loadings from various pollution sources, processes of nutrient transport, as well as transformations and retention.

Keywords: catchment properties, land use, Latvia, water quality

INTRODUCTION

Many factors control the concentrations of dissolved substances and suspended matter in river waters. However, the determinants of aquatic chemistry can be grouped and analysed using the concept about watershed influence on water quality. As far as development of water composition takes place in whole catchment area, all activities taking place there can influence water quality. The major factors influencing aquatic chemistry are geological and geographical factors (catchment geology, relief, soils, climate, hydrological regime), biological factors, and anthropogenic factors (direct point source impacts and diffuse loading, impact on river system hydrology). It is evident that impacts of many of these factors are overlapping.

Flows of dissolved substances have been analyzed worldwide, particularly in regard to human loading, climate change, and forestry activities. The pattern and intensity of biological processes within catchments can also affect the flows of dissolved substances, at first those of nutrients (Scott et al., 1998). On the other hand, natural processes much interfere with human-induced processes. Human impacts alter the chemical composition of waters and supplement the loads of dissolved substances, especially nutrients to sea and coastal areas. Transport of pollution from diffuse sources and also industrial and municipal effluents can be sources of increased fluxes of materials (Jarvie et al., 2002). Leaching of nutrients from agricultural areas due to surface runoff, especially during flood periods can be of key importance in intensively used agricultural areas (Ekholm et al., 2000). At the same time, an understanding of the contemporary relationships between watershed characteristics and river water composition provides a fundamental basis for assessing the impact of future changes in land use, climate and human impacts in different combinations. To implement river basin management as suggests EU Water Framework directive and Latvian legislation it is highly important to evaluate processes within the river catchment and their impacts on water quality.

It is clear that tight links exist between catchment properties and flows of dissolved substances, but these relations are regionally specific (Smith et al., 2003; Rantakari et al., 2004). However, there are few publications concerning water chemical composition and factors influencing aquatic chemistry for situations relevant for Latvia (Vagstad et al., 2000; Kļaviņš et al., 2002). Latvia has witnessed a substantial reduction of human loads to the environment due to transformation of the political, economic and social systems at the beginning of 1990'ies. For example, fertilizer and manure use has fallen by five times and the number of livestock has decreased by around three times (Lofgren et al., 1999), and it is assumed that these changes have reduced loading of nutrients to the surface water.

The aim of this study is to describe relationships between river discharge, catchment characteristics and water chemistry to determine factors controlling runoff of dissolved substances, spatial variability of water chemical composition, and possible impacts of pollution sources.

MATERIALS AND METHODS

The study site covers the entire territory of Latvia (Fig. 1). Latvia is located on the north-western part of East European Plain on the coast of the Baltic Sea. The territory of Latvia occupies 64 000 km^2. Bedrock is covered by Quaternary deposits consisting of moraine material, limnoglacial or fluvioglacial deposits. The climatic conditions in Latvia can be characterized as humid (Klavins et al., 2002).

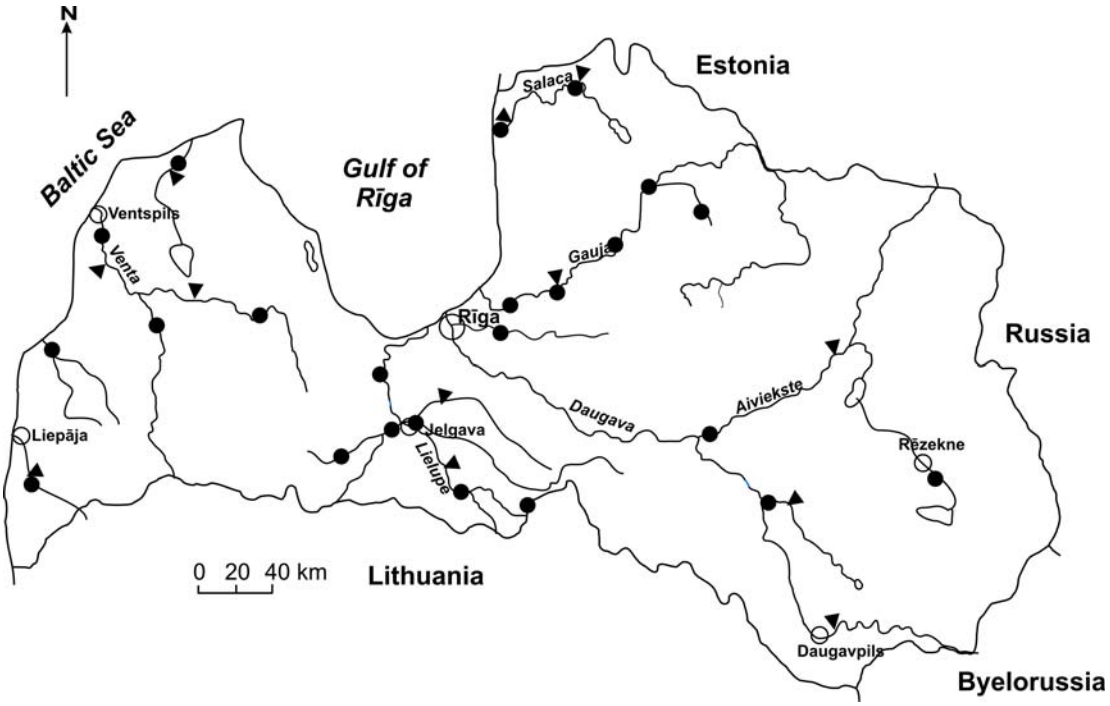

Figure 1. Location of water quality (#) and hydrological (%) monitoring sites.

Data on water composition and monthly mean river discharge used in this study were obtained from state monitoring programme results carried out by the Latvian Environment, Geology, and Meteorology Agency for time period 1977 – 2001. Water composition data contains information about monthly concentrations of $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, N_{tot}, P_{tot}, chemical oxygen demand (COD), water colour and bimonthly concentrations of HCO_3^-, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, Na^+, K^+ and mineralization. Concentrations of $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$, N_{tot}, P_{tot}, SO_4^{2-} and COD were determined spectrophotometrically. Water colour was determined using Pt/Co scale spectrophotometrically. Concentrations of HCO_3^-, Ca^{2+}, Mg^{2+} and Cl^- were determined titrimetrically, but Na^+ and K^+ by flame photometry. Water mineralization was expressed as a sum of concentrations of inorganic ions (Standard Methods…, 1973). Data on land use within river subbasins were obtained from the GIS data base "Corine Land Cover Latvia" (2003).

Before analysis, the data set containing mean values of concentrations of dissolved substances and data on land-use proportions in 22 river basins were examined for normality of the distribution by Kolmogorov-Smirnov test. The relationship between land-use types and aquatic chemistry (for time period 1991-2001) were studied using Pearson's r correlation coefficients, and factor analysis. Factor analysis is a statistical technique which is used for reducing the dimensionality of large data sets without loosing the information. Factor analysis includes principal components analysis (PCA), which is a factor extraction method used to form uncorrelated linear combinations of the observed variables. The first component has maximum variance. Successive components explain progressively smaller portions of the variance and are all uncorrelated with each other (Jöreskog and Sörbom, 1979). PCA with Varimax rotation method was conducted using program SPSS 12.0 for Windows.

RESULTS AND DISCUSSION

Both the spatial and seasonal variability of concentrations of dissolved substances in surface waters of Latvia can be considered to be comparatively high (Fig. 2). The highest concentrations of dissolved substances but especially nutrients are usual for rivers in the Lielupe and Aiviekste basins.

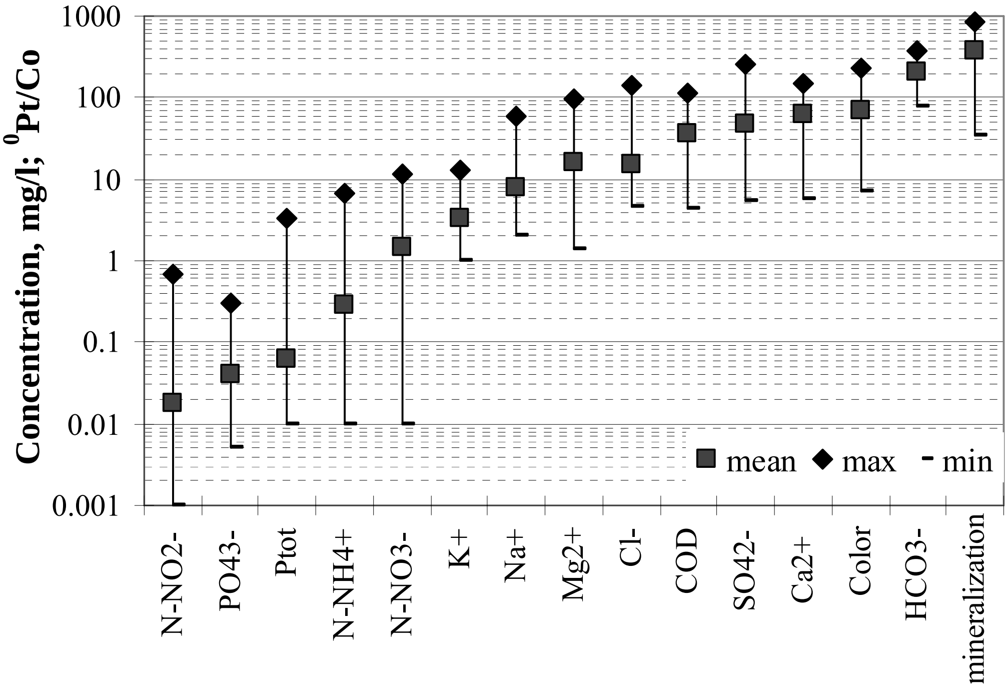

Figure 2. Variability of major dissolved substances in rivers of Latvia (1977-2003).

Water runoff is one of the main factors influencing aquatic chemistry. Discharge has tight negative correlation ($p \leq 0.01$) with concentrations of the major inorganic ions (HCO_3^-, SO_4^{2-}, Ca^{2+}) and total mineralization (Table 1). Discharge is well positively correlated with indicators of the concentration of dissolved organic matter and nutrients, especially nitrates. Concentrations of base cations differ much from stream to stream at low discharges, mainly due to inflow of groundwater of differing chemical composition. Concentrations of base cations become increasingly similar as discharge increases, probably due to inflow of soil waters and precipitation.

Table 1. Correlation between discharge and selected water quality parameters in Latvian rivers (1977-1999).

River	***Color***	***COD***	***$N–NH_4^+$***	***$N–NO_3^–$***	***$P–PO_4^{3–}$***	***Minera-lization***	***$HCO_3^–$***	***$SO_4^{2–}$***	***$Cl^–$***	***Ca^{2+}***	***Na^+***	***K^+***
Venta	0,654**	0,254**	0,162**	0,618**	0,420**	–0,413**	–0,498**	–0,187*	–0,316**	–0,240**	–0,668**	–0,096
	N=248	N=259	N=258	N=240	N=249	N=150	N=149	N=156	N=185	N=156	N=159	N=158
Tebra	0,545**	0,203**	–0,079	0,484**	0,237*	–0,687**	–0,701**	–0,315**	–0,128	–0,625**	–0,476**	0,167
	N=196	N=196	N=194	N=181	N=111	N=124	N=123	N=118	N=147	N=117	N=119	N=119
Lielupe	0,528**	0,209**	–0,049	0,487**	–0,362**	–0,633**	–0,433**	–0,707**	–0,624**	–0,642**	–0,715**	–0,363**
	N=264	N=264	N=267	N=267	N=267	N=134	N=136	N=140	N=149	N=140	N=139	N=140
Salaca	0,701**	0,258**	0,003	0,439**	–0,058	–0,346**	–0,390**	–0,195*	–0,146	–0,305**	–0,354**	–0,313**
	N=250	N=267	N=249	N=232	N=240	N=138	N=138	N=138	N=140	N=138	N=145	N=144
Gauja	0,836**	0,359**	–0,012	0,618**	0,104	–0,835**	–0,867**	–0,545**	–0,420**	–0,832**	–0,646**	–0,169*
	N=250	N=261	N=258	N=233	N=257	N=143	N=142	N=143	N=147	N=143	N=148	N=148
Tulija	0,366**	0,285**	0,036	0,558**	0,016	–0,796**	–0,795**	–0,586**	–0,317**	–0,799**	–0,567**	0,237*
	N=106	N=106	N=101	N=104	N=92	N=98	N=97	N=98	N=99	N=96	N=92	N=92
Daugava	0,710**	0,249**	–0,119	0,327**	0,036	–0,726**	–0,787**	–0,435**	–0,397**	–0,698**	–0,752**	0,109
	N=225	N=229	N=231	N=212	N=215	N=141	N=136	N=141	N=161	N=141	N=145	N=145
Aiviekste	0,697**	0,193**	0,014	0,396**	–0,093	–0,633**	–0,700**	–0,298**	–0,324**	–0,622**	–0,680**	–0,139
	N=212	N=222	N=222	N=204	N=223	N=126	N=126	N=126	N=144	N=127	N=135	N=135
Dubna	0,683**	0,141	–0,028	0,626**	–0,222**	–0,688**	–0,736**	–0,251**	–0,406**	–0,615**	–0,763**	–0,008
	N=211	N=223	N=222	N=216	N=214	N=119	N=120	N=119	N=120	N=120	N=125	N=126

* – $p \leq 0,05$

** – $p \leq 0,01$

N – number of observations

Land use patterns within the catchment were obtained from the *Corine Land Cover 2000 Latvija* data base. Nutrient concentrations in the river waters are correlated with the proportion of land use types in the catchment. In general, the correlation between N_{tot} concentration and land use pattern is closer than that between P_{tot} and land use pattern due to different inflow, transport and retention processes of these nutrients. There is a positive correlation ($r = 0.61$ and $r = 0.42$, respectively; $p = 0.05$) between the coverage of agricultural land within the river basins and concentrations of N_{tot} as well as P_{tot}. Between coverage of forests and concentrations of N_{tot} and P_{tot} there was a negative correlation ($r = -0.56$ and $r = -0.40$, respectively; $p = 0.05$) (Fig. 3).

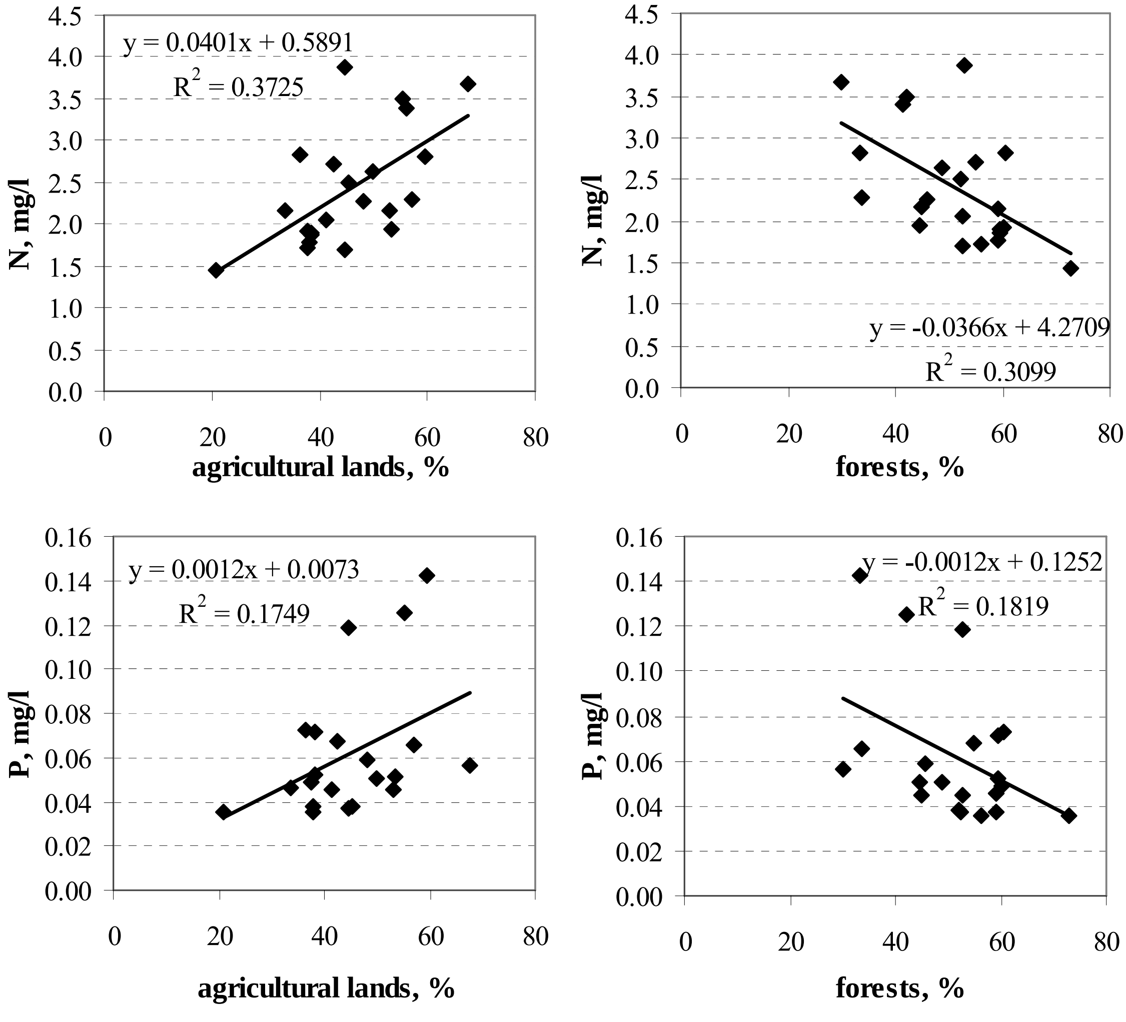

Figure 3. Correlations between concentrations of total nitrogen and total phosphorus and percentage of agricultural lands and forests in river basins.

Within this study, multivariate data analysis methods were applied to average concentrations (for time period 1991-2001) of 14 different water quality ingredients obtained from 22 monitoring stations. The first seven principal components described 99.1 % of the original data set and three principal components with eigenvalues greater than one explained 90.5 % of the data variability. Calculated factor loadings showed that the first factor was related to changes in concentrations of major inorganic ions, and to lesser extent to concentrations of total N and $N\text{-}NO_3^-$ (Table 2). The first factor describes mainly natural processes. The second factor had a stronger correlation with total P, PO_4^{3-}, $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$, and a weaker correlation with total N and $N\text{-}NO_3^-$. This factor might be related to pollution from point sources. Factor analysis reveals that factors determining concentrations of total N and $N\text{-}NO_3^-$ differ from those determining concentrations of $N\text{-}NH_4^+$, $N\text{-}NO_2^-$ and phosphorous compounds. The third factor was related to COD concentrations, and also but less with $N\text{-}NH_4^+$ concentrations in river waters. This factor probably can be explained by the impact of wetlands on water composition.

*Table 2. Matrix of rotated factor loading of ingredients of water chemical composition of Latvian rivers (data from 22 monitoring stations, 1991-2001) on 3 PCA components.**

Ingredients of water composition	**Components**		
	1	**2**	**3**
$\mathbf{N_{tot}}$	**0,761**	**0,564**	0,031
$\mathbf{P_{tot}}$	0,143	**0,970**	-0,017
$\mathbf{N\text{-}NH_4^+}$	0,198	**0,793**	0,418
$\mathbf{N\text{-}NO_2^-}$	0,207	**0,950**	0,140
$\mathbf{N\text{-}NO_3^-}$	**0,697**	**0,631**	0,002
$\mathbf{PO_4^{3-}}$	0,089	**0,973**	-0,056
COD	0,118	0,101	**0,944**
$\mathbf{Mg^{2+}}$	**0,952**	0,027	-0,023
$\mathbf{Cl^-}$	**0,828**	0,140	0,209
$\mathbf{SO_4^{2-}}$	**0,900**	0,122	0,209
$\mathbf{Na^+}$	**0,847**	0,253	0,299
$\mathbf{K^+}$	**0,924**	0,231	0,238
$\mathbf{HCO_3^-}$	**0,921**	0,152	-0,245
$\mathbf{Ca^{2+}}$	**0,964**	0,172	-0,024

*Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser normalization. Rotation converged in 4 iterations. Factor loadings **in bold** are greater than 0.5.

CONCLUSIONS

Water quality for the study period is influenced both by intensity of natural processes and human loading. Long-term variability of river discharge should be considered as one of the major driving processes influencing water chemical composition and loads of dissolved substances. However, anthropogenic activities can change loads of dissolved substances, especially nutrients. This study showed a positive correlation between the coverage of agricultural land within the river subbasins and concentrations of N_{tot} as well as P_{tot}. Both natural and anthropogenic factors affect nutrient loadings from various pollution sources, processes of nutrient transport, as well as transformations and retention.

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THE HEAVY METAL BALANCE IN TWO SMALL INTEGRATED MONITORING CATCHMENTS IN LATVIA

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ABSTRACT

Heavy metals have accumulated in the soil and catchments over a long period of years. Very high accumulation can be hazardous to the ecosystem, including vegetation, where root damage is one of the impacts. Heavy metals are leached into the surface waters where freshwater organisms, among which are fishes, may have an elevated heavy metal content.

The heavy metal balances were calculated for two Latvian ICP-IM (International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems) sites located in the catchments of small forest streams, Taurene and Rucava. The balance of metals is a tool that allows to estimate net accumulation and the loss of substances in an ecosystem and the stability of an ecosystem.

Mass budgets were calculated using bulk deposition, throughfall and runoff data. Output responses from the catchments were calculated from the runoff water data.

The calculation results for 1995-2005 show very high accumulation of heavy metals in the catchments of the forest streams. Lead and cadmium showed the highest accumulation of up to 98 %.

INTRODUCTION

From an ecological point of view, air pollution may be defined as ‘a condition in which concentrations of substances in the air are elevated above typical background levels to the degree that they are measurable and have undesirable effects on organisms and/or ecosystems’. Heavy metals are the most important air pollutants to forest ecosystems. Heavy metals have accumulated in the soil and catchments over a long period of years. Very high accumulation can be hazardous to the ecosystem, including vegetation, where root damage is one of the impacts. Heavy metals are leached into the surface waters where freshwater organisms, among which are fishes, may have an elevated heavy metal content.

Input-output (or mass balance) budgets are a useful means of describing the mobility, retention and flows of substances, including heavy metals, in the environment. The interaction between the airborne pollution pressure and the ecosystems is complex and depends on some interacting factors such as catchment geology, climate, hydrological flow path and management. Within the framework of the International Co-operative Program on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP-IM), heavy metals have been measured of two IM sites in Latvia, Rucava and Taurene. This study presents balance calculations for heavy metals in the catchments of two small forest streams for the period 1995-2005.

Integrated Monitoring site description

The IM sites Rucava and Taurene are located in forested areas in western and central Latvia (Fig. 1).

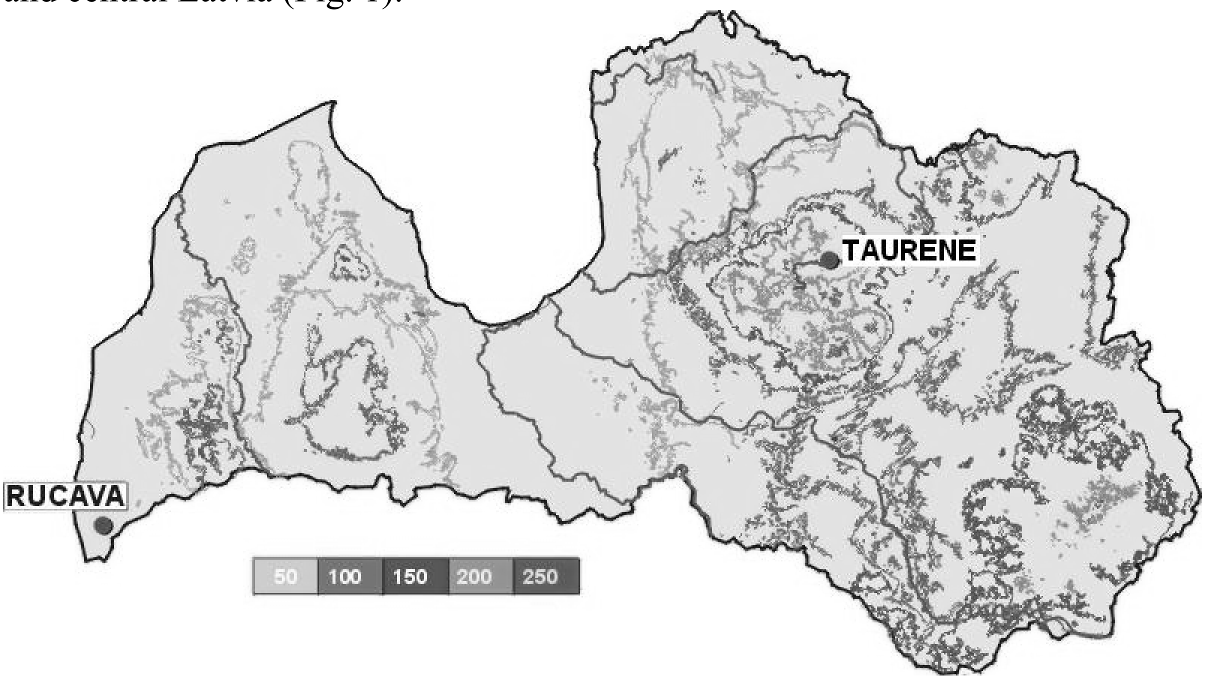


Figure 1. The location of ICP-IM sites.

The ICP-IM site Rucava is situated at 56º12' N and 21º07' E in the south-west of Latvia, some 10 km east from the Baltic Sea. The area of the catchment is 6.65 km^2, with 5.36 km^2 to a discharge measurement site. The topography is very flat, 6.2 to 15.7 m above sea level.

Almost the whole of the catchment area (97%) is covered by forests, representing 15 forest types. Over a half of the forests are on moist and excessively wet substrates. Most common are forests on wet mineral soils (44% of the area): *Myrtilloso-sphagnosa* (34%), *Vacciniosa-sphagnosa* (9%); forests on wet peaty soils (18 %): *Caricoso-phragmitosa* (12%) and

Dryopterioso-cariosa (4%). A small part (5%) of the wetland forests is drained. The forests on dry mineral soils account for one third (34%) of the total area, the most common being *Hylocomiosa* (16%) and *Myrtillosa* (11%). In terms of trophicity, the mesotrophic forest type dominate the area (80%) followed by oligotrophic forests (19%); the share of eutrophic forests is insignificant. During the years 1933-1996, the dry type forests were gradually diminishing, while the area of wetland forests was increasing (especially after 1960). The proportion of oligotrophic sites has somewhat reduced, and that of mesotrophic sites – increased.

The soil in the vicinity of the site is mainly sandy. Much of the upper catchment area is covered with histosols. Due to the previous drainage, the extent of decomposition in the peat varies, with raised bogs being more acid (pH_{H2O}<5.5) than in the rest of the wetland area. On the slopes with shallow water tables, there is a transition from Maplic Podzols to Ferric Podzols with the iron-rich cemented B-horizon. The soil texture is sandy throughout the area, being coarser on the left side of the river when looking down the stream.

The ICP-IM area Taurene is situated at 57º10' N and 25º41' E in the east of the country, in the northern part of Vidzeme Hills. The area has a hilly-range landscape, with round-shaped hills with convex slopes. The total area of the catchment is 0.27 km^2, with 0.10 km^2 to a discharge measuring section. Absolute height is 184.3 to 191.8 m above sea level.

As in the IM site Rucava, almost the whole of the catchment (93 %) is covered by forests that represent 7 forest types. Dry type forests dominate (67%): *Hylocomiosa* (41%) and *Myrtillosa* (21%), are found on the knolls and their slopes; forests on wet peaty soils (*Dryopterioso-caricosa* – 25% and *Caricoso phragmitosa* – 5%) are found along the forest brook. In terms of trophicity, mesotrophic forest types are dominant (93%); oligotrophic forests cover only 7% of the area; there are no eutrophic forests over the IM Taurene area. During the 20th century, there have been no changes in the ratio of the dry to wet type forests. However, the proportion of dry oligotrophic forests has reduced significantly, from 16% in 1926 to 4% in 1988 and testifies to the eutrophication of the forest sites.

The soil material is formed of moraine loam and sand (72%) and sand (20%). The upper Devonian deposits lie at a depth of 100-120m and are formed of dolomites, silt stones and marls seam. Acidic Histosols (pH_{H2O}<5.5) are found in the Taurene river's upper basin. Histosols occur throughout the river plain and pH of the peat becomes more neutral down the river (pH_{H2O}>5.5).

The whole of Latvia is within one climatic region, moderately mild and moist. Due to the proximity of sea, Rucava is within a zone of a milder marine climate with the longest annual mean duration of insolation, the highest annual mean air temperature, the longest period of vegetation and no air and ground frosts, and by the shortest period of snow cover and the least snow depth. The annual average temperature is 6.3ºC, precipitation averages to 772 mm and the vegetation period lasts 198 days. Under the influence of Vidzemes Hills, the climate of Taurene is more continental, with a high cloud amount, the shortest annual mean insolation duration, the longest period of snow cover and the deepest snow, the shortest period of vegetation and no air and ground frosts. The annual mean temperature is 4.5ºC and the total average precipitation amounts to 727 mm; the vegetation period lasts 186 days. (TemaNord 1996:552)

MATERIALS AND METHODS

Heavy metal budgets for the IM sites were calculated using the open area bulk precipitation, forest stand throughfall and runoff water data. There is one discharge station at each IM site catchment where water level is continuously measured by water stage recording, and discharge measurements are taken once per month. The measured discharges ($l\ s^{-1}$) is transformed into specific runoff values ($l\ s^{-1}\ km^{-2}$) using the surface-area of the catchments. Open area precipitation samples are collected as bulk deposition from 2 collectors. For stand precipitation 7 throughfall collectors in summer and 4 – in winter are used.

The analytical techniques and observation programmes carried out at the ICP-IM sites are provided in Table 1. The Manual for Integrated Monitoring is followed in sampling and analysis made in a laboratory that has passed accreditation according to the LVS EN ISO/IEC 17025 standard.

Table 1. Methods used for sampling and chemical analysis.

Observation programme	Sampling frequency	Parameter	Period of observation	Analysis method
Open area precipitation	monthly	Pb	1995-2005	Atomic absorption spectrometry, graphite furnace
Throughfall		Cd	1995-2005	Atomic absorption spectrometry, graphite furnace
Surface water at discharge site		Zn	1995-2005	Atomic absorption spectrometry, flame
		Cu	1995-2005	Atomic absorption spectrometry, graphite furnace

The ions included in the output/input calculations were: Pb, Cd, Cu and Zn. The determination of total deposition to the catchments was based on open field measurements (bulk deposition) and throughfall studies. For budget calculation, the method elaborated in Finland was used (Forsius et al., 1996).

The total deposition onto the forests was estimated using throughfall data. In missing throughfall data, open field data were used.

Deposition (dep) calculations are made according to the equation:

$$\text{dep} = \sum_{I=1}^{12} C_i \times P_i \text{ , (mg m}^{-2}\text{ yr}^{-1}\text{), where}$$

C_i – monthly concentration of a substance in atmospheric deposition, mg/l
P_i – monthly precipitation, mm

The output fluxes (out) from the basin are calculated from the quality and quantity of the runoff water from the equation:

$$\text{out} = 31.54 \times Q_{an} \left(\frac{\sum_{i=1}^{12} C_i \times Q_i}{\sum_{i=1}^{12} Q_i} \right) \text{, (mg m}^{-2}\text{ yr}^{-1}\text{), where}$$

Q_{an} – annual specific runoff, l × $s^{-1}km^2$
Q_i – monthly specific runoff, l × $s^{-1}km^2$
C_i – monthly mean concentration of a substance, mg/l
The net export is defined as:

$$\text{p.ne} = \frac{100 \times (\text{out} - \text{dep})}{\text{dep}}$$

In negative p.ne values, the substances accumulate in the catchment, in positive - are leached out; zero values show that the substance concentrations are in balance.

RESULTS

The annual mean net export (%) of heavy metals is shown in Table 2. In the heavy metals balance calculations, there may be various sources of uncertainty: changing analysis method; errors in the chemical analysis, precipitation and runoff water collection; quantification of precipitation; transportation of samples; land use information, as well as the various assumptions in the calculation methods.

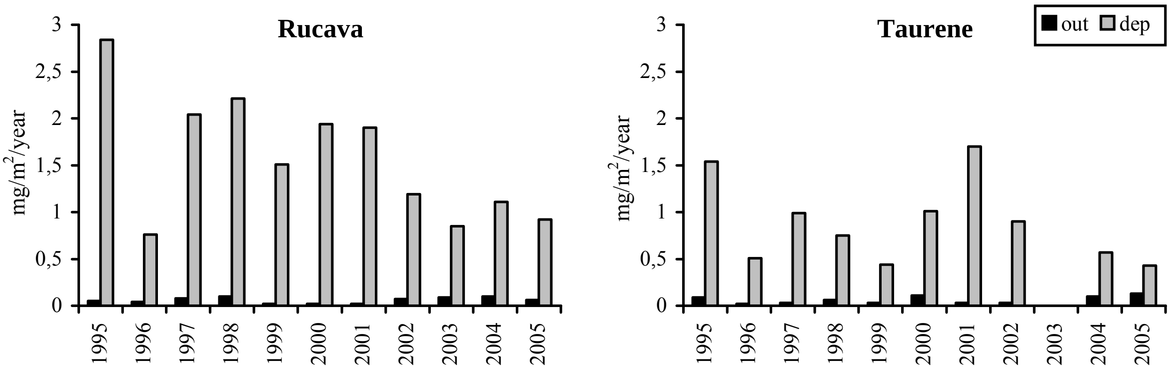
Table 2. Net export (%) of heavy metals in forest stream catchments, 1995-2005.

	Rucava	**Taurene**
Pb	-95	-91
Cd	-92	-89
Cu	-74	-86
Zn	-89	-90

The annual mean budget values for 1995-2002 indicate that much of the atmospheric inputs of heavy metals retained within both forest stream catchments. The relative amount of retention was 89% or more, except for copper (74%) at Rucava. For Pb and Cd, the retention at Rucava was more than 92%.

Judging from Figure 2, annual deposition of lead at Rucava is twice higher than at Taurene, cadmium - even three times higher. This is caused by long-range transboundary pollution from Western Europe and Central Europe regions, as the IM Rucava site is in the immediate region of its impact. Despite this fact, lead input loads in Rucava forest stream catchment showed a significant downward tendency, from 2.84 to 0.92 mg/m^2/year. This is attributable to decreased in Pb concentrations in atmospheric deposition due to lower Pb emissions in Europe, partly because of Pb-free gasoline introduction (EMEP Report, 2000). The same downward tendency has been observed since 1998 at Rucava in annual deposition of Cd. In turn, Cd and Pb input loads fluctuated in the Taurene forest stream catchment in the period 1995-2005, with absolute loads in 1995 and 2001. Maximum output loads of Cd and Pb in the Rucava forest stream catchment were in 1998, in the highest runoff, and Pb in 2004 due to increases in concentration. In Taurene, output load of Pb reached its maximum in 2000 and 2005 due to increases in concentration in the stream, but output load of Cd - in 1998, in the highest runoff.

a)



b)

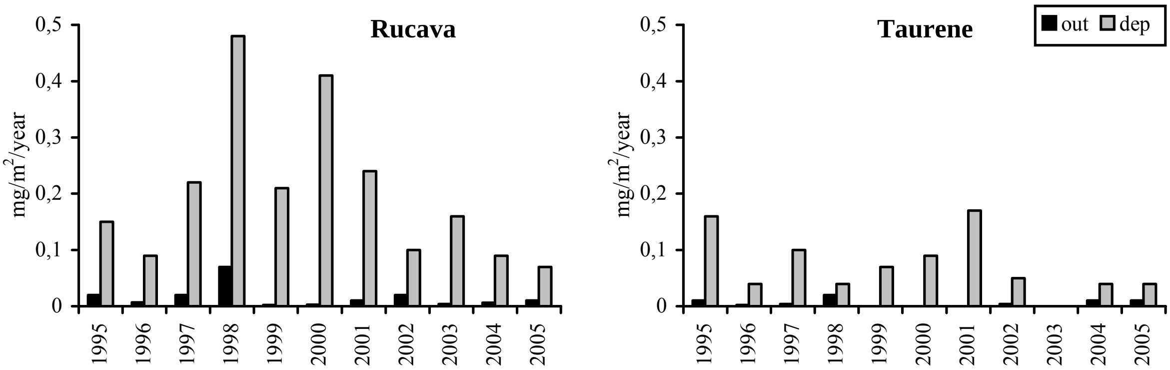


Figure 2. Pb(a) and Cd (b) balance in forest stream catchments.

The analysis of the Cu and Zn balances in the forest stream catchments showed that long-range transboundary pollution impact on the IM Rucava site is not so strong as of Pb and Cd. The average annual deposition of zinc and copper in Rucava forest stream catchment was 1.4-1.6 times higher than in Taurene (Fig. 3 and 4).

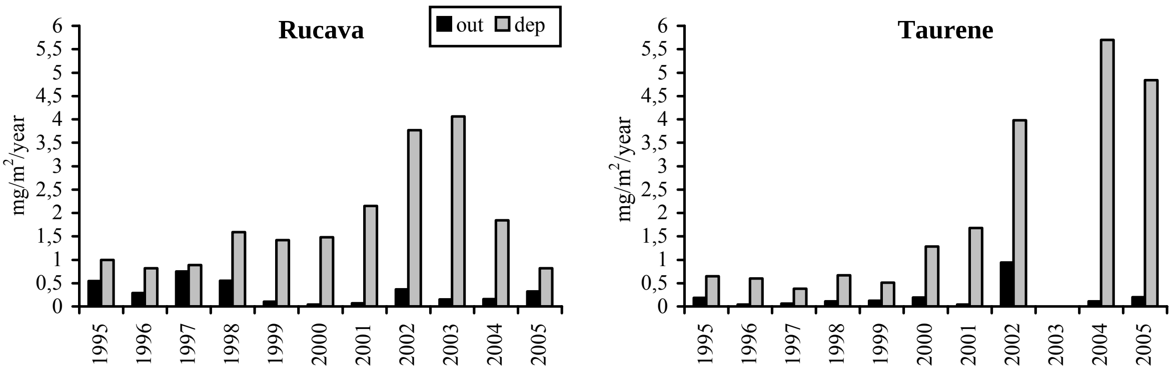


Figure 3. Cu balance in forest stream catchments.

The input loads of Cu in Figure 3 testify to the fact that a dramatic rise of up to 4 mg/m^2/year started in 2002 and continued in 2003 (Rucava) and 2004 (Taurene) with a little decrease in 2005. Maximum output loads in Rucava forest stream catchment were reported 1997 and 1998, in highest runoff, in Taurene – in 2002 due to increase concentration in stream water.

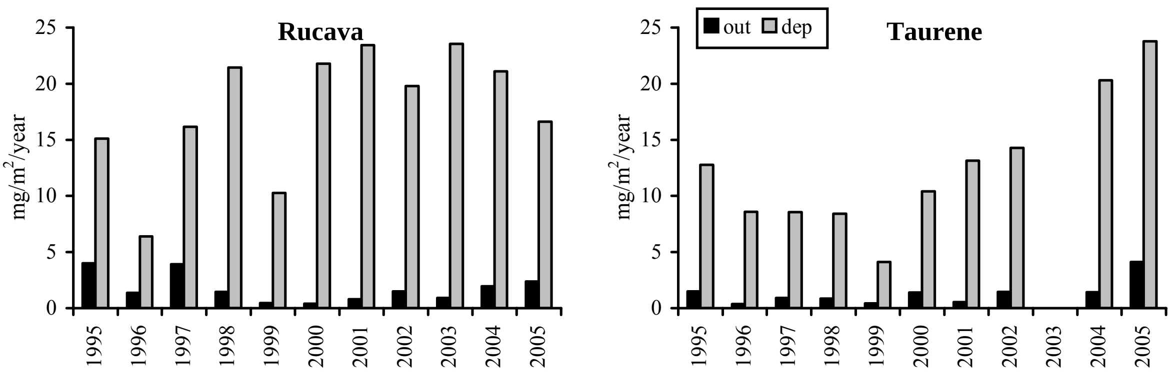


Figure 4. Zn balance in forest stream catchments.

Over the whole period of the observation, the deposition of Zn in Rucava greatly varied between the years, from 6.4 to 23.6 mg/m^2/year. In IM Taurene, the input load of Zn showed a tendency much like that of Cu with as rise in 2000 and the upward tendency until the end of the observation period. The maximum of zinc output load was observed in 1995 and 1997 in the Rucava catchment and in 2005 in Taurene.

It's worth noting that the dynamics of heavy metal output is effected by the amount of precipitation (Fig.5) and the hydrological regime of the stream (Fig.6), e.i. flow. In the years of low water, the output was lower.

a)

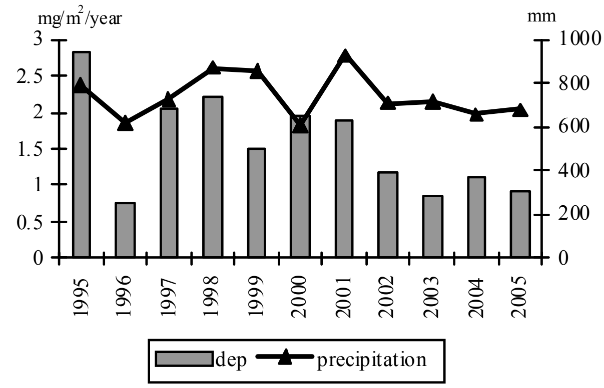


Figure 5. Correlation of input load of Pb with annual precipitation in Rucava forest stream catchment

b)

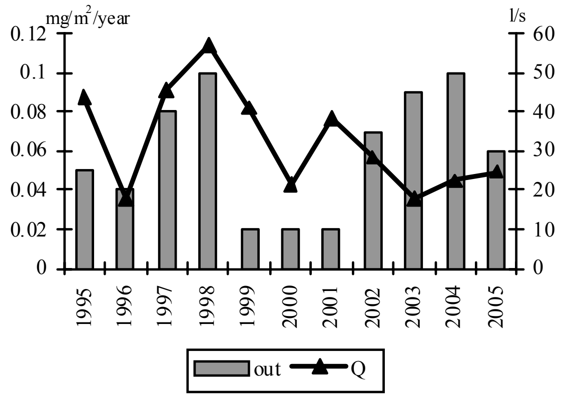


Figure 6. Correlation of output load of Pb with annual runoff in Rucava forest stream catchment

CONCLUSIONS

The annual mean budget values for 1995-2002 show that much of the air-borne heavy metal inputs retain within the catchments.

Pb and Cd deposition loads in the catchment of the forest stream Rucava are 2-3 times higher than in the forest stream Taurene catchment because the IM Rucava site is exposed to long-range transboundary pollution.

Over the observation period 1995-2000, a great decrease occurred in the Pb concentration in atmospheric deposition in the IM Rucava due to lower Pb emissions in Europe partly, because of Pb-free gasoline introduction.

The year 2000 saw the start of rising in the deposition of Cu in both forest stream catchments and Zn – in the Taurene forest stream catchment.

Despite the weaknesses of the output-input budget calculation method, it is a very useful tool for simple analysis of the processes occurring in the catchments of small natural water bodies.

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FLOWS OF DISSOLVED ORGANIC MATTER IN CONDITIONS OF CHANGING ENVIRONMENT

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ABSTRACT

During the last decades, anthropogenic pressure onto the environment in Latvia has been considerably reduced. Within this study, the impact of reduced human loading on the concentrations and flows of organic matter in Latvian rivers has been investigated; as well as influence of land-use types and soil texture on water quality. It is becoming apparent that long-term changes (1977-2004) of concentrations of total organic carbon do not follow linear trends but rather show oscillating patterns, indicating impact of natural factors, e.g. changing hydrological and climatic conditions. There is a positive correlation between content of TOC and water discharge. A closer relationship between TOC concentrations and soil texture was found.

Keywords: dissolved organic carbon; long term changes; land-use

INTRODUCTION

Dissolved organic substances (characterized as total or dissolved organic carbon – TOC or DOC) play a significant role in the carbon global biogeochemical cycle, but at the same time influence mineral weathering, nutrient cycling, metal leaching as well as pollutant behaviour and toxicity. The principal sources of DOC are processes within the corresponding water-body (autochtonous sources) or those taking place in the terrestrial supply (allochtonous sources). The flows of dissolved organic matter are very important indicators of a climate change. Flows of organic substances are influenced also by bedrock geology, intensity of agricultural use and other most significant features of the catchment area, leading one to the conclusion that their character evidently much depends on the studied region. An increase in DOC levels also for rivers in upland United Kingdom has been observed (Worrall et al., 2003). At the same time, the patterns and intensity of biological processes within the catchments of rivers and lakes can also substantially affect the flows of dissolved organic matter (Scott et al., 1998). It is clear that there exist tight links between land-use patterns and flows of organic substances and these relationships appear to be specific for each region. On the other hand, it has been observed that natural processes interfere significantly with the human-induced processes. Flows of DOC have been analyzed worldwide (Arvola et al., 2004; Evans et al., 2005) and also in Latvia (Klavins et al., 1997; Apsite and Klavins, 1998). However, manifestations of the organic matter trends appear to be quite contradictory: on one hand, i.e. increasing DOC trends have been observed (Evans et al., 2005; Roulet and Moore, 2006), whereas at the same time decreasing trends (Arvola et al., 2004) as well as fluctuations of the DOC values have been found. As factors influencing DOC changes, climate change with increasing amounts of precipitation and changes in the hydrological regime (increase in the discharge and changes of flow-path as well as impacts of droughts), also changes in acidic precipitations as in the case of Norway (Hongve et al., 2004), have been observed. Elevated temperature and increasing atmospheric carbon dioxide concentrations apparently have influenced an increasing primary productivity and concurrently have caused decay of the living organic matter. The aim of this study is to analyse long-term changes of organic matter in the surface waters of Latvia, factors controlling their runoffs, spatial variability of water chemical compositions and the possible impact of pollution sources.

MATERIALS AND METHODS

The study site covers the entire territory of Latvia (Fig. 1).

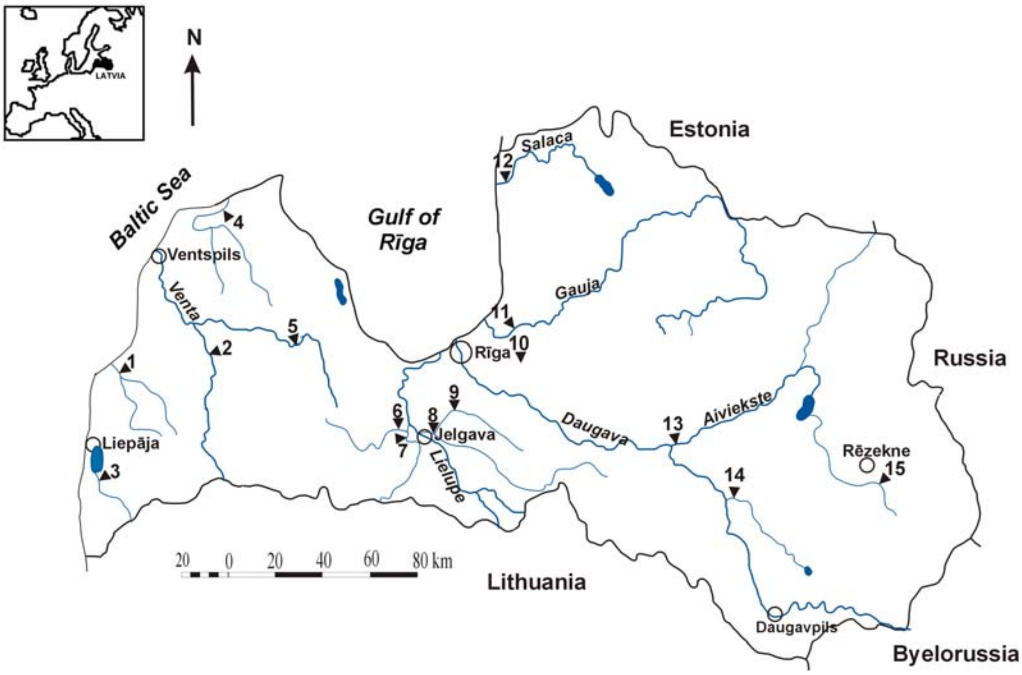

Figure 1. Map of the study area (▼ - monitoring sites).

It has been shown that, for surface waters, the DOC, on an average, constitutes 95 % of the TOC, therefore it can be surmised that the TOC values essentially are equivalent to those of the DOC. Data on COD (after 2001 TOC), water color and river discharges used in this study have been obtained from the Latvian Environment, Geology and Meteorology Agency for time period 1977 – 2001. Water color was determined using Pt/Co scale spectrophotometrically. COD was determined by oxidation with $K_2Cr_2O_7$ and titration with ferrous ammonium sulphate (Standard Methods…, 1973). At the same sites discharge, temperature and basic chemistry have also been measured. Starting as far back as 2002, COD measurements were replaced by TOC measurements and for one year (2003) COD and TOC measurements were run in parallel at all the monitoring stations. Since 2003 total organic carbon was measured using Shimadzu TOC – VCSN. The relationships between COD and TOC were estimated using the results of 328 measurements. The calibration experiment indicated the following relationship between recorded COD and TOC:

$TOC = 0.2928COD + 7.9503$ $r^2 = 0.811$

Similar approach has proved to be valid in several studies to extrapolate measurements of organic carbon concentrations (Maurice et al., 2002; Arvola et al., 2004; Hongve et al., 2004), but also in other studies on organic carbon long term changes, similar approaches have been used (Maurice et al., 2002; Worrall et al., 2003), extrapolating COD_{Mn} or water color data, to the extent that relationships between integral indicators COD, TOC, colour describes properties of aquatic organic matter (Hounslow, 1995).

Data on land use in the river sub-basins were obtained from the GIS data base *"Corine Land Cover Latvia"* and information on soil texture was taken from a GIS-based soil map created by the Latvian Environment Agency. Soils, depending on their texture, were divided into three groups: clay and loam, sandy soils and organic soils.

The long-term changes in the river discharge and TOC were studied by using the non-parametric Mann-Kendall test (Hirsch and Slack, 1984). This test can be applied to the data sets that have non-normal distribution, missing values or "outliers", and serial character (e.g., seasonal changes). The program *MULTIMK/CONDMK* was used to detect trends, as it allowed the inclusion of covariates representing natural fluctuations (e.g., meteorological and hydrological data) (Libiseller and Grimvall, 2002). If the Mann-Kendall test value was greater than 1.65, the trend is increasing (significance level $p<0.05$). If the test value was smaller than –1.65, the trend is decreasing at a significance level $p<0.05$.

RESULTS AND DISCUSSION

Both the spatial and seasonal variability of concentrations of organic substances in the surface waters of Latvia can be considered to be comparatively high. TOC levels in the study area vary from high, characteristic of waters draining from bogs and wetlands (Aiviekste up to 40 mgC/l) or rivers dominated by areas of agricultural use (Lielupe up to 45 mgC/l), to waters with comparatively high mineralization and low levels of TOC (Venta 22 mgC/l). The highest TOC concentrations are usually for the river basins of Lielupe and Aiviekste, and also in the bog lakes and the eutrophic waters. Climate changes do have a pronounced effect on the organic carbon loadings to surface waters and runoffs by them. The first level of impact can be related to the seasonal variability of TOC in the water. Export of TOC, calculated using monitoring data for the period 1977-1998, varies between river basins in Latvia by nearly twice that, of the 5226 kg/km^2/year for the Mūsa River and up to 12731 kg/km^2/year for the Iecava River, both rivers situated in the Lielupe basin.

Table 1. Results of conditional Mann-Kendall test for Latvian rivers (1979-2004).

	TOC	**$N\text{-}NH_4^+$**	**$N\text{-}NO_3^-$**	**$P\text{-}PO_4^{3-}$**	**Q**
Daugava, Jēkabpils	-0.276	**-3.278**	-0.314	1.265	0.020
p-value (one-sided test)	0.391	0.001	0.377	0.103	0.492
Aiviekste	-0.650	**-2.473**	**-1.661**	-1.025	0.583
p-value (one-sided test)	0.258	0.007	0.048	0.153	0.280
Gauja	-0.710	**-3.644**	**-3.840**	**-3.315**	-0.277
p-value (one-sided test)	0.239	0.000	0.000	0.000	0.391
Lielupe	-1.590	**-3.716**	**-2.751**	**-3.440**	-0.040
p-value (one-sided test)	0.056	0.000	0.003	0.000	0.484
Venta	**-2.013**	**-2.847**	**-2.006**	-0.636	**-2.726**
p-value (one-sided test)	0.022	0.002	0.022	0.262	0.003
Salaca	-0.667	**-2.229**	**-2.472**	1.269	-0.119
p-value (one-sided test)	0.252	0.013	0.007	0.102	0.453

Bold – test is statistically significant at 95% level.

The highest loss values due to of TOC export, evidently are due to the agricultural activities and a high percentage of wetlands in the basin. The lowest loss in TOC export values most commonly are for the highly forested river basins. Highest specific loading of organic substances is contributed by the Salaca River basin. The basin of this river has a relatively high coverage of bogs, and waters of the river originate in the eutrophic Lake Burtnieks. However, runoffs of substances from domestic and non-point sources for this river are among the lowest of the river basins studied in Latvia.

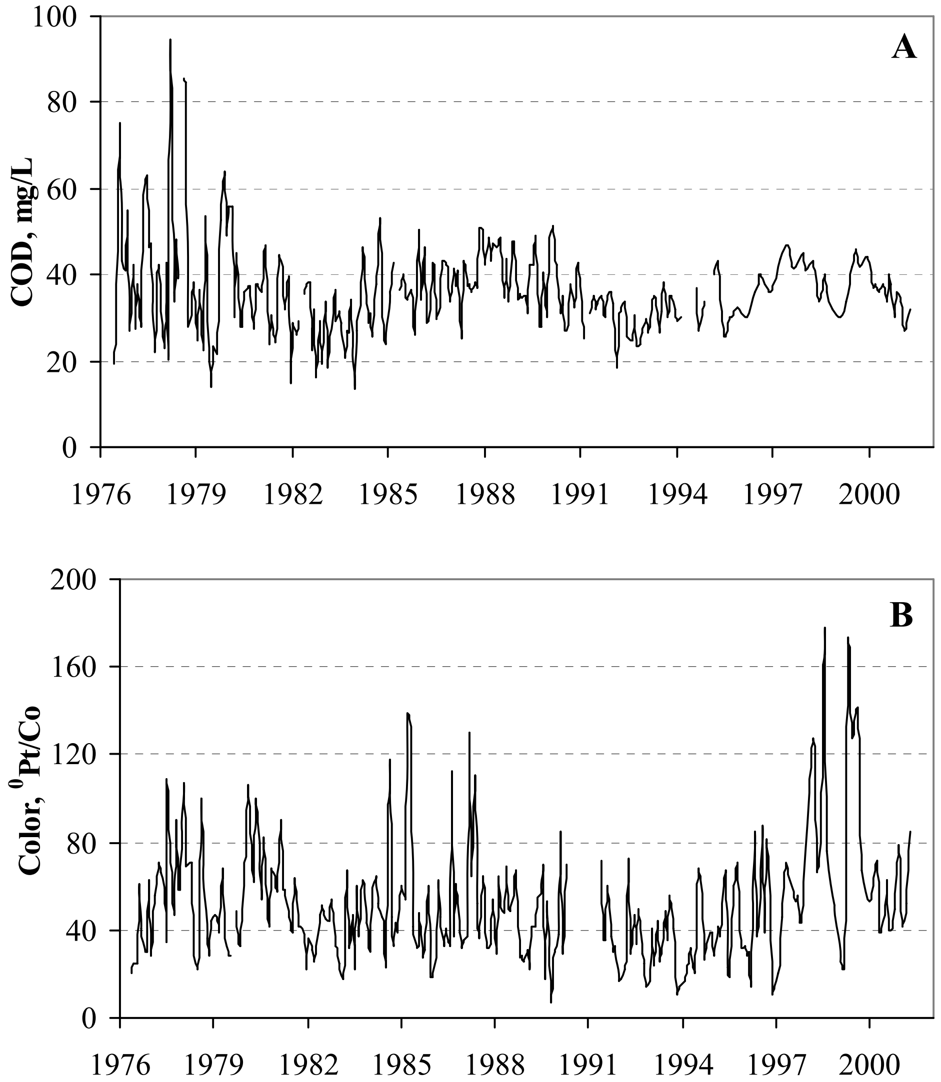

Figure 2. Long-term changes of chemical oxygen demand and water color in the Daugava (A) and Venta (B) Rivers (1977-2004).

A conditional Mann-Kendall test was applied to detect changes of TOC during the last decades. Despite the dramatically reduced anthropogenic pressure on the environment during this period, the Mann-Kendall test results show even increasing trends of estimates of organic matter content. In the most studied rivers statistically insignificant decrease of TOC values have been observed (Table 1). River discharge does not reveal any statistically significant changes. Changes of TOC seems to be coupled to a reduction of anthropogenic loading and oscillating patterns of long-term changes of river discharge (Fig. 2), leading to suggest that natural processes play a significant role in the actual flows of organic matter. For example, changes in the hydrological regime and climate can influence both the production and leaching of organic matter at a level exceeding the impact of human loading. Typically, a positive relationship exists between estimates of organic matter content and river discharge. However, this study did not reveal a close correlation between water discharge and TOC, likely due to the multitude of factors affecting the concentrations of organic substances in waters.

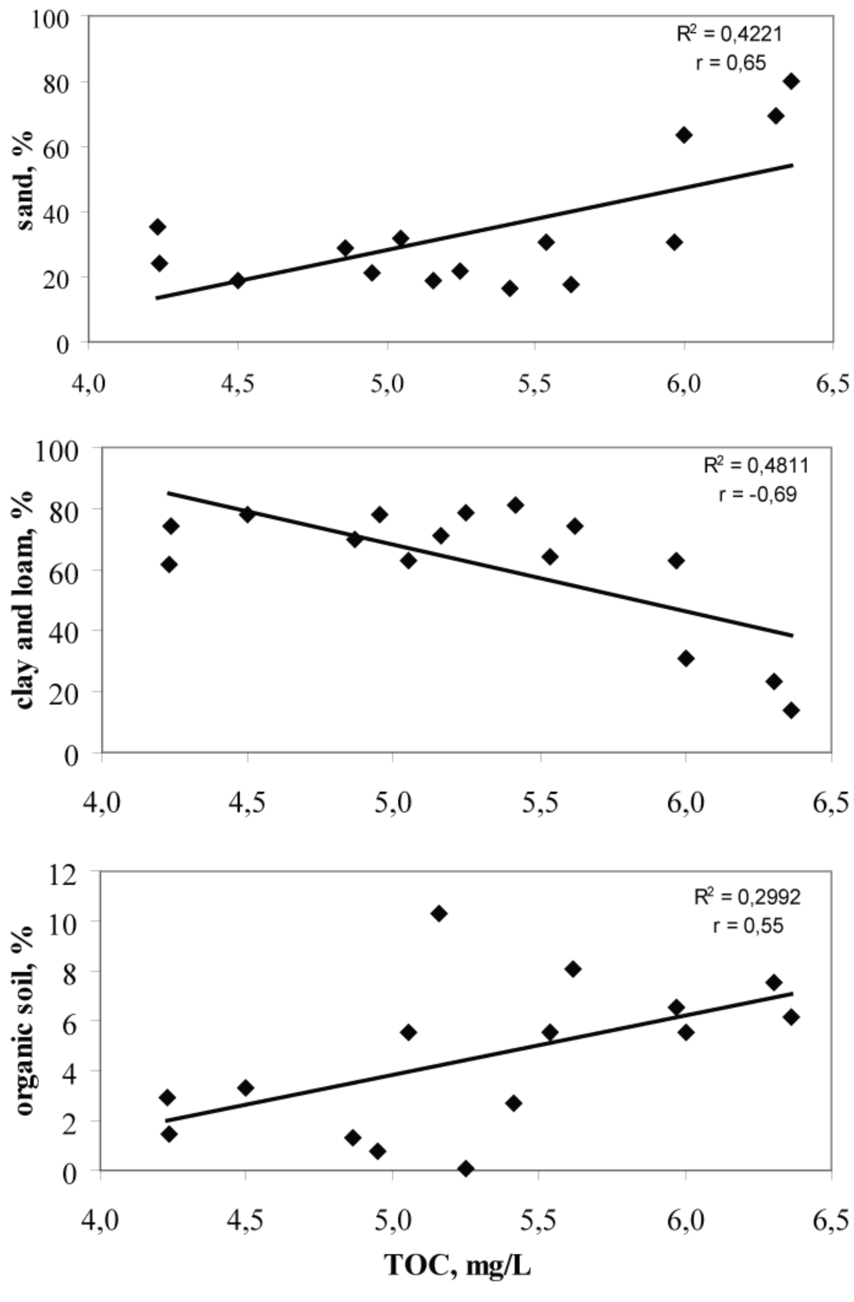

Figure 5. Correlation between the proportion of catchment area (%) covered by sandy soil, clay and loam, organic soil and TOC concentrations in river water (1998 – 2003).

Soil composition can be mentioned among the factors influencing runoffs of the organic matter. Our study revealed a positive correlation between TOC concentrations in the river water and the relative coverage (% of area) of the sandy and organic soils within the river catchment (r = 0.65 and r = 0.55, respectively). A negative relationship was observed between TOC concentrations and the proportional area covered by clay and loamy soils (r = -0.69) (Fig. 3).

A clear relationship between the concentrations of TOC in the river water and land-use classes was not observed. There was a positive relationship between TOC and the coverage (%) of forest area within the river basin (r = 0.33) and coverage (%) of mires area (r = 0.52), also a negative correlation (existed) between TOC and the coverage (%) of agricultural land (r = -0.38). The above relationships may be explained by the low anthropogenic pressure, as the TOC concentrations used for calculations were for the time period 1995-1999. Probably, soil texture and adsorption of organic matter on clay particles have a more significant impact on flows and retention of organic substances. The results show that the TOC loading is highly dependent on the hydrological regime and the land-use properties, but in particular on the amount of peatlands in the drainage area.

Changing hydrological and climatic conditions also influence the structure (physiochemical characteristics, molecular weight) of dissolved organic matter, and changes in the solar radiation can affect the photodegradation rates of organic matter.

CONCLUSIONS

Long-term data on chemical oxygen demand were used in this study to estimate flows of dissolved organic carbons in Latvia. Long-term changes (1977-2001) of chemical oxygen demand and water color do not follow linear trends but rather show oscillating patterns. Typically, there is a positive relationship between estimates of organic matter content and water discharge as well as soil composition in the river basin.

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SPATIAL DISTRIBUTION OF DISSOLVED CONSTITUENTS IN ICELANDIR RIVER WATERS

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The objective of this study was to map the spatial distribution of dissolved constituents and the alkalinity of Icelandic river waters using GIS methods, in order to study and interpret the connection between river chemistry, bedrock, hydrology, vegetation and aquatic ecology.

The results of this study can be used for example to: 1) predict river water response to acidification and the spatial variation of the response and 2) predict the rate that determines macronutrient quantities for primary production within the rivers and how this varies spatially.

Spatial distribution of constituents has been modeled before (Arnason, 1976; Sigurdsson, 1993; Kardjilov et al., 2006) but GIS methods have not been used to map the distribution of dissolved constituents in Icelandic rivers until now and therefore this emphasis was the main scientific objective of this study.

By applying the methods of the spatial analysis in GIS, a clearer view of the distribution of dissolved constituents and alkalinity for the whole country can be achieved and the changes in the concentration of dissolved elements and alkalinity can be studied further with respect to, bedrock age, hydrological classification, soil and vegetative cover.

For this purpose five parameters were selected and are listed below:

1. Alkalinity – indicates how the river waters will respond to external acidification. The higher the alkalinity, the more acidification the water can sustain without great pH changes.
2. Silica (SiO_2) – is the most abundant element in the basalt bedrock but with low concentrations in the oceans and is a good criterion for weathering. It is also a very important nutrient for aquatic life and primary production
3. Molybdenum (Mo) – an important element of nitrogen-fixing enzymes, called nitrogenases. It is suggested that it may govern the N fixation in the terrestrial environment.

4. Fluorine (F) – is not consumed by a secondary mineral and is therefore an indicator of how much rock-weathering a unit mass of water has caused. Its presence also indicates some geothermal activity.
5. DIN/DIP mol ratio[1] – nitrate and phosphorous are very important nutrients for life in rivers, lakes and soil. These nutrients were chosen since their availability could limit primary production in rivers and lakes when the DIN/DIP mol ratio is > 16 it is likely that DIP is the limiting factor and vice versa when the mol ratio is <16.

MATERIAL AND METHODS

The concentration of each dissolved constituent was mapped in GIS by applying GIS techniques.

In 2006 the Hydrological Service of the National Energy Authority (Halldorsdottir er al., 2006). divided river catchments into several sub-basins where the sub-basins were classified into a category, representing the hydrological condition of the region. The concentration of each chemical constituent was applied to the hydrological classification in order to connect the river chemistry to the hydrological classification to get a better view of the conjunction between precipitation, hydrology and river chemistry.

The databases used in this study are of various size and are described as follows:

1. 30 rivers were sampled and samples were collected up to 10 – 12 times each year and up to 50 parameters were analyzed and pH and temperature and electrical conductivity were measured. These databases therefore give the best information on variation in both discharge and the concentration of dissolved constituents (Armannsson et al., 1973; Rist, 1974; Rist, 1986; Gislason et al., 2004; Gislason et al., 2003 and 2006; Gislason et al., 2006; Kristmannsdottir et al., 2006).
2. 47 rivers were sampled and only one sample was collected in each river. 31 parameters were analyzed along with measurements of discharge, pH/T, temperature and electrical conductivity (Adalsteinsson and Gislason, 1998; Louvat et al., 2007).

All the samples were collected close to the hydrometric stations run by the Hydrological Service. Discharge, water and air temperature were measured at the time of sampling.

The discharge and concentration of dissolved elements in direct run-off rivers and glacial rivers varies considerably over the year. The discharge and concentration were fitted by a second order power function and a regression coefficient that describe the relationship between discharge and concentration

[1] DIN/DIP mol ratio: the ratio of Dissolved Inorganic Nitrate and Dissolved Inorganic Phosophorous.

mathematically, a relationship called rating curve (Gislason et al., 2006). Rating curves were calculated for each constituent in each river in this study. Thus the variability in discharge and concentration between seasons does not have to be accounted for. The long-term average concentration values are then imported in ArcGIS and mapped.

Various agents own the data and they were used by their permission. The data were imported in a relational chemical database where both the owners and the users of the data can watch and alter the data.

The attributes of the spatial distribution were added to the hydrological classification using Zonal analysis method in GIS, where the values of each dissolved constituent in the spatial distribution are assigned to the hydrological classification and mean and standard deviation are calculated (Oskarsdottir, 2007; Oskarsdottir et al., 2008).

RESULTS

The main results of the spatial distribution are that alkalinity, SiO_2 and F concentrations are highest in catchments draining the youngest rocks and are located within the volcanic rift zone (Fig. 1). In contrast SiO_2 concentration was lower in catchments draining lakes due to primary production of diatoms in the lakes. All three constituents had low concentration in catchments draining older Tertiary rocks despite some catchments that drain wetlands or are influenced by geothermal activity outside the volcanic rift zone. As for the three constituents, Mo concentrations were highest within the volcanic rift zone and especially in catchments draining rhyolitic terrain and central volcanoes. In contrast the lowest concentrations are in catchments draining older Tertiary rocks outside the volcanic rift zone. Mo is thought to play a role in N fixation and that it may govern the primary production in Icelandic lakes where primary production is limited by the amount of fixed nitrogen (NO_3^-, NO_2^-, NH_4^+) (Oskarsdottir, 2007; Oskarsdottir et al., 2008).

In terms of DIN/DIP mol ratio the highest concentrations were within catchments that drain rocks older than 2 My (Tertiary and older). It was higher than 16 in rivers draining old rocks, but lowest in rivers within the volcanic rift zone (Fig. 2). Thus primary production in the rivers is limited by fixed dissolved nitrogen within the rift zone but dissolved phosphorous in the old Tertiary catchments. Nitrogen fixation within the rift zone can be enhanced by high molybdenum concentration in the vicinity of volcanoes.

A study of the hydrological classification revealed that the dissolved river water values, underlying each category, were too variable to take account of and resulted in high standard deviations. Thus the results were statistically insignificant. More data are needed from rivers draining each single river category in order to add the river chemistry to the hydrological classification.

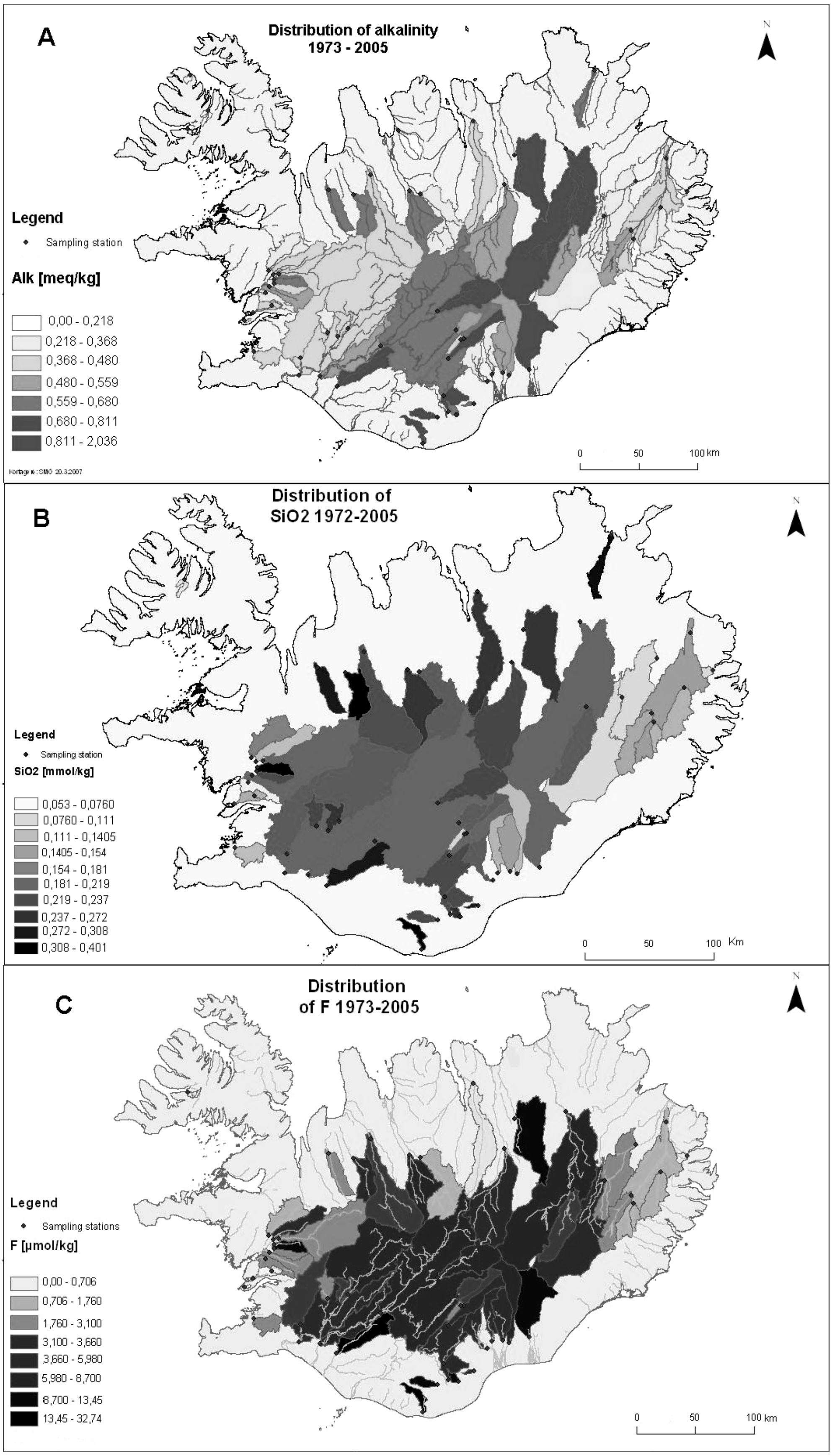

Figure 1. Spatial distribution of alkalinity (A), dissolved SiO_2 (B) and fluorine (C).

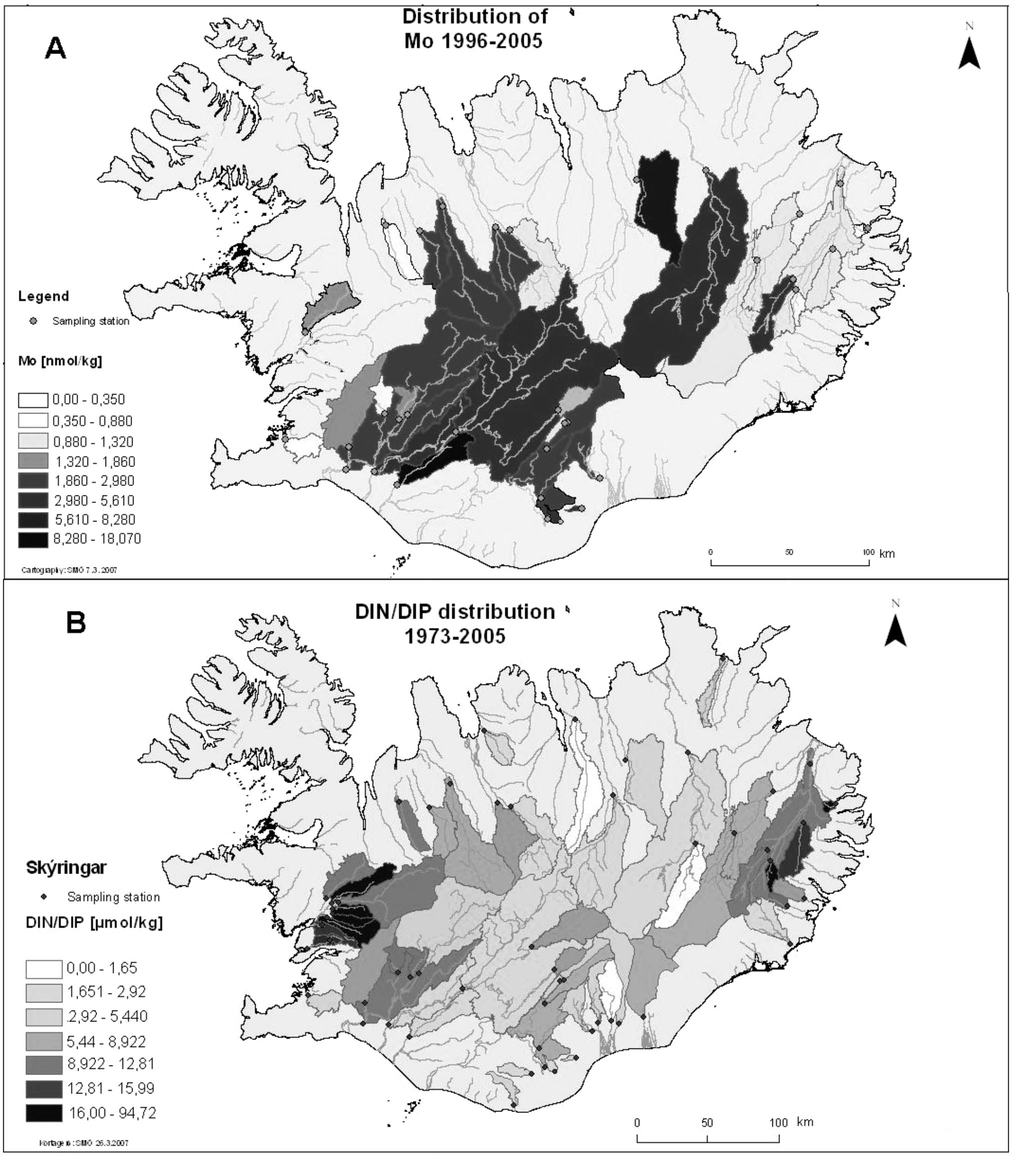

Figure 2. Spatial distribution of dissolved Mo (A) and DIN/DIP mol ratio (B).

The spatial distribution clearly revealed the difference between the two extremes, the volcanic rift zone and the old Tertiary terrain. However, more research and sampling needs to be undertaken in order to explain the concentrations in rivers at the margins of the two extremes, as well as to ascertain a more precise spatial distribution of dissolved constituents.

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SESSION 8: CLIMATE AND ENERGY SYSTEMS, CES

CLIMATE AND ENERGY SYSTEMS (CES) 2007–2010
A NEW NORDIC ENERGY RESEARCH PROJECT

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ABSTRACT

A new Nordic Energy Research project, Climate and Energy Systems (CES) – Risks, Potential and Adaptation, was initiated in 2007 with a 4-year-funding from NER, the Nordic energy sector, and individual partners. The project focuses on three main renewable energy resources; hydropower, bio-fuels and wind power, and how future climate change within the next 20–30 years can impact these resources. An overview is given of the project organization, the main objectives and a working plan for the project is given.

INTRODUCTION

The project Climate and Energy Systems; Risks, Potential and Adaptation (CES) is in many ways a follow up of the Climate and Energy (CE) Nordic-Baltic research project (2003–2006), which have both been funded by Nordic Energy Research (www.nordicenergy.net) and the Nordic energy sector (Fenger, 2007). The main objective of the CE project was to make a comprehensive assessment of the impact of climate change on renewable energy resources in the Nordic area including hydropower, wind power, bio-fuels and solar energy on a longer time horizon. Scenarios for the period 2070-2100 for climate and renewable resources were developed and compared through systems simulations (Fig. 1). This comparison led to estimates of the changes in the production of the system, nevertheless, analysis of the energy systems development and of the market led to the conclusion that these changes would be overwhelming on this time scale, except for Iceland, where melting of glaciers would increase the production capacity by some 50%.

The results of the CE project serve as an important basis for an in-depth understanding of the impact of climate change on Nordic renewable energy resources, but are also important for rational decisions regarding strategies for energy policies, including strategies for the reduction of greenhouse gas emissions.

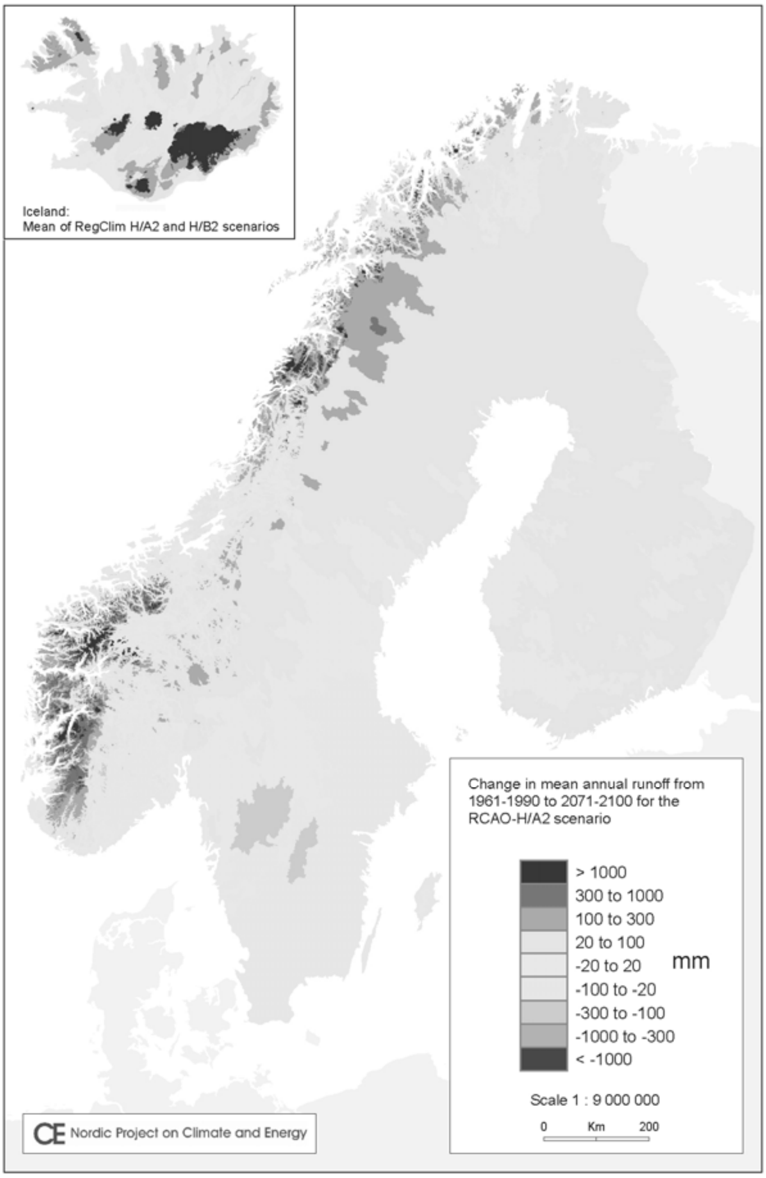

Figure 1. Change in mean annual runoff from 1961-1990 to 2070-2100 for Scandinavia and Iceland. Color version of the figure is included in the electronic version of the paper. (See Beldring et al., 2006 and Bergström et al., 2007 for further discussion).

ORGANIZATION OF THE CLIMATE AND ENERGY SYSTEMS (CES) PROJECT

Funding for the CES project comes from the Nordic Energy Research (53%), the Nordic Energy Sector (33%) and the internal funding of the individual participants (14%). The project management is located at NEA, Iceland, under which the project is organized as a matrix structure with four working groups (WG) on renewable energy resources, i.e. Hydropower–hydrological models, Hydropower–glaciers/snow/ice, Biofuels and Wind power groups (Fig. 1). Another five WG have been created to work on the interdisciplinary level and cross-cut the renewable energy resource groups; Statistical Analysis, Risk Assessment, Climate Scenarios, Energy System Analysis and Information Management. These WG are served and supported by a Steering Group, consisting of a representative from each of the WG and a spokesman from each of the five partners from the Nordic energy sector (Fig. 2). Bi-annual meetings of the Steering group will be held and the individual WG will have their workshops in conjunction with the annual meetings. To secure collaboration on the national level between the different activities, individual partners will establish national groups. The Information Management group will then be responsible for information dissemination, active stakeholder involvement and the public outreach throughout the project.

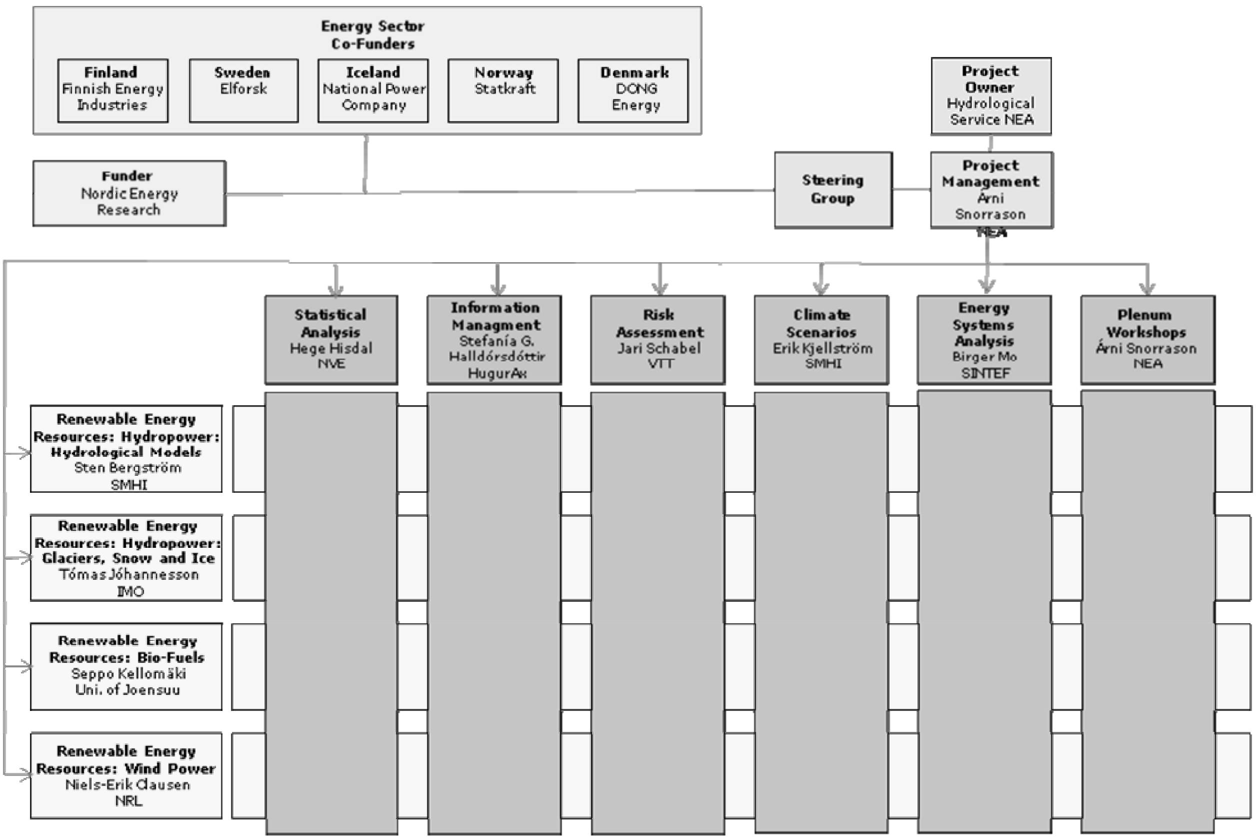

Figure 2. Organization of the Climate and Energy Systems (CES) project 2007–2010.

MAIN OBJECTIVES OF THE CES PROJECT

An increase of uncertainty about the future of renewable resources under climate change is a key issue for the energy sector. Some renewable energy resources are likely to increase their productivity, on the other hand, changes in the seasonal and geographical patterns of production and demand need to be managed. Disturbances and costs due to possible changes in extremes as floods, droughts or storms need to be dealt with. Uncertainty translates into riskier decisions within the sector including operational and market issues, short term responses or investments. It also calls for adaptation measures including e.g., ensuring dam safety.

The goal of the new Climate and Energy Systems project is to look at climate impacts closer in time and assess the development of the Nordic electricity system for the next 20–30 years. It will address how the conditions for production of renewable energy in the Nordic area might change due to global warming. It will focus on the potential production and the future safety of the production systems as well as uncertainties.

The key objectives are summarized as:

- Understanding of the natural variability and predictability of climate and renewable energy systems at different scales in space and time.
- Assessment of the risks due to changes in probabilities and nature of extreme events.
- Assessment of the risks and opportunities due to changes in production of renewable energy.
- Development of guiding principles for decisions under climate variability and change.
- Development of adaptation strategies.
- A structured dialog with stakeholders.

WORKING PLAN FOR THE PROJECT

Each of the partners within individual working groups has laid out detailed working plan for the years 2008–2010 and has started their work accordingly.

Renewable Energy Resources

Identical questions await the four renewable energy resource groups, i.e. how will future climate change affect the different resources. The analyses of the impacts on renewable energy sources will be based on climate scenarios, and depending on the energy source, different types of models will be used for both production and safety analyses.

Climate Scenarios

New regional climate scenario simulations will be conducted using the advanced regional climate models RCA and HIRHAM. The scenarios will cover the period until 2050. Probabilistic analysis will provide both decadal ranges and probabilities of climate variability and change in the Nordic region until 2050. The link between regional climate scenarios and the recent/ongoing climate behaviour will be analyzed. Customized regional climate scenarios for risk analyses will be developed.

Statistical Analysis

Historical time series and scenarios for the Nordic area will be analysed on all time scales with a focus on extremes. It will include statistical methods to quantify uncertainties in extreme estimates caused by climate variability and change, and to improve the understanding of links between large scale circulation patterns, climate, hydrology and renewable energy.

Energy System Analysis

Future development of the electricity system will be outlined with focus on possible developments of the Nord Pool electricity system up to 2050. System analysis for the near future will be based on detailed simulations for the Nordic electricity system with the EMPS model for a few specific scenarios for given future years, e.g. 2010 and 2015, with the 'correct' climate.

Risk Assessment

An evaluation of risk under increased uncertainty in order to improve decision making in a changing climate will be carried out through the following steps: 1) Review of risk and uncertainty management approaches used in the energy sector; and 2) Integration of risk and uncertainty in decision support tools. A risk management framework will be adopted according to the emphasis of the industrial partners and will be developed during the early phases of the project.

Relevance to stakeholders in the energy sector

One of the primary goals is though to involve stakeholders in the energy sector as a change in hydro-climatological variability may lead to changes in the operation of reservoirs and wind turbines and the energy production potential itself. In particular the variability in hydropower is a great concern in the light of some very wet years and some sudden dry years, which have resulted in highly variable prices on electricity. To do so stakeholder meetings will be held, focusing on information needs of stakeholders, and the quality, context of use, accessibility, and overall benefit (or cost) of incorporating climate data into the decision-making framework. Mechanisms for evaluation and feedback will be incorporated into stakeholder meetings. Emphasis on two-way communication between groups that develop products and tools and those who use them implies an evolving relationship; therefore, an iterative approach involving testing of products and services over time may be useful.

Information Management

It is the responsibility of the information management group to disseminate information both within the project and to the public using a public outreach program based on modern web-based, multi media information technologies and methodologies (www.os.is/ces). The program will make important information on the impact of climate change on the Nordic energy environment accessible and understandable to the energy sector, public, policy makers and the educational and scientific community. Extensive use of modern geographical tools on the web will provide means to disseminate map-based results on climate, climate scenarios, scenarios on the renewable energy resources, demands, risks, etc.

During the timeframe of the former CE project (2003–2006) over 300 abstracts, reports and papers were published (www.os.is/ce). Similar activity is planned within the CES project where reports on studies within each working group will be published in the scientific literature, at conferences and through the news media. A final report will summarize the main results from the project and highlight measures of success in collaboration. In addition to bi-annual meetings and workshops planned throughout the whole timeframe of the project, a concluding international science meeting is planned in 2010.

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CREATING A CLIMATE CHANGE RISK ASSESSMENT PROCEDURE – HYDROPOWER PLANT CASE, FINLAND

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ABSTRACT

This paper examines the risk assessment procedure for a Nordic hydropower production process in the light of climate change. The case study research focused on hydropower plants in the Kemijoki region of northern Finland. This paper describes the development of the risk assessment framework and presents the tools developed during this process: the general risk assessment procedure, guidelines for gathering the background information, the seasonal plan, risk identification model and risk/opportunity table, and a method for risk estimation and evaluation. A generic model of the risk assessment procedure will initially be sought, for application within the Nordic countries. The study is a part of the Nordic Energy Research funded Climate and Energy Systems (CES) project.

INTRODUCTION

This paper examines the risk assessment procedure for Nordic hydropower production in the light of risks and opportunities raised in association with recent observations on climate change. The case study focuses on hydropower plants in the Kemijoki region of northern Finland. A generic model of the risk assessment procedure will initially be sought, for application within the Nordic countries. The study is a part of Nordic Energy Research funded Climate and Energy Systems (CES) project. A description of the information gathering and risk assessment procedure design based on functional modelling is included in this paper.

VTT has developed risk assessment methods since the 1970s. An overall knowledge-based methodology for hazard identification, so-called *functional modelling* (Suokas 1995), has been a favoured approach in VTT's method development for process industrial risk management. Functional modelling has also been applied in the field of food safety (Rasmussen *et al.* 2001). Other recent relevant work at VTT includes, for instance, environmental risk analysis methods for industrial accidental emissions (Wessberg *et al.* 2008). Climate change risk assessment methods are not only being developed in the CES project, but also in the Finnish national TOLERATE (2007) project, where the special focus is on flooding and severe droughts that are associated with climate change. In general, the area of study is developing and is not especially mature; and few references dealing specifically with risk assessment exist.

RISK ASSESSMENT FRAMEWORK

The general risk assessment framework follows the industrial safety standard of risk analysis for technological systems (IEC 60300-3-9 2000). Other references, especially the climate change risk assessment guide made by the Australian Greenhouse Office (2006), and Kirkinen *et al.* (2005) describing the potential consequences of climate change in Finland, are also used to guide this work. In the context of possibilities and frequencies, we have adopted the same system that is used in the reports of Intergovernmental Panel on Climate Change (IPCC, 2007).

The draft version of the risk assessment procedure includes a general framework of the entire procedure (Figure 1), guidelines for gathering the background information, a seasonal plan, risk identification model, risk/opportunity table, and tools to estimate and evaluate the identified risks. These tools are shown in italics in Figure 1 (Risk assessment framework). The key aspect involves conducting the risk identification and assessment process within brainstorming sessions involving the hydropower and power plant specialists.

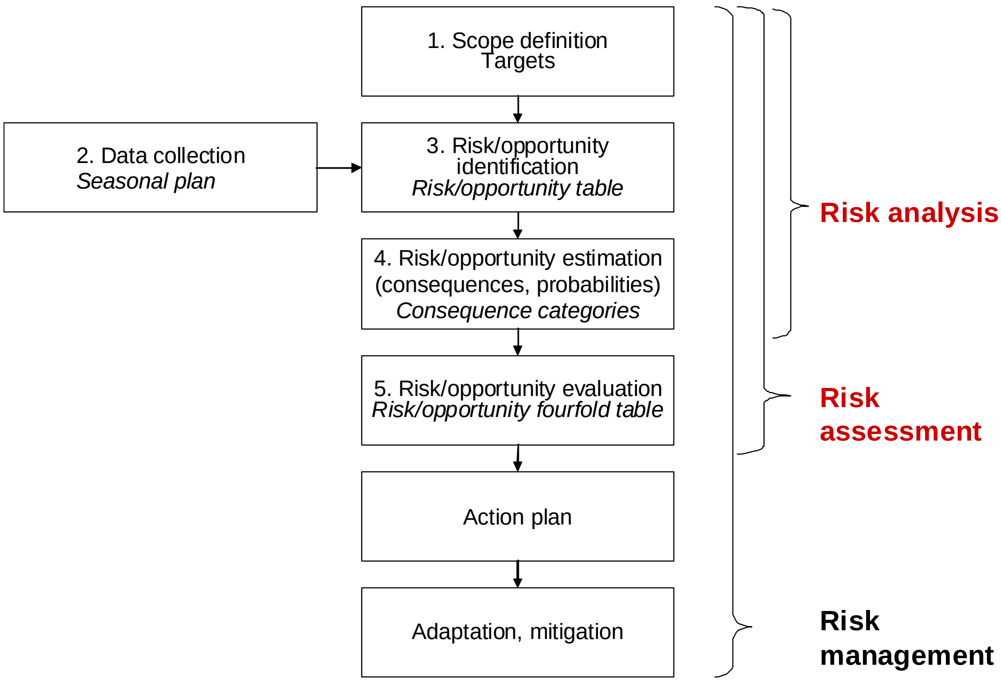

Figure 1. Risk assessment framework.

CASE STUDY

The case study centres on the catchment area of Kemijoki – the largest river in Finland. The catchment area of this 550 km long river is about 51 000 km^2. Although the greatest flood flow was about 5000 m^3/s (in 1973), the average flow is about 500 m^3/s. The twenty hydropower plants along the river produce about 1000 MW – about one tenth of Finland's energy needs. According to spatial climate models and hydrological models in the Kemijoki area, future winters might be milder than those of today. However, increased precipitation might mean more water in the river during winter – or if the temperature is below zero, more snow cover and potentially more floods in the spring. At the same time, the summers might be drier.

VTT's researchers visited the power production company Kemijoki Ltd at the end of January 2008. After a long brainstorming session with the personnel, the risk/opportunity table was completed together with other parts of the draft risk assessment procedure. During the process the most critical risks of power plant were roughly identified and, together with the company representatives, the more significant were selected for further investigation. Useful knowledge was gained through the discussions even though a detailed risk assessment could not be done at this stage, (especially areas of the risk estimation and evaluation parts were unclear) because we lacked detailed data concerning the hydrological models of Kemijoki region.

Applying this approach roughly in the case study area identified some risks and opportunities that are common to all of northern Finland. Fortunately, due to increasing precipitation there is an opportunity for additional water power in the future. On the other hand, factors which counter this opportunity also exist. Foremost, due to the milder winters and increased water flow, the ice covers on the rivers will freeze more slowly. In such conditions, ice dams and frazil ice can form, which can lead to flooding, and in the worst case, result in a dam break or damage to turbine equipment. The other surprising risk relates to extreme weather phenomena: if in a certain year the snow melts first in the more northern part of the catchment area, the frozen rivers will not be able to handle the extra water flow. In such a situation the northern area will flood and that water will typically not reach the power plants.

RISK/OPPORTUNITY IDENTIFICATION

A simple functional model for hydropower production is shown in Figure 2 – including the energy source, power plant, and distribution network. These three elements help to structure the risk identification process into different phases for the risk assessment process.

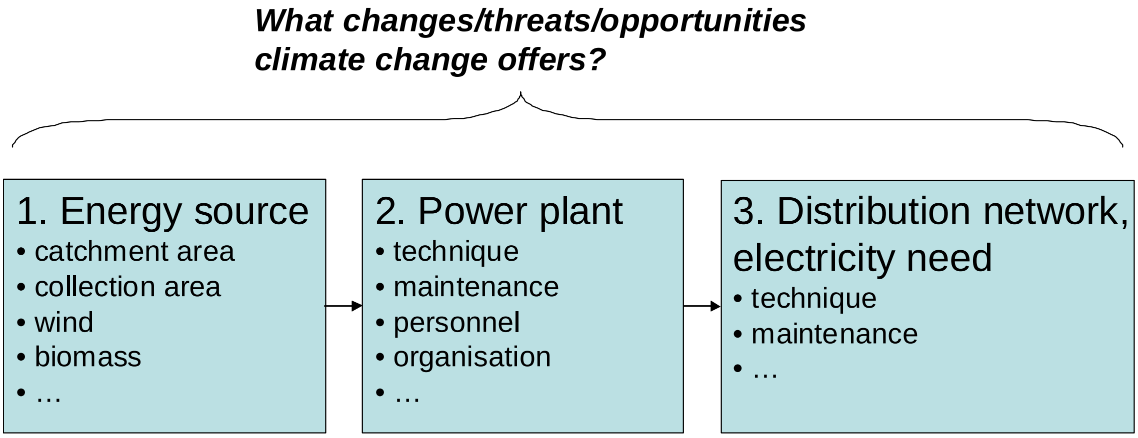

Figure 2. An example of input for the three dimensions of risk/ opportunity identification and assessment.

The main tool for identifying risks is the Risk/Opportunity table (Figure 3), which includes all the necessary information for guiding and documenting a risk analysis session. Some parts of the forms can already be completed prior to the brainstorming session.

To create the Risk/opportunity table, data about the basic information concerning the possible future climate (regional scenarios) and flood situation (hydrological models) in the study area was collected. Information about the changes in climate was obtained from the Finnish Meteorological Institute (FMI), and information about the hydrological changes in the Kemijoki region from the Finnish Environment Institute (FEI). In addition, the information about the power production was collected from Kemijoki Ltd.

Scenarios and Phenomena	**Probability of the phenomena**	**Energy source, (e.g. catchment area, peat or biomass production area)**	**Power plant**	**Distribution network**	**Risk reduction / control / potential**	**Probability of the consequences to the energy production**	**Consequence category**
Phenomena according to regional scenario of future climate, hydrological model or wind model.	*Probability according to IPCC 2007*	*The consequences of the phenomena to energy source and its usability*	*The consequences of the phenomena to the power plant*	*The consequences of the phenomena to the distribution network*	*The operations which will be done to protect against the phenomena and its consequences*	*Probability according to own ranking (Table 2)*	*Consequence category according to Figure 6*
Scenario 1. warmer climate							
Phenomena 1.1 - higher temperatures, especially during winter	Very likely, the probability that the next decade is warmer is 90%.	increasing water capacity	hot weather decreases the lifetime of transformers	increased electrical resistance ◊ energy losses	increase turbine capacity	very likely	3
1.2 - …							
2. increased precipitation							
2.1 - More rainfall: annual runoff will increase 0-8 %	very likely						
2.2 - …							

Figure 3. Sample risk/opportunity table.

Much general knowledge about the expected changes in Finnish weather conditions, especially in the northern parts of Finland, was identified in the discussions with FMI and FEI. However, not all of this knowledge was exclusively attributable to the Kemijoki region.

All the basic information was then used to develop the rough scenarios for the Risk/opportunity tables. The data collected in the case study was then assigned to the five scenarios: warming climate, increased precipitation, drought, shortened and warmer winter, and exceptional weather conditions. Each scenario was then assigned a probability, in accordance with the associated data. The data related to the frequency of the scenarios and phemonema was recorded, i.e. is the phenomena very likely, likely or unlikely. In this phase, the terminology and classification from IPCC can be useful (Table 1).

Table 1. The Frequency of scenarios and phenomen. (IPCC, 2007).

Terminology	***Likelihood of the occurrence/outcome***
Virtually certain	>99% probability of occurrence
Very likely	90 to 99% probability
	66 to 90% probability
About as likely as not	33 to 66% probability
Unlikely	10 to 33% probability
Very unlikely	1 to 10% probability
Exceptionally unlikely	1% probability

The final Risk/opportunity table was then created from the data by associating it with the three elements of hydropower production and the five scenarios (Figure 3). In this phase the most important questions are related to what kind of effects the realizations of the scenarios or phenomena have to the energy source, power plant or distribution systems. Also columns for the information concerning the consequences and risk reduction are included in the table. The likelihood of the consequences should be ranked according to power plants' own ranking systems (see an example in Table 2).

Table 2. An example how to rank the frequency of the harmful consequences.

Terminology	***Explanation of the term***
	If the phenomena happens there is/are:
Very likely	- only a one in a million chance to prevent the consequences
	- some possibilities to prevent the consequences
Unlikely	- a lot of possibilities to prevent the consequences
Very unlikely	- no difficulties to prevent the consequences

To enhance the discussion within brainstorming sessions, an extra tool, Seasonal plan tool (Figure 4) was developed. With this tool, the year's activities can be collected for discussion. The tool aids the visualisation of the seasonal changes: the autumn changes to winter and again to spring smoothly. The Seasonal Plan provides the possibility to imagine what happens in the power plant, for example, if the winter comes later than normally. The idea is to depict the risk/opportunity relevant knowledge in order to easily link the main conditions, tasks, etc. during the year in order to guide the risk identification process and assessment.

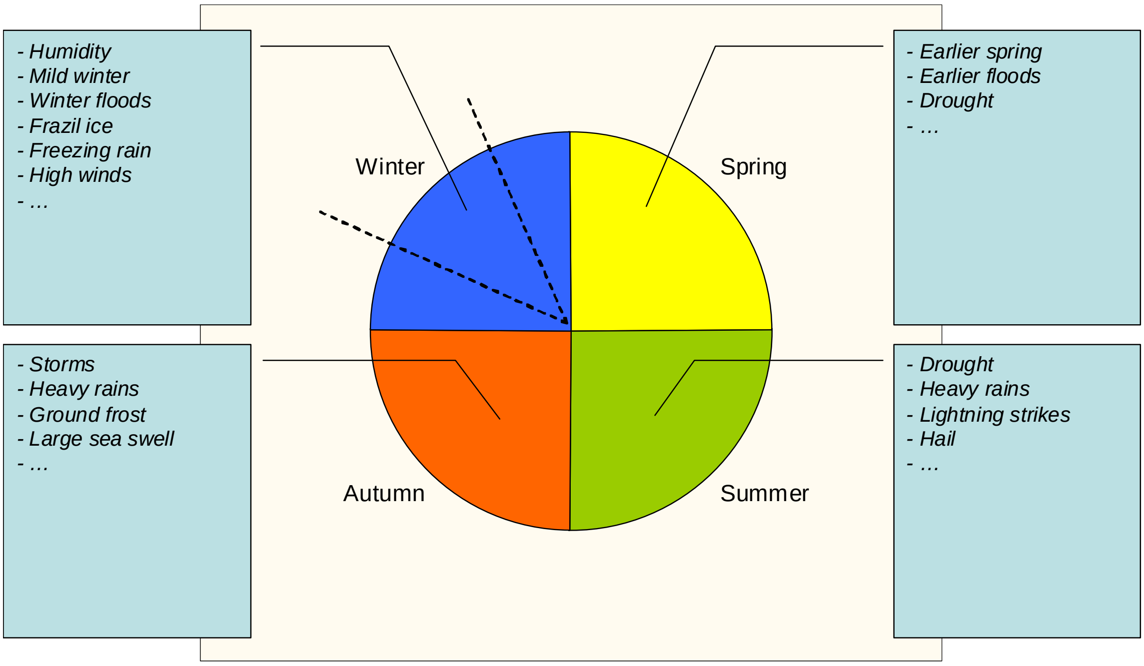

Figure 4. Example of the Seasonal plan.

Risk/opportunity identification was carried out in a brainstorming session, with the aid of the Risk/opportunity table and Seasonal plan, by discussing the scenarios and completing the risk/opportunity table.

RISK ESTIMATION AND EVALUATION

The risk/opportunity fourfold (R/O Fourfold) table (Figure 5) has been developed as a tool for guiding the risk estimation and risk evaluation during the risk analysis process. Further clarification is provided by the consequence categories (ConseMatrix, Figure 6) – two tools are designed to be used in conjunction with each other.

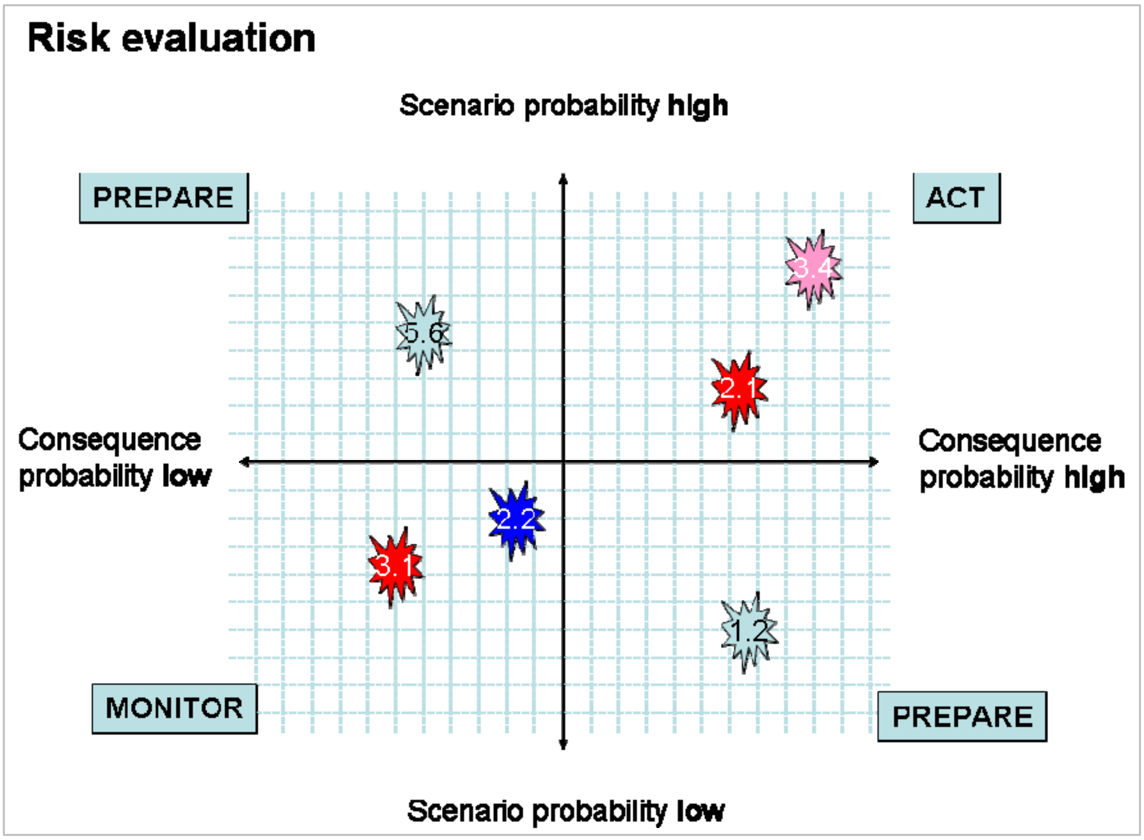

Figure 5. A sample "risk/opportunity fourfold table", mapping various scenario aspects according to the scenario and consequence probabilities. (R/O Fourfold).

	Consequence	Risk colour	Opportunity colour
1	Minor		
2	Moderate		
3	Major		

Figure 6. Consequence categories. (ConseMatrix).

All the identified risks and opportunities are mapped to the fourfold table (as a spot or star), and these then guide the company on how to deal with the topic: act, prepare or monitor. The colour of the designated marking originates from the ConseMatrix (Figure 6), while the identifying number stems from the Risk/Opportunity table (serial number of the identified risk/opportunity). ConseMatrix categories indicate the magnitude of the identified risk or opportunity in the fourfold table.

The fourfold table is used in place of the traditional risk matrix, and includes the associated probabilities and consequences. The tool is useful and provides a means to represent the scenarios relative to each other, even though the existing knowledge on these kinds of future risk assessments is very uncertain.

FUTURE EXPECTATIONS

The initial stage of the method development has recently been completed. The subsequent stage will involve refining it into a new, more specific risk analyses for further testing in the case plant. Prior to this, detailed hydrological models for the Kemijoki region will be prepared by SYKE. These models are expected to be ready in later in 2008. A return visit to Kemijoki Ltd will then be arranged and a detailed risk assessment for a selected hydropower plant will be performed together with the company's experts. It is anticipated that the method will also be tested with biomass power production in Finland.

Selected CES consortium partners will also apply the method, using the associated guide, with (especially hydro-, wind-, and bio-) energy providers in their respective countries so as to generate a collection of case studies. The associated feedback on the procedure will be discussed and appropriate amendments will then be made to the risk assessment framework. After all the experiences have been incorporated, the procedure will be subjected to a further round of testing in the project during 2009.

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SEASONAL VARIABILITY AND PERSISTENCE IN TEMPERATURE SCENARIOS FOR ICELAND

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ABSTRACT

More than 150 years of temperature observations and dynamic downscalings of temperature scenarios for Iceland are explored. The simulations show greatest warming in spring and autumn, but less warming in mid-winter and mid-summer. An important reduction is projected in the number of summer days with potential of subzero temperatures, while freezing may hamper the extension of the growing season into the autumn. Temperature observations in the past and the control simulation indicate high probability of a cold summer if the preceding winter was cold. Such a connection can neither be detected in past warm periods nor in future scenarios.

INTRODUCTION

Changes and opportunities in land use in a future climate in Iceland depend mainly on temperature. Here, important aspects of plausible regional changes of temperature in Iceland are explored in dynamic downscalings of global atmospheric simulations from the Hadley centre model (HadAM3H, Johns et al., 2003). The downscalings were carried out with the HIRHAM regional climate model (Bjørge et al., 2000) for a limited area (Fig.1 in Ólafsson and Rögnvaldsson: Regional and seasonal variability in precipitation scenarios for Iceland [in these proceedings]) over the N-Atlantic and NW-Europe (Haugen and Iversen, 2005). They were an integrated part of the international PRUDENCE climate project (Christensen, 2004). The global model represents a coupled ocean-ice-atmosphere system with a horizontal resolution of T106 which corresponds to roughly 125 km. The HIRHAM downscaling was carried out in 19 vertical levels with a horizontal resolution of 55 km. Some further discussions of the HIRHAM simulations and the simulated domain are elsewhere in these proceedings (Ólafsson and Rögnvaldsson: Regional and seasonal variability in precipitation scenarios for Iceland). Global simulations based on two emission scenarios were downscaled, the IPCC SRES A2 and IPCC SRES B2 (Nakicenovic and Swart, 2000).

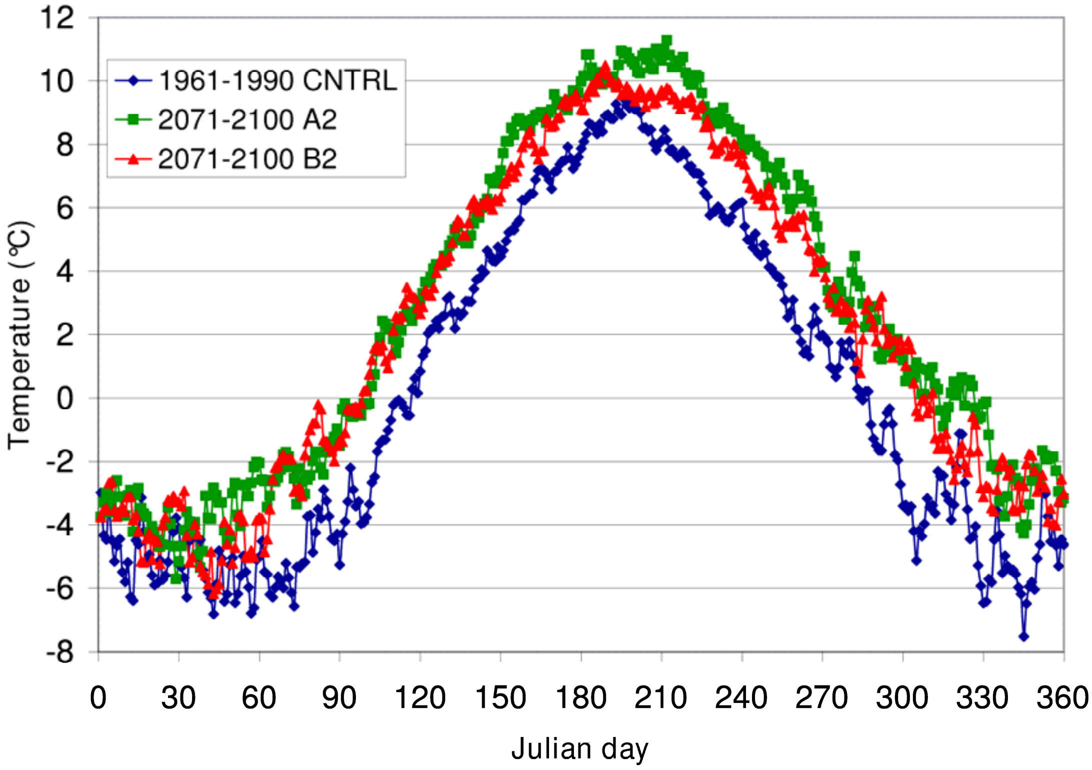


Figure 1. Temperature at an inland gridpoint in SW-Iceland in HIRHAM downscalings of HadAM3 GCM, control (1961-1990) and scenarios A2 and B2 for 2071-2100.

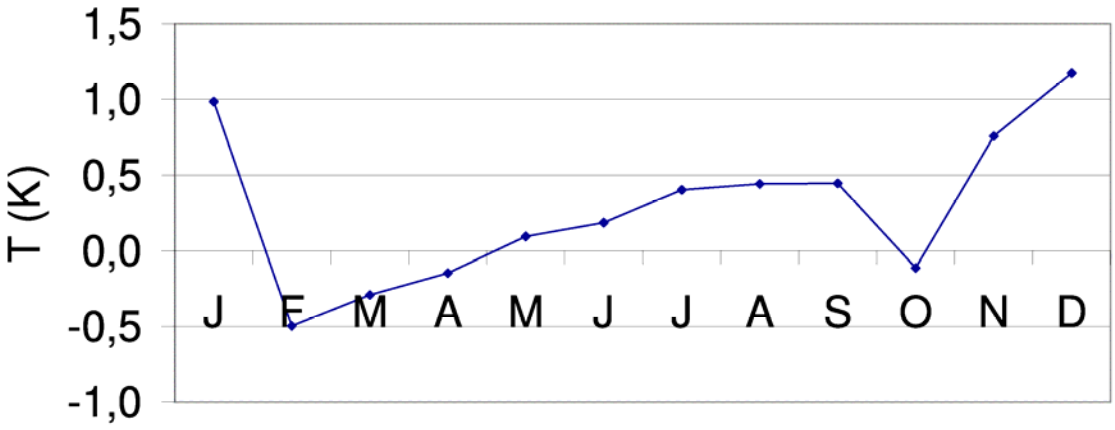
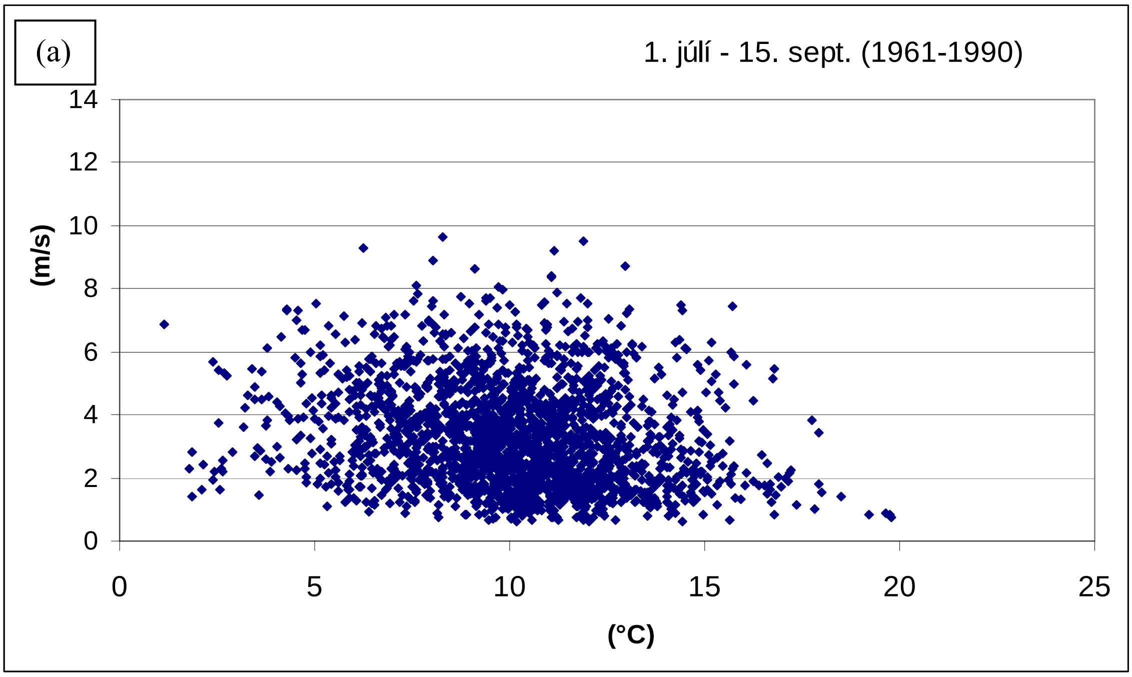
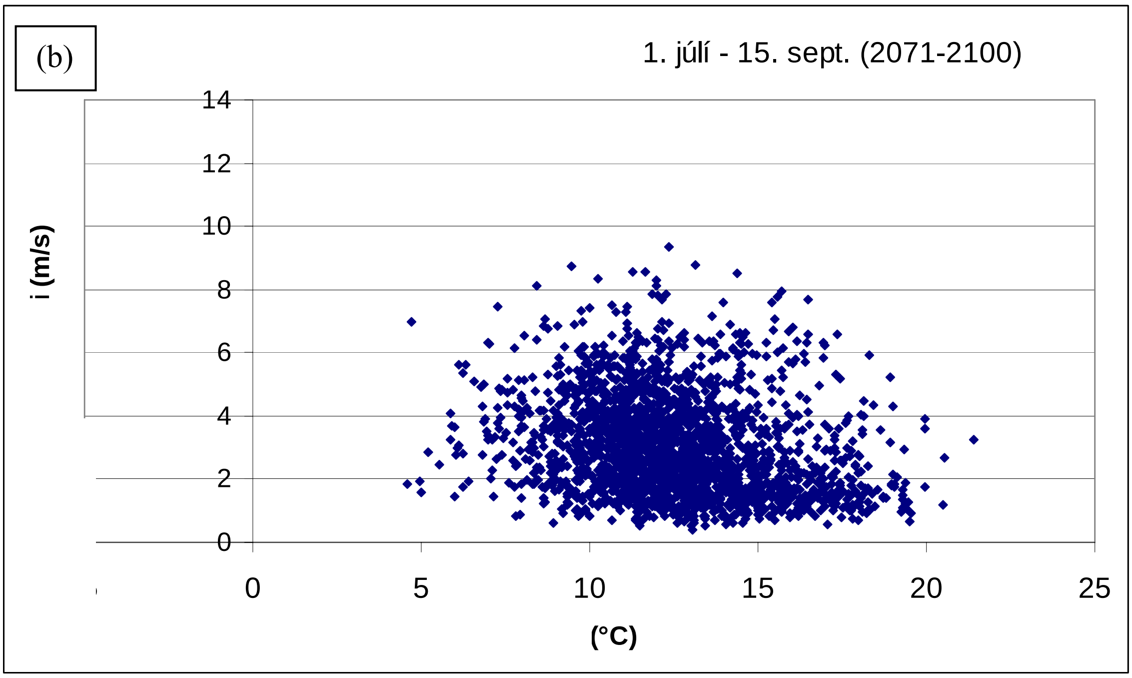


Figure 2. Observed changes in temperature in SW-Iceland (Mean temperature 1987-2006 minus mean temperature 1947-1986).

SEASONAL VARIABILITY OF MEAN TEMPERATURE CHANGE

Figure 1 shows the annual cycle of temperature in Iceland in the control simulation and the two scenarios. The values are from an inland gridpoint in SW-Iceland, representing the character of the predicted temperature change elsewhere in Iceland. The greatest warming is in late winter/spring and in the autumn, while in mid-summer and in mid-winter, the changes are relatively small. The lack of warming in mid-winter can be expected to relate to a relative reduction in the northward heat flux generated by extratropical cyclones moving NE between Iceland and Greenland. Such cyclones are connected to the temperature gradient between E-Canada and the warm airmasses over the N-Atlantic east of N-America. A considerable warming is predicted over Canada, leading to weakening of the horizontal temperature gradient and a degradation of the conditions for cyclones that would otherwise generate a northward heat transport towards Iceland. Figure 2 shows the observed mean temperature change for individual months of the year (mean temperature 1987-2006 minus mean temperature 1947-1986). The character of this change is different from the future scenario: there a considerable mid-winter (DJ) warming, but much less warming or even cooling late winter and in the spring.





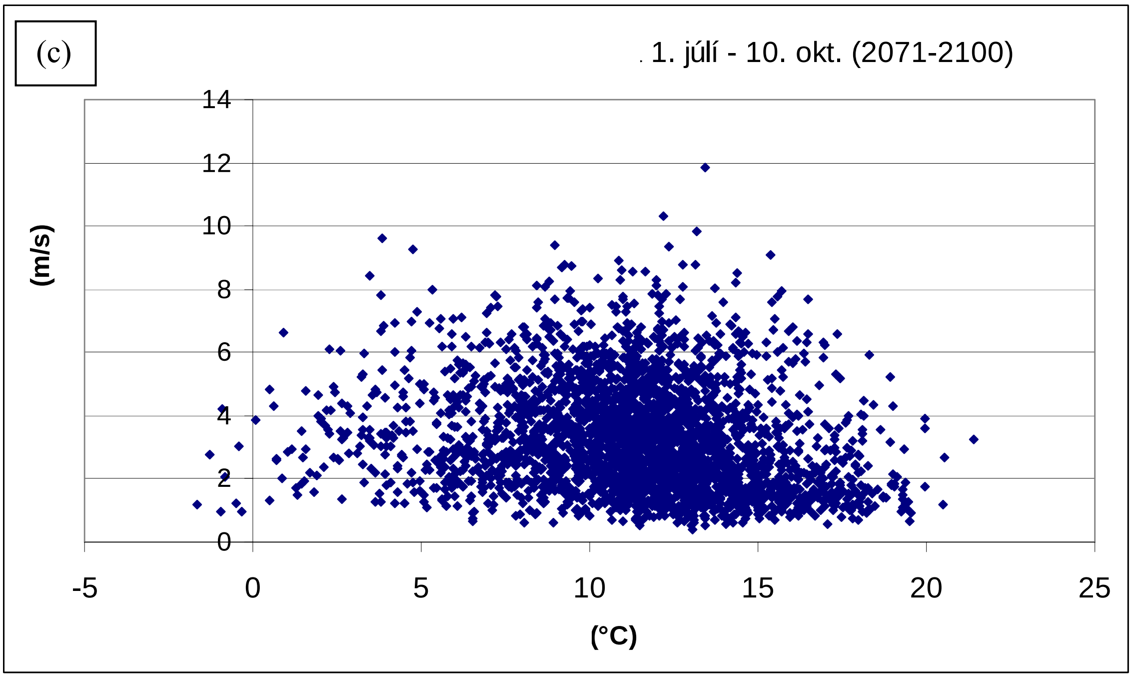


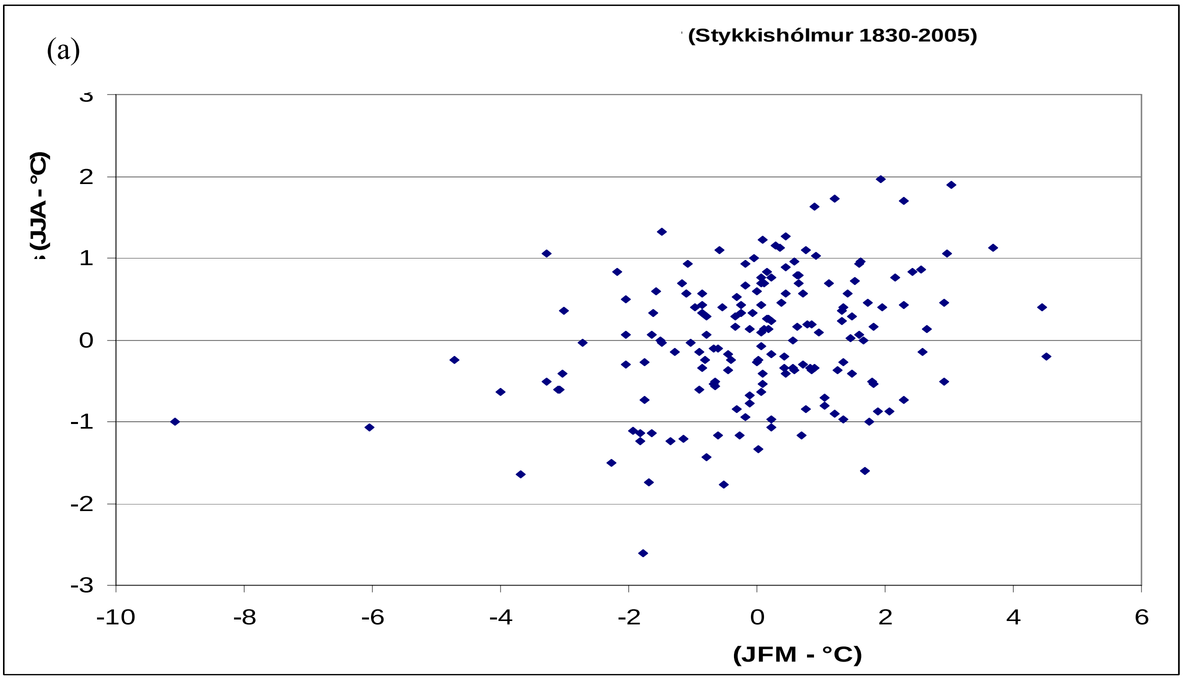
Figure 3. Plots of mean daily wind speed and mean daily temperature at an inland gridpoint in SW-Iceland. (a) in the control simulation 1 Jul – 15 Sep, (b) in a climate projection (A2) for 1 Jul – 15 Sep 2071-2100. (c) is the same as (b), but for the period 1 Jul – 10 Oct.

COLD SUMMER SPELLS

If the mean temperature was the only temperature criteria determining the length of the growing season, the temperature curves indicate that this period could be extended about 3 weeks in spring and autumn. However, other elements are also important. Damage to vegetation due to cold spells in summer is a problem in current climate and it is of interest to assess the change in frequency of such spells. Figure 3 shows values of mean daily wind speed and mean daily temperatures. The dots in the lower left corner of the graphs indicate days with favourable conditions for low level inversions and possible freezing at the ground. Comparing the control simulation and scenario A2 reveals a substantial change in the frequency of such events. In fact, the simulation of a future climate does not have any event within a surface cold-spell parameter space (in the lower left corner of the scatterograms) where there is one event a year in the control simulation. This is a big predicted change. Testing the idea whether it is possible to extend the growing period into the autumn one may look at a similar scatterogram, extending 25 days further into the autumn (10 October, Fig. 3(c)). Here, there are many more days with low temperatures and low wind speed than in the control simulation, indicating that the growing season can indeed not be expected to extend into the autumn as far as the changes in mean temperature may indicate. Other aspects such as sunlight and windstorms may also play an important role for certain species, limiting as well the usefulness of a possible temperature increase in the autumn.

SEASONAL PERSISTENCE

A cold winter may lead to late thawing of the soil. Under such conditions, the start of the growing season is delayed and it is particularly important to get a favourable summer. Otherwise, there may be no harvest in the autumn. Figure 4 shows the connection between mean winter temperature and the mean temperature of the following summer in the Stykkishólmur (W-Iceland) temperature series (Hanna et al., 2004). Although there is a large overall scatter, the figure shows that out of ten of the coldest winters, only one was followed by a summer with temperatures above average. However, looking only at the warmest 30 years in the same dataset, there is no similar connection. A cold winter is in other words not more likely to be followed by a cold summer than by a warm summer. The control simulation shows a connection between cold winters and cold summers (Fig. 5(a)) with 8 out of 10 of the coldest winters being followed by a cold summer. The 2071-2100 scenario shows on the other hand no such connection. (Fig. 5(b)).



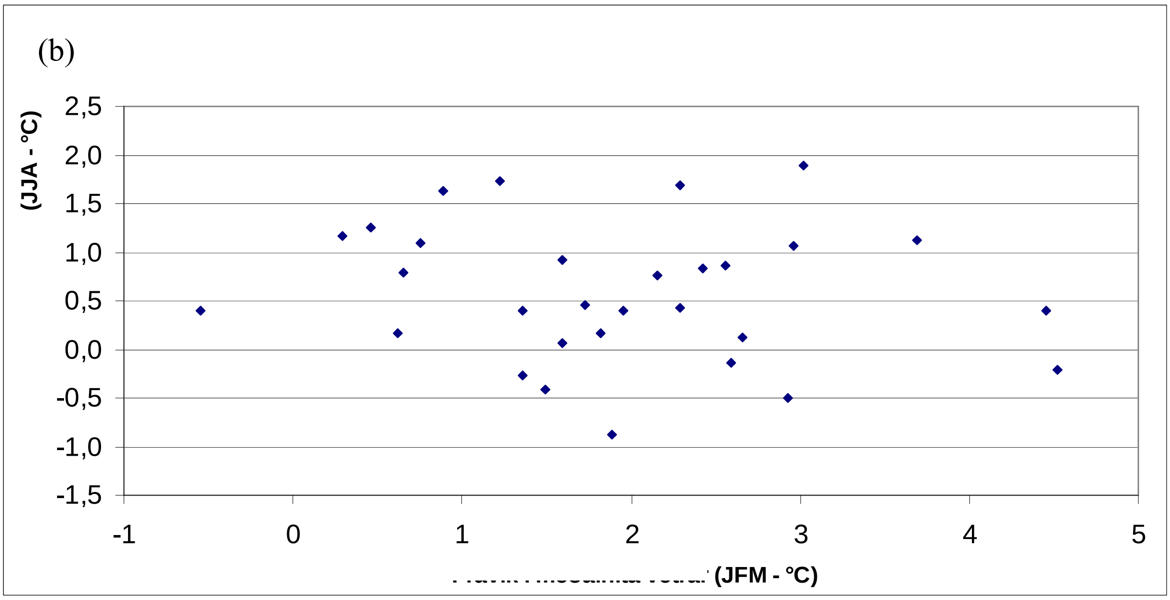
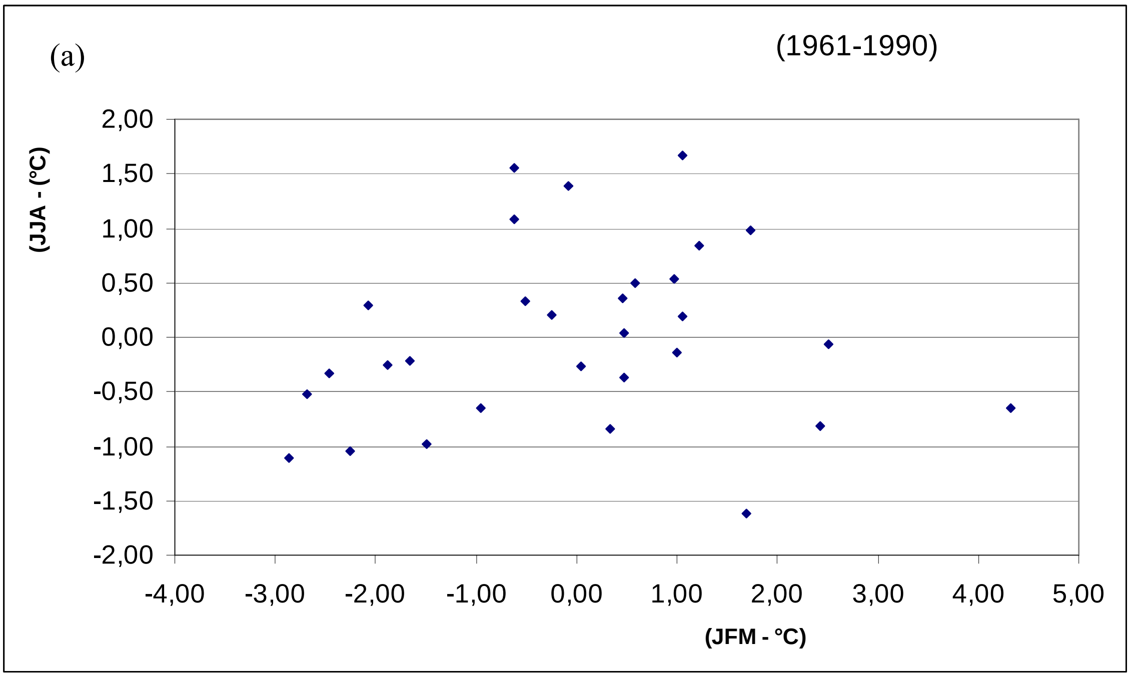


Figure 4 (a). Deviation of mean winter and mean summer temperatures of the same year from the 1830-2006 mean temperatures in Stykkishólmur (W-Iceland). (b) as (a), but only for the 30 warmest years.



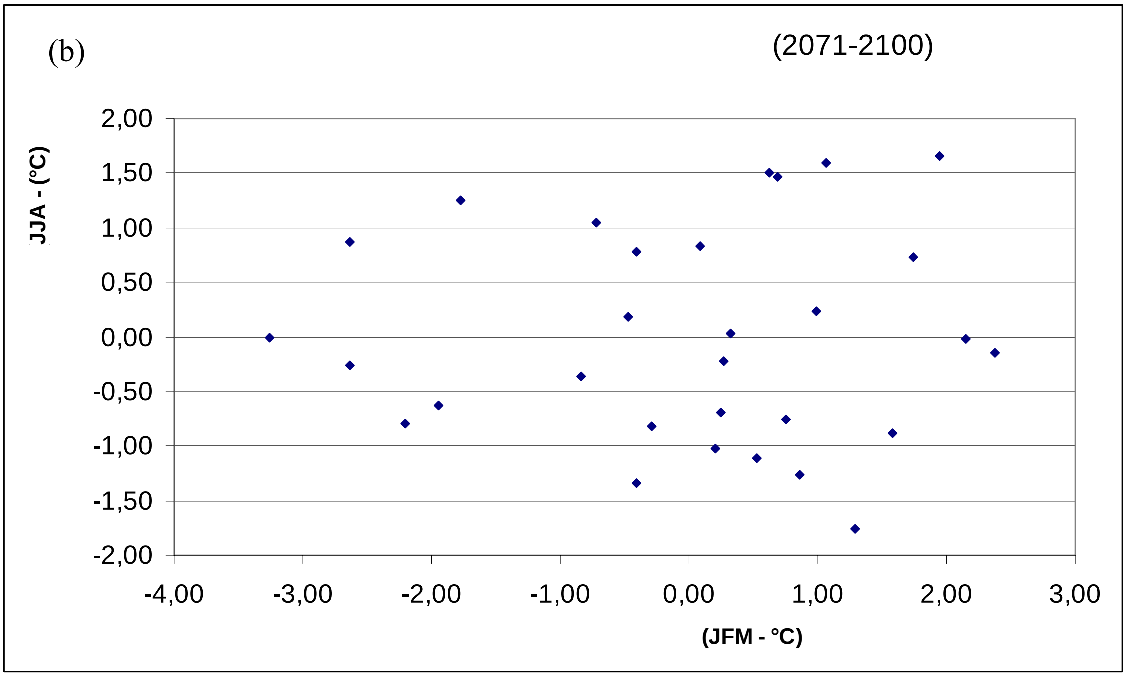


Figure 5. As Fig. 4, but from the control simulation (1961-1990) and the A2 scenario for 2071-2100.

SUMMARY

Dynamic downscalings of simulations of future climate have been explored (HIRHAM/HadAM SRES A2 and B2). A warming of 2-3°C is predicted for Iceland in the 21st century. The warming is greatest in late winter/spring and in the autumn, but less in mid-winter and mid-summer. Calm winds and low temperatures are considered to be indicative of subzero temperatures at the ground in the summer. The simulations indicate a very large reduction in such cases in a future climate. Another important factor for agriculture is the persistence of cold weather from winter into the summer. Such a connection is found in cold periods in past climate and in a control simulation of current climate, but not in the future climate simulations and not during warm periods of past climate

ACKNOWLEDGEMENTS

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CLIMATE CHANGE ADAPTATION FOR THE HYDROPOWER SECTOR

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ABSTRACT

Changes in future runoff due to potential climate change need to be accounted for in hydropower operation and planning. The hydropower sector relies on historical time series for operational strategies and future planning. Assuming future flows as stationary and ergodic extension of measured runoff series is no longer a probable scenario in a warming climate. There is need for developing mechanisms for adjustment of historical time series based on historical and possible future climate trends. These adjustments need to take into account the time frame of possible scenarios or planning horizons, such as 1 year for operational planning, 10 to 20 years for investment planning and longer for flood and drought risk. Different methods for sophisticated risk analysis accounting for climate change must be explored and extensively used. The results of the projects Climate Water and Energy 2002-2003 (CWE), Climate and Energy 2004-2007 (CE) and now Climate and Energy Systems 2007-2010 (CES) provide a framework for prediction of future changes in seasonal temperature and precipitation trends. Here these seasonal climate trends are used as input into rainfall-runoff models of Icelandic rivers, where historical climate data is adjusted into the future. The runoff output from the models is used as an input into energy simulation models of the Icelandic Power System and the impact from the future runoff is studied.

INTRODUCTION

Estimates for runoff at hydropower stations are inevitably based on measurements of river flows for some time past. The obtained records may or may not represent the flows at the exact location of the exact site in question and may or may not be continuous for the required period of time. It is therefore common practice to build a hydrological model of the watershed and use this for adjusting the flows, extend the records and fill up gaps. The end result is a time series that can be used for estimation of means, standard deviations and other stochastic properties of the runoff at the relevant sites.

Further processing depends to some extent on the actual situations of the power market being served. Probably most common is the situation where hydro is a fraction of the power system and all potentially generated power can be sold at the right price. In such a situation the averages are most important for investment planning and other stochastic properties are important for maximization of income during operations. In the Icelandic situation hydro is the dominating part of the power system and the rest is supplied by geothermal power, which is a very stable source of energy with practically zero variable cost components. Market fluctuations are therefore mostly born by the hydro, especially in the short term. Demand is the single most important constraint for hydro production and security of supply is the primary goal of operations. In this situation an accurate description of the lower part of the frequency curve becomes more important for both investment and operational planning. The upper end of the curve is of course always very important for spillway design and other safety issues.

CLIMATE CHANGE IMPLICATIONS

Up to recent times it has commonly been assumed that river flow behaves like a stationary and ergodic process so the characteristics of future flows should be accurately described by historical records. With the assertion that global warming as a consequence of the "Greenhouse Effect" is a phenomenon to be reckoned with, this assumption is no longer a plausible one. It is therefore necessary to develop new mechanism for adjustment of historical time series based on historical and possible future climate trends. This task is made more complicated by the facts, that not only do the means have to be adjusted but the entire range of the frequency curve including floods and droughts and this needs to be done for many possible planning horizons, e.g. one year for operations, 10 or 20 years for investment planning and 100 years or more when safety issues are considered. All this combined with the demands for efficient allocation of monetary resources calls for sophisticated risk analyses of possible climate change in both near and far future, where different methods must be explored for different situations and tasks.

For demonstration purposes we have in this paper chosen to estimate a possible impact of global warming on the power producing capability of the Icelandic hydro power system in the year 2010. This for example involves correcting historical time series so that each year of the historical time series can be considered to reflect the climate in the year 2010.

The results of the projects Climate Water and Energy 2002-2003 (CWE), Climate and Energy 2004-2007 (CE) and now Climate and Energy Systems 2007-2010 (CES) provide a framework for prediction of future changes in seasonal temperature and precipitation trends. Even though this framework must still be deemed rather crude, it is sufficient for exploring some methods that could be used for future decision making. The comprehensive hydrological models already in use provide opportunities for interpreting the results from such studies and others to produce future flow scenarios for planning purposes.

The first step when dealing with flows like prevalent in Iceland, where glacial melt and snowmelt are major components of the runoff is to adopt a warming scenario. As an example we can look at one of the IPCC (2001) scenarios that was presented at the Euronew conference in Reykjavik 2006 (Rummukainen et al., 2006). As indicated by Fig. 1, future warming in Iceland over a 110 year period is estimated from 2.5 to 3°C in the inland mountain regions where the glaciers contributing to runoff to the power plants are situated. This expected warming enhances glacial melting and consequently causes increased river flows and power production capabilities of the affected power stations.

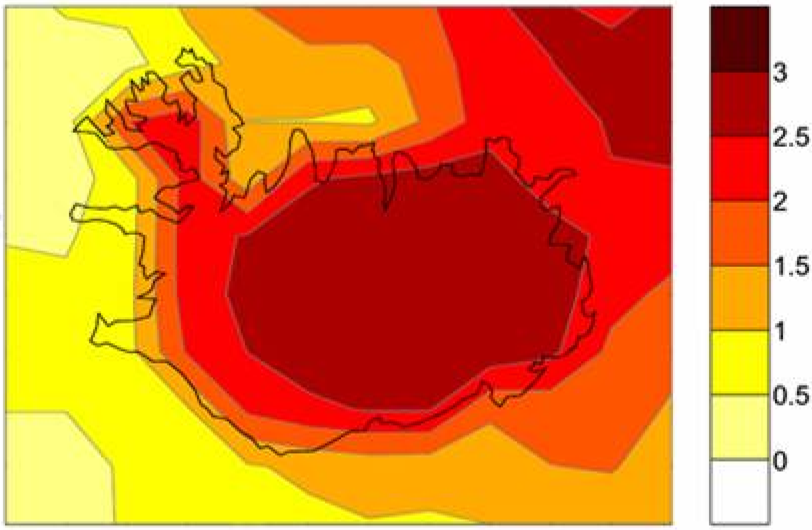

Figure 1. *Estimated warming in Iceland from 1960-1990 to 2071-2100 HIRHAM-H-A2 Rummukainen (2006) (for scenario A2 see IPCC, 2001).*

An associated scenario for changes in precipitation has also to be adopted. In Table 1 below one such scenario is shown. This is prepared by specialists of The Icelandic Weather Bureau and the Hydrological Service of the National Energy Authority by processing the results of the CWE and CE projects. The resulting changes have much less impact on flows in the Icelandic rivers than the temperature changes, but must never the less be accounted for. The changes are quite different in different parts of the country and we have chosen to preserve those differences in this study. Also we have preserved the seasonal fluctuation of the scenario both in precipitation and temperature (also shown in Table 1).

The scenario shown here is but one of many possible and the outcome of each must be considered as having a rather large spread as indicated by Fig. 2.

MONTH	CHANGES I NPRECIPITATION IN % BY REGION					WARMING
	SW	NW	NE	SE	All	°C/century
1	-0.45	0.00	0.82	0.15	0.38	1.0
2	-0.96	-0.15	1.97	0.45	0.33	1.3
3	-0.81	-0.30	0.91	0.45	0.06	2.8
4	-0.40	-0.15	0.45	0.61	0.13	2.8
5	-0.05	-0.15	-0.45	0.30	-0.09	2.2
6	0.10	0.15	0.30	0.30	0.21	1.7
7	0.45	0.15	0.30	-0.61	-0.08	1.7
8	0.96	0.91	0.00	-0.45	0.35	2.8
9	1.72	1.21	-0.15	0.15	0.73	3.7
10	1.92	1.97	0.91	1.21	1.50	3.7
11	1.57	1.36	1.36	1.06	1.34	3.5
12	0.51	0.91	1.82	0.45	0.92	3.0

Table 1. *A scenario of estimated changes in precipitation (%/decade) and temperature (***°C/century***) in Iceland from 1960-1990 to 2071-2100.*

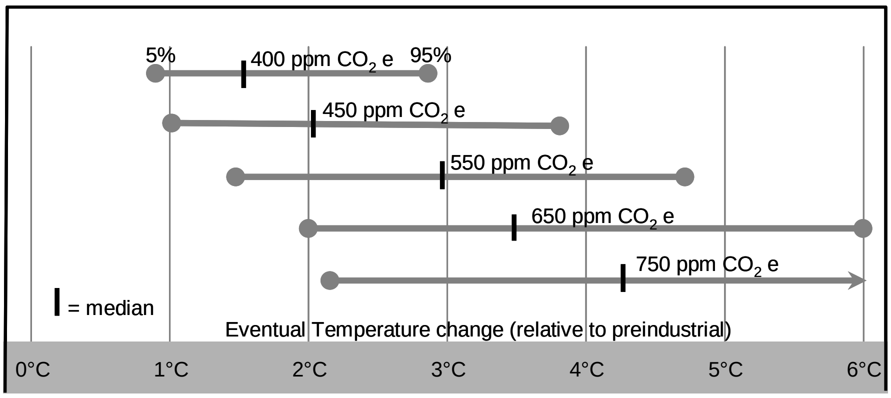

Figure 2. *Results from the Hadley Center on temperature increase caused by air pollution. (Source: Stern (2006)).*

RESULTS

The scenarios resulting form the CWE and CE projects are estimated as changes from the period of 1960-1990 to the period 2071-2100, which of course is an altogether to long a timeframe for capability studies like the one to be demonstrated in this example. One has to bear in mind, that the greenhouse gasses causing global warming have risen slowly from the start of the industrial revolution in the nineteenth century until the post war period after 1944, but started to accelerate some years later and is expected to rise even more rapidly in the coming years with consequent increase in temperature following a certain time lag. Estimates of global warming with time throughout the literature are generally in accordance with this as there seems to be consensus about a comparatively slow development in the later half of the last century, accelerating in the beginning if this one (that is now) until the middle and then gradually decelerating again. We can therefore expect a much more rapid increase in temperature in the coming decades than can be asserted by measurements until say 2005. In order to produce a scenario that could be plausible for the reference year 2010 we have estimated that the trend of the climate changes in the period 1960 to 2010 is on the average 70% of the average trends estimated for the 110 years used in the CWE/CE studies. Further we have assumed that the spread of this estimate follows a gamma distribution and the resulting one is shown in Figure 3. This distribution is then the basis for risk analyses when determining the power production capability for the Icelandic system.

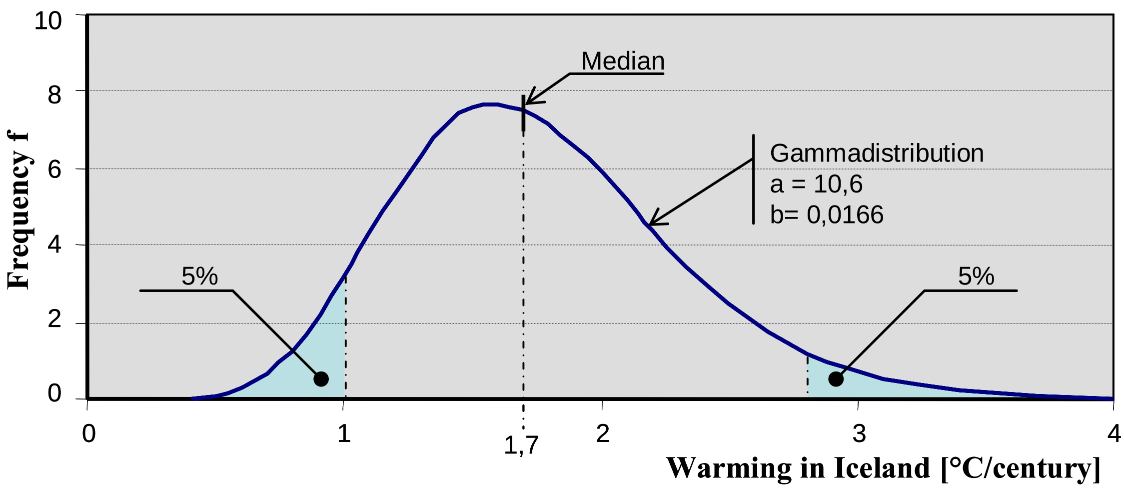

Figure 3. *A constructed frequency function for temperature trends in Iceland from middle of the 19 hundreds and a decade into the next century in degrees/century.*

The runoff series used in Iceland for estimating power production capabilities are constructed using a series of hydrological watershed models created and maintained by an engineering firm, Vatnaskil ehf. (Verkfræðistofan Vatnaskil ehf., 2006a;2006b;2006c). The models are calibrated using all available measurements on flow, precipitation and temperatures. The calibrated models output flow series from 1950 for simulation purposes. These models differ from others in that they contain both rather sophisticated sub models of groundwater flow and a simple glacial sub model. By feeding new time series of temperatures and precipitation as obtained from the scenario studies described above, new flow series are obtained and then used for production estimates.

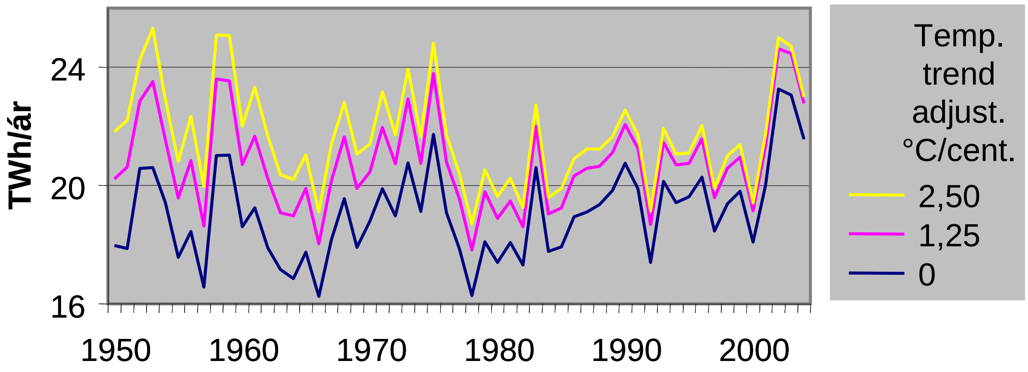

Figure 4. *Possible energy supply in the runoff to Icelandic power stations as measured and adjusted for climate trends.*

Figure 4 shows the energy that could be extracted based on the runoff series using three different warming scenarios and assuming unlimited market and unlimited installed capacity in the present power stations. The baseline case assumes no warming, while the other two assume seasonal warming trend of 100% and 50% of that shown in Table 1 from 1950 to 2010. As seen in the picture, the maximum adjustment (for the trend 2,5 °C/century) actually reverses the trends in the flows observed from 1950 (Jóhannesson, 2006a;2006b).

In order to determine the load that can be scheduled for the current capacity of the power system in 2010 without an unacceptable risk we guess a load and use water value based simulation technique to estimate the expected generation costs for all possible outcomes of the climatic trends from 1950 to 2010. Figure 5 shows the results of such calculations for a given load scenario, which is intentionally higher than presently estimated production capability of the system. For each trend outcome the costs are ordered from highest to lowest obtaining a series of risk curves as shown in the figure. In the case of no trend adjustment being made (trend = 0), very high costs are obtained, but very low if the trends of Table 1 are assumed (trend = 2.50).

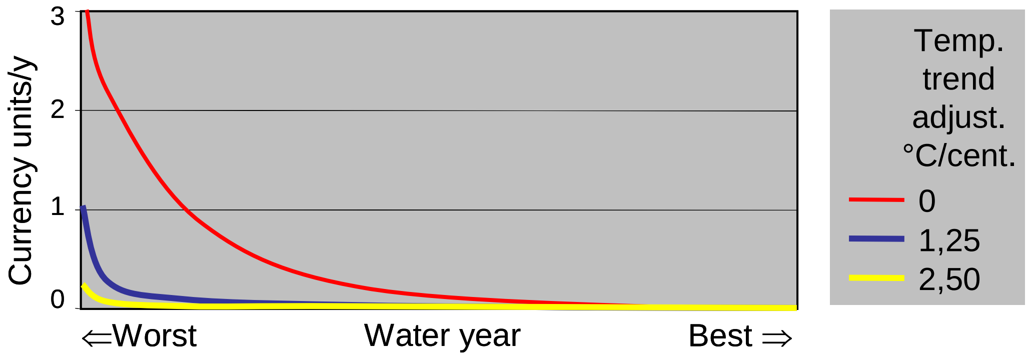

Figure 5. *Generation costs obtained for a given load scenario for three possible outcomes of climate trends from 1950 to 2010.*

Taking the effects of global warming into account, one needs to select a warming scenario before the production capability can be determined from the associated risk curves. Each warming scenario is by Figure 3 attached to a probability, making it is possible to combine the risk curves from Figure 5 into one curve of the same type, thus including the risk adopted by selecting a certain warming scenario. This aggregate risk curve can then be the basis for determining the optimum production capability. In Figure 6 it is marked how the production capability would be increased using this approach relative to accepting no trend at all and compared to a curve showing the change that occurs when accepting ever higher warming trends. The optimum load increase occurs when accepting a trend of 1.56°C/century from 1960 to 2010.

It is interesting to note, that when using the warming scenario of 1.56°C/century to calculate annual energy supply in the same way as in Figure 4, the resulting energy flows do not indicate any trend at all.

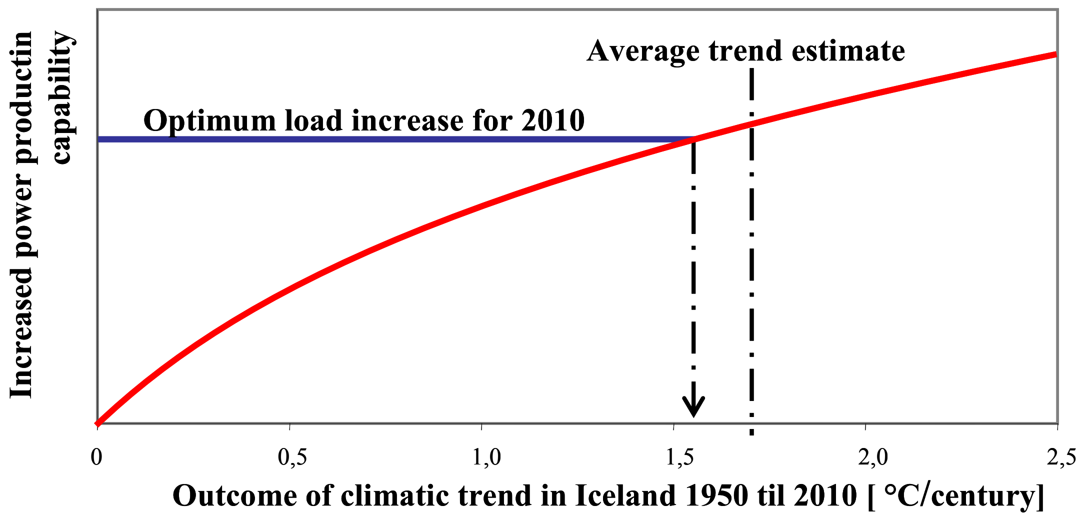

Figure 6. *Change in power production capability as function of climatic trend.*

CONCLUSIONS

We have in this paper taken the results of the projects Climate Water and Energy 2002-2003 (CWE) and Climate and Energy 2004-2007 (CE), constructed a probability function to assess the risks associated with selecting one outcome of such studies above all others and determined an optimal selection. In the process we have made a number of assumptions, both direct and implied, the validity of which is not asserted. There is obviously a considerable room for improvements. We have also chosen only one time horizon out of many possible to work with. We have however demonstrated how information on probabilities can enhance the value of studies on climate change like the presently active Climate and Energy Systems 2007-2010 (CES) with the aim of emphasizing fields of current importance.

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REGIONAL AND SEASONAL VARIABILITY IN PRECIPITATION SCENARIOS FOR ICELAND

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ABSTRACT

Dynamic downscalings of precipitation scenarios are explored. The simulations show only a moderate change in the mean annual precipitation in Iceland. However, there is a substantial precipitation increase predicted in S-Iceland and W-Iceland in the autumn and in NE-Iceland in the winter. The simulations show a maximum increase above sloping topography, leading to the conclusion that due to poor resolution of the topography, an increase in precipitation in the mountains may be much greater than simulated. This emphasises the need for high-resolution climate simulations.

INTRODUCTION

In order to assess plausible regional changes of precipitation in Iceland, dynamic downscaling of global atmospheric simulations from the Hadley center model (HadAM3H, Johns et al., 2003) have been explored. The downscalings were carried out with the HIRHAM regional climate model (Bjørge et al., 2000) for a limited area (Fig.1) over the N-Atlantic and NW-Europe (Haugen and Iversen, 2005). They were an integrated part of the international PRUDENCE climate project (Christensen, 2004). The global model represents a coupled ocean-ice-atmosphere system with a horizontal resolution of T106 which corresponds roughly to 125 km. The HIRHAM downscaling was carried out in 19 vertical levels with a horizontal resolution of 55 km. Most weather systems approach Iceland from the south and the west. The outer boundaries of the simulation domain, southwest of Iceland, are only about 1200 km away and this may have an impact on the development of extratropical cyclones arriving from this direction. It is not clear how important this effect may be and should be investigated in connection with future simulations. Some numerical noise is found at the outermost gridpoints of the HIRHAM domain, but this noise fades out within

5 grid points or even less. Global simulations corresponding to two emission scenarios were downscaled, the IPCC SRES A2 and IPCC SRES B2 (Nakicenovic and Swart, 2000).

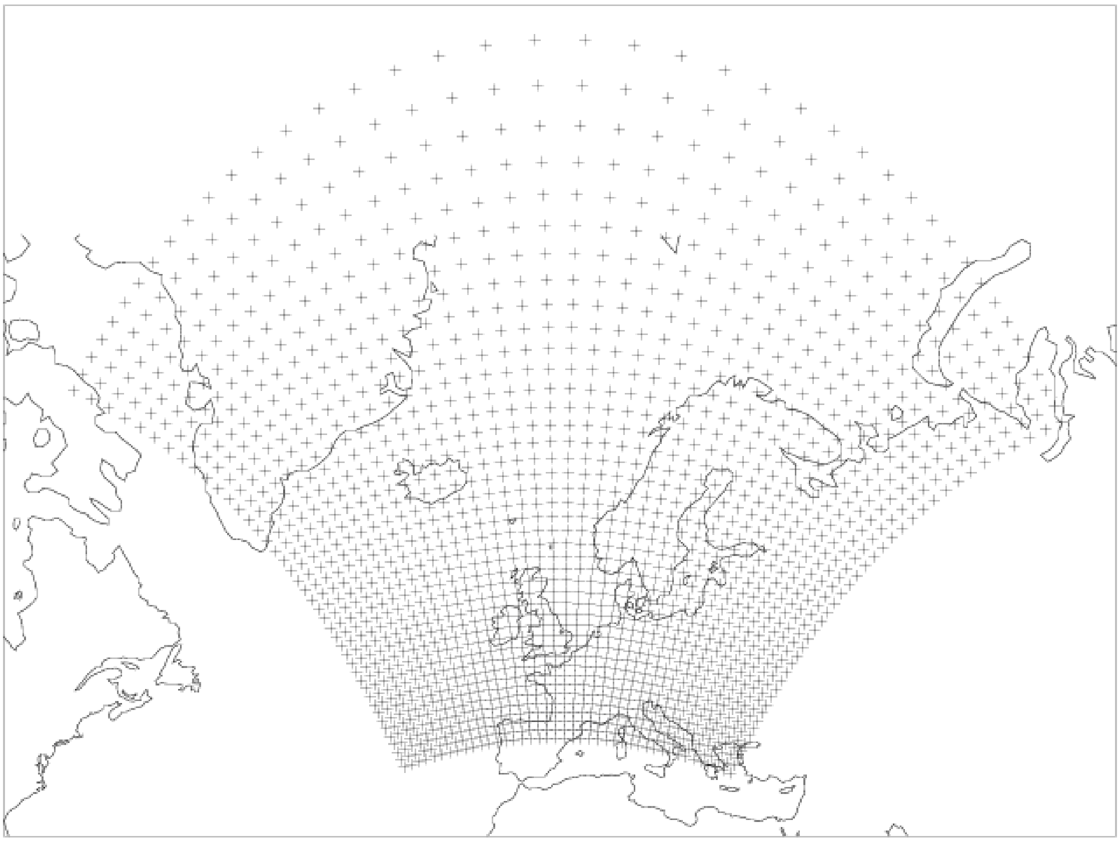


Figure 1. The simulation domain and of the HIRHAM dynamic downscaling.

REGIONAL AND SEASONAL VARIABILITY OF PRECIPITATION

Figures 2 and 3 show the projected changes in the mean annual precipitation and the mean seasonal precipitation from the reference period (1961-1990) to 2071-2100 as simulated with the HIRHAM model. The changes in the mean annual precipitation are quite moderate. In most coastal regions there is an increase of 0-10%, but in the central highlands there is a small decrease. In general, the predicted patterns of precipitation change are similar in both scenarios, A2 and B2. While there is only quite a moderate increase in mean annual precipitation, there is a relatively large change in the mean precipitation in individual seasons (Fig. 3). The autumn is expected to be considerably wetter in S-Iceland and W-Iceland, while the projections for N-Iceland and E-Iceland are more ambiguous. The spring becomes slightly drier everywhere and the winter is expected to be drier in SW-Iceland and much wetter in NE-Iceland. The summer predictions are rather noisy. As for most other aspects of projected changes in precipitation, it is unclear to what degree these local and seasonal changes are due to ”natural” fluctuations in the climate simulations or to what extent they represent a true deterministic signal caused by greenhouse warming.

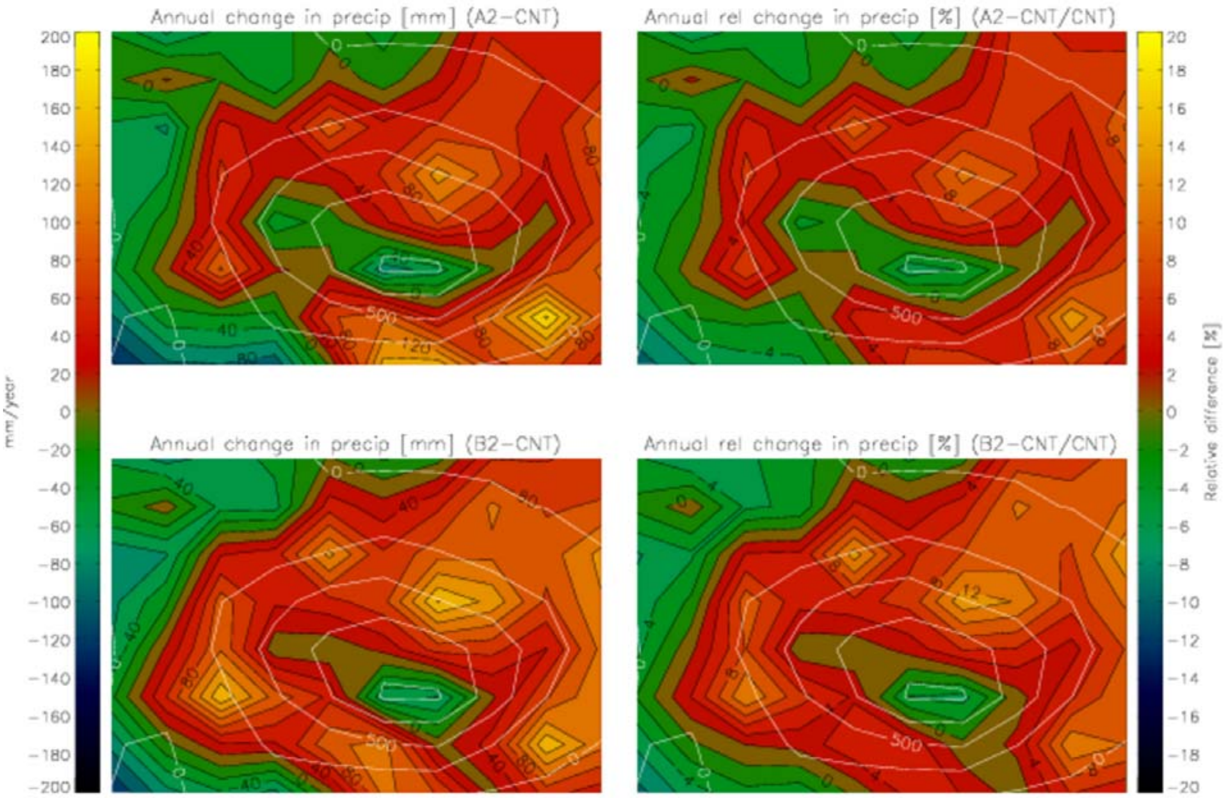
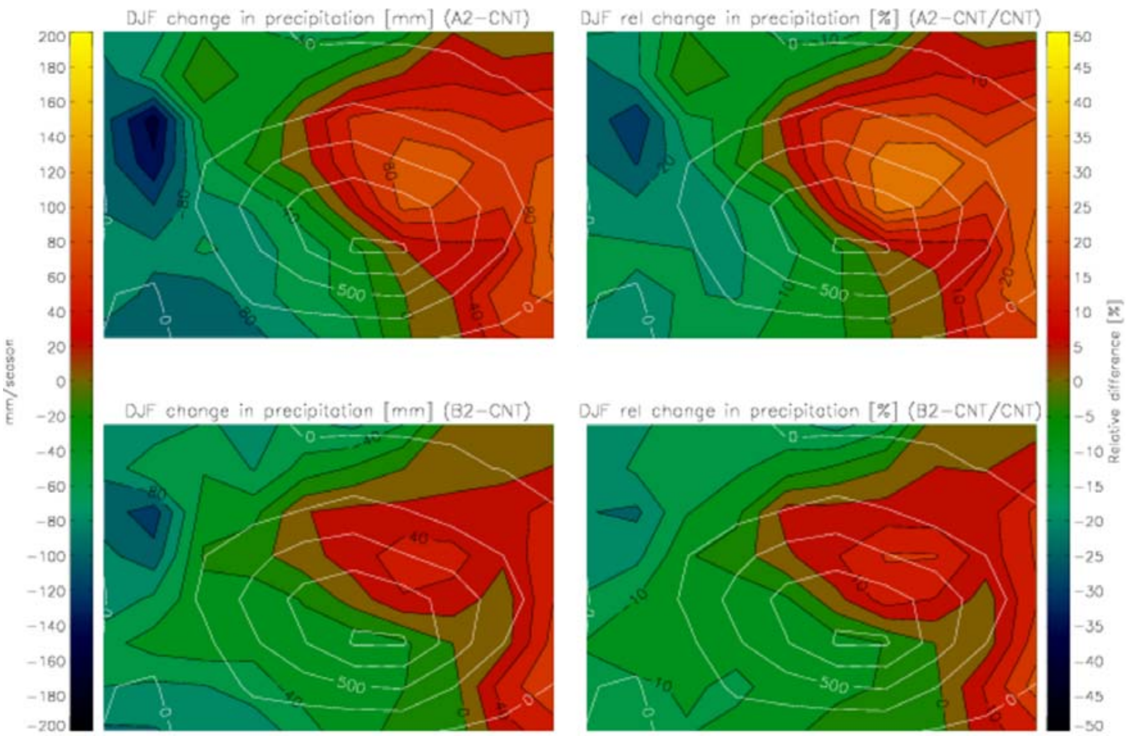
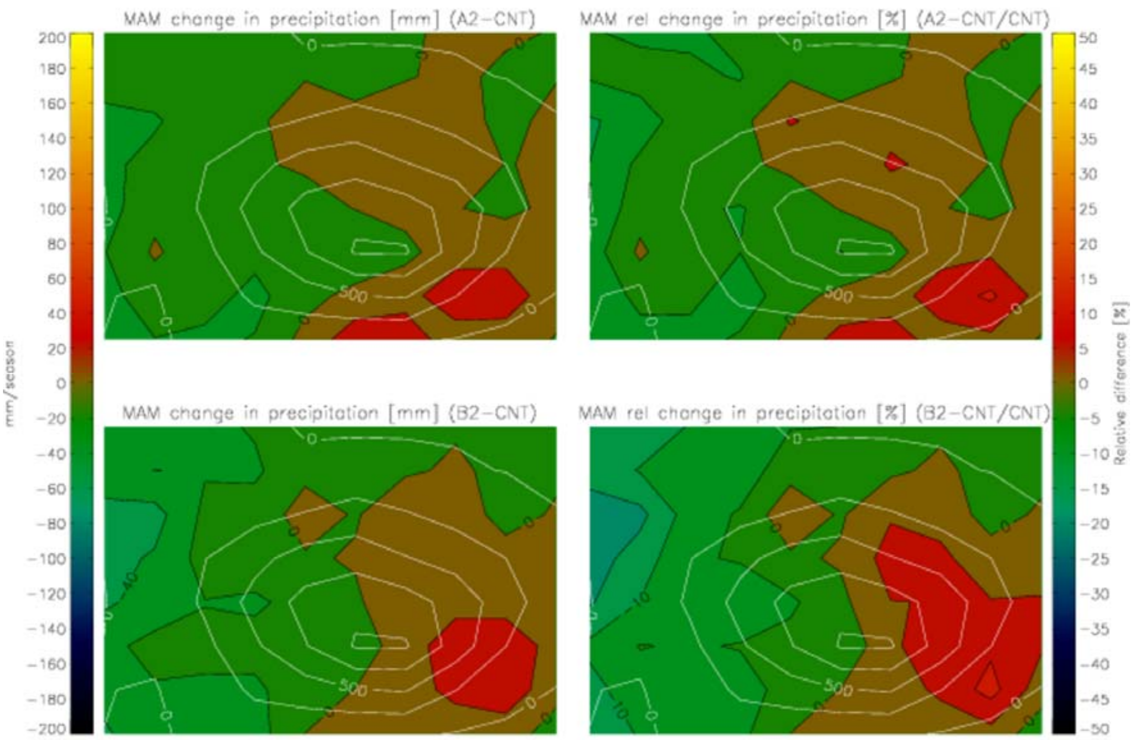


Figure 2. Change in annual precipitation in Iceland according to the HIRHAM A2 and B2 downscaling of HadAm3 GCM simulations. The left panels show changes in mm and right hand panels show relative changes (difference of the mean precipitation in the periods 2071--2100 and 1961--1990 relative to the mean precipitation of 1961--1990). The top panels show scenario A2 and the bottom panels scenario B2. White contours indicate the model topography of Iceland with 250 m intervals.

THE SLOPE SIGNAL

There is a clear slope-signal in the predicted precipitation change, particularly in the autumn precipitation increase in the south and in the winter precipitation increase in the NE. The maximum precipitation increase coincides with the maximum slope of the topography, indicating that the orographic enhancement of precipitation will increase. The complexity of the connection on climatic time-scales between precipitation in the mountains and in the lowlands may in other words be greater than previously considered. If this is correct, time-series of precipitation that are created by assuming linear connection between precipitation in the mountains and precipitation in nearby lowlands must be revised. If mountains are poorly resolved, which is almost always the case, the





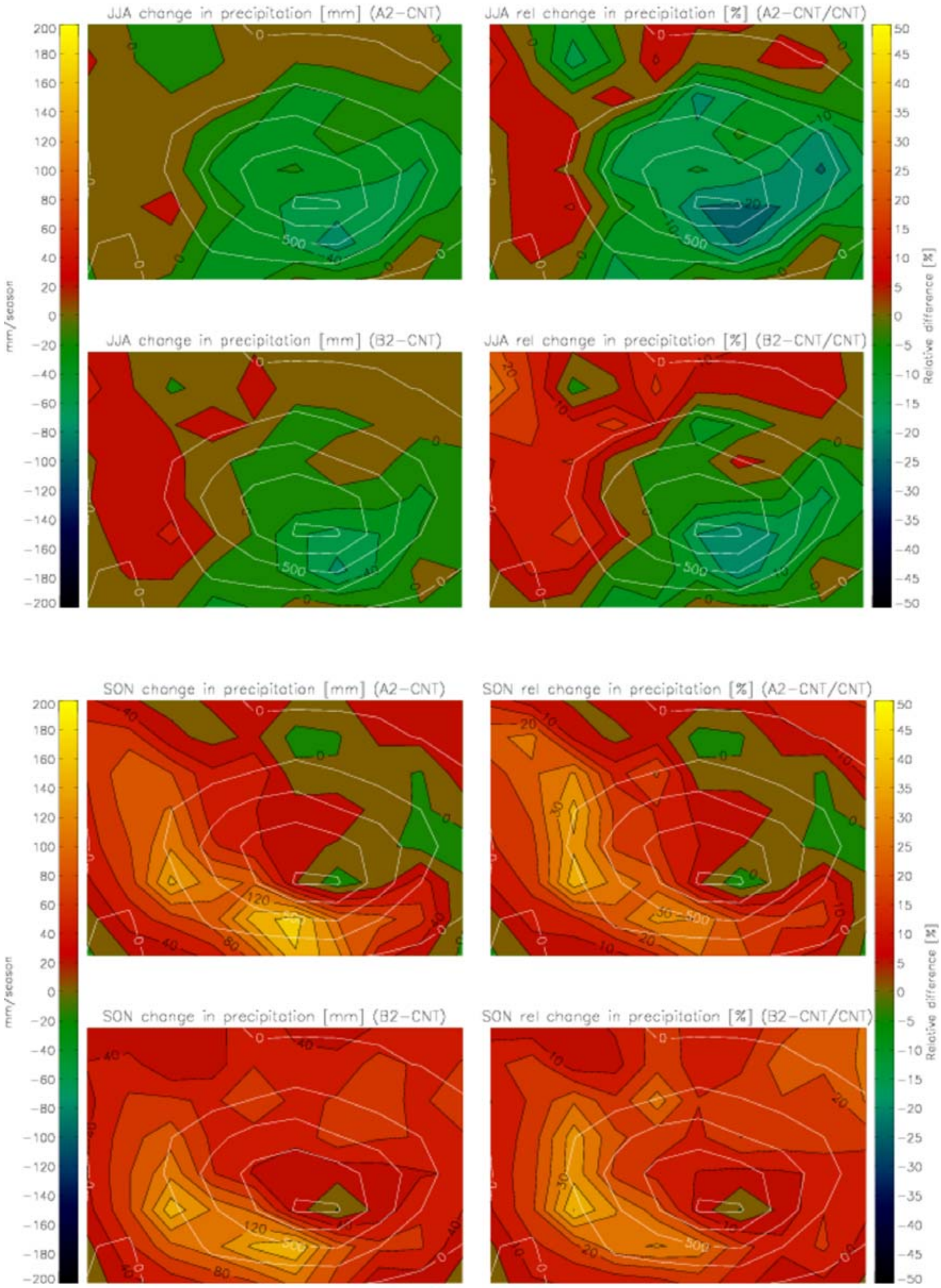


Figure 3. As Figure 2, but for individual seasons (DJF, MAM, JJA and SON).

use of the delta method (future scenario minus control simulation) for estimating precipitation change in the mountains becomes questionable.

The orographic signal raises the question on how the ratio of precipitation in mountains to lowland precipitation looks like in the past. Figure 4 shows that there is indeed not only interannual, but also substantial interdecadal variability in this ratio. This needs to be investigated further and connected to elements of the meso- and synoptic scale airflow.

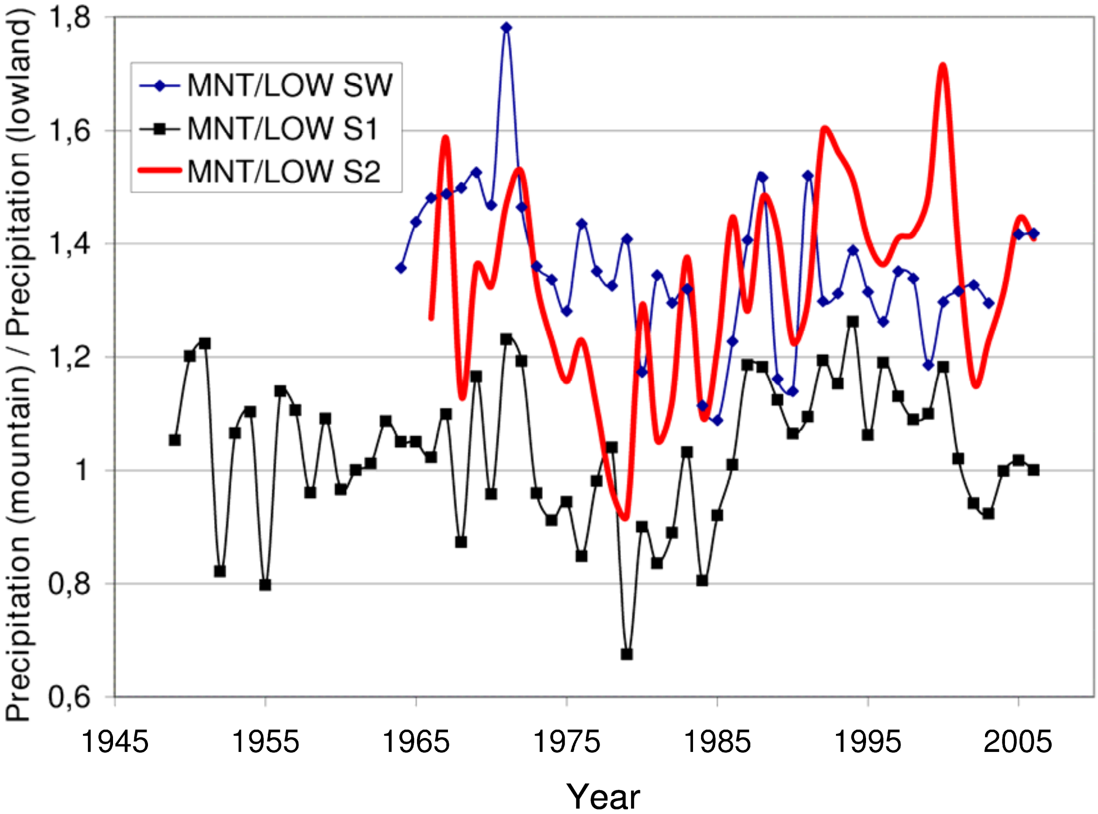


Figure 4. Ratio of observed precipitation at locations where there is significant orographic enhancement of precipitation (mountain) to precipitation observed in the same region, but farther away from the mountains (lowland). The weather stations are Stardalur and Keflavíkurflugvöllur (SW), Vatnsskarðshólar and Stórhöfði (S1) and Skógar and Stórhöfði (S2). The figure is redrawn from Ólafsson and Arason (2007).

CONCLUSIONS

Apart from quantitative results on precipitation in different regions and in different seasons in Iceland, a key conclusion of this study is that a strong slope signal in the projected precipitation changes calls for high-resolution simulations of future scenarios. The resolution should be sufficient to reproduce the topography. Optimal resolution for climate studies can therefore be expected to be dependent upon the steepness of the mountains.

ACKNOWLEDGEMENTS

The authors would like to thank J. E. Haugen and T. Iversen for providing the HIRHAM data. This study was supported by the CE/VO/VVO projects.

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RUNOFF MODELLING IN ICELAND WITH THE HYDROLOGICAL MODEL, WASIM

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ABSTRACT

The distributed hydrological model WASIM has been employed in studies carried out at the Hydrological Service in the past five years. The model has been used to produce a runoff map of Iceland for the decades 1961-1990 and a projection of future runoff for the decades 2071-2100. Modeled runoff data are also being provided as boundary conditions for oceanographic modelling. Further application of the WASIM model in coming years is outlined.

INTRODUCTION

Hydrological quantities are important in many respects: for utilization and management of water resources; as an input to other research fields, e.g. oceanography; as indicators of climate changes and more. But since measurements are sparse in both space and time, models are often used to produce time series for past time periods and ungauged areas. As a part of the joint Nordic research project, CE (Climate and Energy, see http://www.os.is/ce) (Fenger, 2007), and the Icelandic sister project VO (Veðurfar og Orka) the WASIM model (Jasper et al., 2002; Jasper & Kaufmann, 2003) was set up and calibrated at the Hydrological Service. The model has been used to make a runoff map for Iceland and a future projection of runoff. The produced data sets on freshwater runoff of Iceland are now being used as a boundary condition in an oceanographic model that computes the ocean's current field, its temperature, salinity and the sea surface elevation.

Further application of the model and development of its use is intended as part of the followup project CES (Climate and Energy Systems, see http://leirhnukur.orkugardur.is/ces). The groundwater modulus of WASIM has not been used up to now because of a lack of calibration data, but will be included in our further work. A new calibration of the WASIM model, using precipitation data on a 1x1 km grid is also planned. Up to now weather data on a 8x8 km grid have been used but orographic precipitation is much better represented on a smaller scale. Further runoff simulations are planned after recalibration and activation of the groundwater modulus.

RUNOFF MAP OF ICELAND FOR 1961-1990 AND FUTURE PROJECTION FOR 2071-2100

The WASIM model was used to make a runoff map of Iceland for the period 1961-1990, which was selected as a reference period in the CE project. A future projection of runoff for the period 2071-2100 was also made. The project was sponsored by: the National Energy Authority, the Icelandic VO project and the joint Nordic CE project. A short description of the project and major results is given below but the reader is referred to Jónsdóttir (2008) for more detailed information.

Data and methods

The WASIM model was calibrated with data from about 70 watersheds covering 1/3 of the country. Data from 30 watersheds were also used for a crude comparison of calculated and measured water balance. Model parameters were evaluated for ungauged watersheds using a division of the country on a catchment scale by hydrological properties.

Meteorological data calculated by Institute of Meteorological Research were used as input in WASIM. Precipitation and other meteorological parameters were calculated on a 8x8 km grid using the PSU/NCAR MM5 numerical weather model (Rögnvaldsson, 2004).

The evaluation of the effects of climate change was based on a climate change simulation from the HIRHAM regional climate model (RCM; Bjørge et al., 2000) with boundary conditions from the HadAM3H global climate model (GCM; Gordon et al., 2000) using A2 and B2 emission scenarios (Nakićenović et al., 2000).

As the volume of glaciers in Iceland is projected to decrease over the next centuries, decreased glacier extent and lower ice surface elevation was accounted for in the scenario calculation for 2071-2100. This was done by using a projection of future glacier geometry for the year 2085 that was made as part of the CE project, produced from a dynamic glacial model for the three largest ice caps in Iceland; Vatnajökull, Langjökull and Hofsjökull, which encompass about 90% of the glaciated area in Iceland (Aðalgeirsdóttir et al., 2006; Bergström et al., 2007).

Results

According to the runoff map (Fig. 1) the mean discharge for the water years 1961-1990 is 4770 m^3/s or 1460 mm/year. This is somewhat lower than runoff estimates obtained for earlier periods; which were 5500 m^3/s or

1690 mm/year for 1948-1955 (Rist, 1956) and 5150 m^3/s or 1590 mm/year for 1951-1980 (Tómasson, 1981). Evapotranspiration was found to be 280 mm/year, whereas Rist (1956) and Tómasson (1981) found values of 100-200 mm/year and 310-414 mm/year respectively.

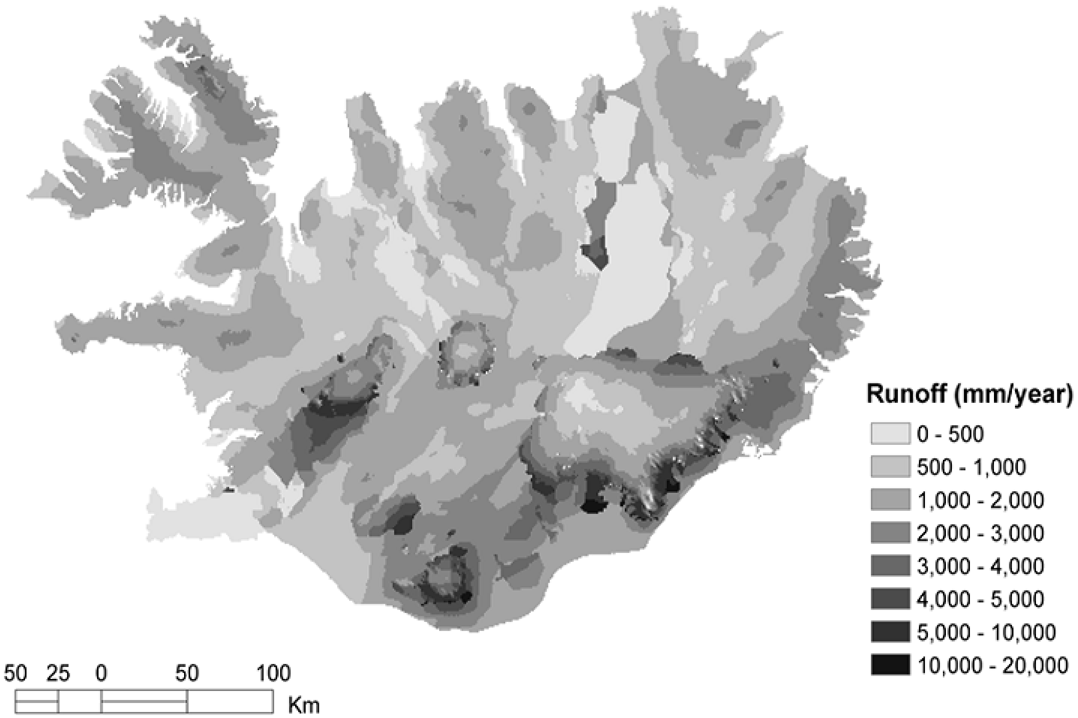

Figure 1. Runoff map of Iceland for the period 1961–1990.

Future runoff was found to become substantially higher in 2071–2100 compared with 1961–1990. According to the runoff projection, the average runoff over the whole country will be 1800 mm/year in the period 2071–2100, which is almost 25% higher than in the reference period 1961–1990 (Fig. 2a). The increase in future runoff is predominantly due to increased glacial melting caused by higher temperatures, which are projected to rise on average by 2.8°C between the two above mentioned periods. Discharge from non-glaciated areas increases by 8%, in part because non-glaciated areas become larger (Fig. 2b), while glacial discharge increases by 90% (Fig. 2c) (Jónsdóttir, 2008).

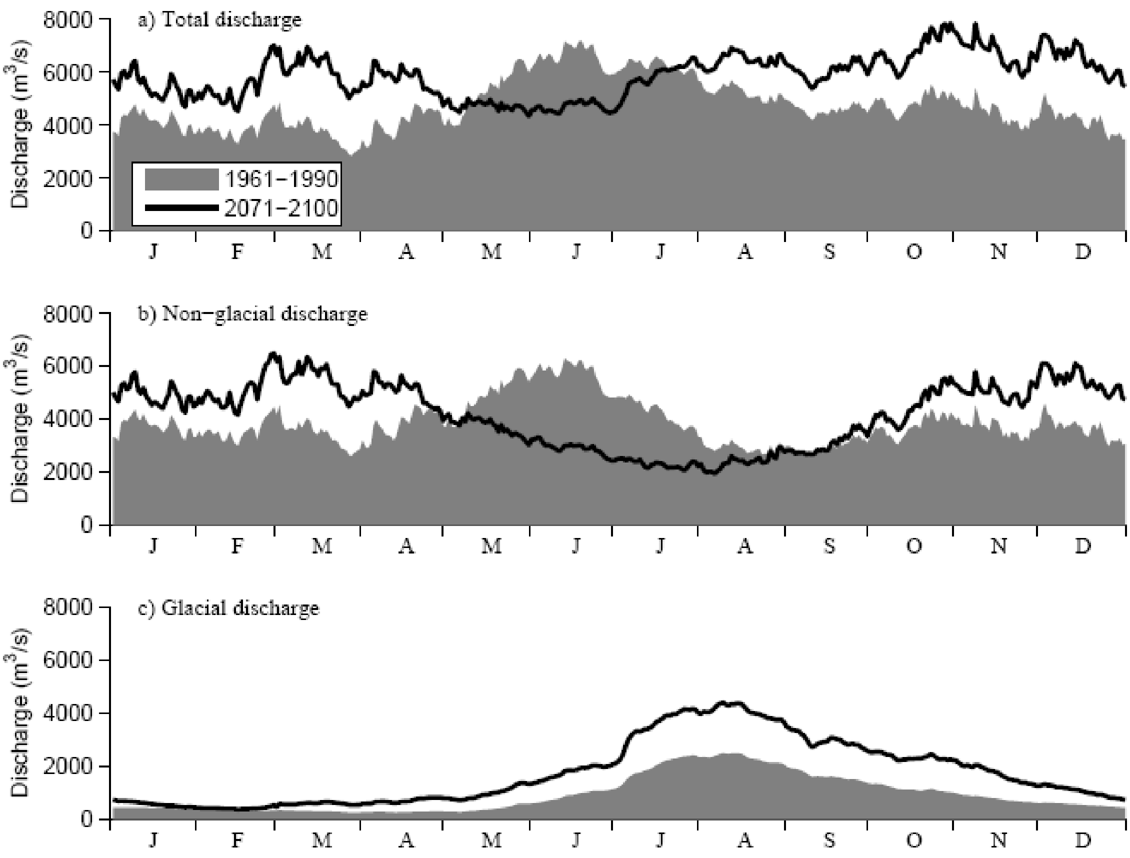

Figure 2. Seasonal variation in mean runoff from Iceland for the reference period 1961-1990 and a future projection for the years 2071-2100. a) Runoff from the entire country. b) Runoff from non-glaciated areas (3% larger area in the future scenario). c) Runoff from glaciated areas (20% smaller area in the future scenario).

FURTHER USE OF THE HYDROLOGICAL MAP

Freshwater runoff influences the salinity field and layering in the costal waters around Iceland. The freshwater influence is not only present at river mouths, but also over the entire continental shelf. The freshwater inflow causes pressure and density gradients that drive a costal current clockwise around the country (Stefánsson, 1999). The salinity and current fields then affect the biosphere. The effects on the spawning and reproduction of cod have gained most attention, as cod is the most important Icelandic fishing stock. Sediment transportation by river flow is also considered to have influence on nutrient supply in the costal waters.

In this context the total runoff from Iceland over the period 1961-1990 has been routed to the shores. The data on which the runoff map is based are available as daily mean values for zones that are based on the division of the country by hydrological properties on a catchment scale. To route the runoff to the shores the country was divided into 46 watersheds that are assigned to certain parts of the coastline. Runoff was then summed up for each watershed from the zones and given as mean daily discharge for each watershed. These discharge series are then provided as boundary conditions for oceanographic models used to simulate the oceanic environment. Results from the oceanographic model are then used in biological studies on cod stocks.

The runoff map depicts natural runoff without human-induced changes (which are mainly in the form of damping of summer and spring peaks in river flow due to hydropower plants construction). Thus the modelled runoff data, together with measured time-series of runoff (which show the effects of hydropower harnessing on the discharge), allow us to contribute to studies of the effect of human activities on the biosphere. This is especially interesting for the Þjórsá-Tungnaá river system where five hydropower plants have been built in steps during the last four decades, because one of the main spawning areas of cod in Icelandic waters is close to the mouth of the river.

This is only one example of possible use of the runoff map and associated data. As an example of other uses it has been used for the calculation of gravitational potential power and other hydrological parameters (Jónsdóttir, 2008).

MODEL APPLICATION IMPROVEMENTS

The WASIM model has proven to be a useful tool for: runoff mapping, future projection of runoff and calculation of runoff from ungauged areas. Modelling use can nevertheless still be improved. As a part of the CES project and its planned Icelandic sister project further use and improvements of application of WASIM is intended. It is planned to activate and calibrate the groundwater part of the model and to calibrate the model with new precipitation data on a 1x1 km grid.

Activation and calibration of WASIM's groundwater modulus

Until now the groundwater modulus of WASIM has not been used in efforts to model the runoff of Iceland. Data on groundwater level are sparse and the groundwater modulus proved to be hard to calibrate, therefore a shortcut was taken and groundwater flow was accounted for by scaling the precipitation. On watersheds where groundwater infiltrates and flows out of the watershed the precipitation is scaled down, and likewise the precipitation is scaled up on watersheds were groundwater emerges as spring water. This method keeps the water balance right but makes the calibration of discharge timing more difficult as the river base-flow, which is fed by groundwater, becomes hard to represent. This also gives problems on porous watersheds were snow accumulates during the winter and infiltrates within a short period during the spring thaw, giving high groundwater levels. In these water systems the precipitation is scaled down on the porous watershed so there is very little snow accumulation during the winter and no peak in infiltration during the spring. This modelling problem (and numerous other smaller ones) shows the importance of representing the groundwater properly by use of the groundwater modulus. This is especially valid for the large areas in central Iceland which are covered with porous postglacial lavas.

One defined subproject within the Icelandic part of CES is to activate and calibrate the groundwater modulus. For this task, we will use maps of hydraulic conductivity and permeability, which have been produced for a substantial part of the country. For the remaining parts, these parameters can be estimated from geological maps. Available data on spring water flow and the sparse data on groundwater level will be used in the calibration efforts.

Recalibration onto new precipitation data

The geographical distribution of precipitation is a key parameter in hydrological modelling. It is important that the effects of mountains and landscape are resolved in precipitation calculations and as the scale in modelling gets smaller landscape is better represented. Therefore it is preferable to use precipitation data on the smallest available scale. As a part of the CE project precipitation was modelled with a model based on linear theory of orographic precipitation on a 1x1 km grid (Jóhannesson et al., 2007). The WASIM model will be calibrated onto these new precipitation data to improve model performance.

DISCUSSION

The WASIM model has proven useful in calculating runoff under Icelandic conditions and a runoff map has been made for the decades 1961-1990. A future projection for 2071-2100 has also been made. The performance of the model and its representation of natural conditions can still be improved and the groundwater modulus will be activated and calibrated for this purpose. The model will also be recalibrated onto new precipitation data sets that are on a finer grid than those that were used previously. After these improvements the model will be used to calculate runoff from Iceland for the period 1957-2007, producing boundary conditions for oceanographic modelling over longer periods than hitherto. The model will also be used to make new future runoff scenarios. These scenarios will be made for the period from present until 2050. Uncertainties and variation in runoff scenarios will also be studied by use of more than one future projection, based on different climate scenarios.

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REGIONAL SERIES OF TEMPERATURE, PRECIPITATION AND RUNOFF FOR LITHUANIA

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ABSTRACT

The temporal and spatial distribution of the runoff is uneven in Lithuania. Annual river runoff varies from 4.2 to 14.0 l/(s km²). Lithuania is divided into three hydrological regions (Western, Central and Southeastern) according different types of rivers feeding and hydrological regime. Long-term regional series of temperature, precipitation and runoff were compiled for three hydrological regions. All series were normalised with reference to the period 1961-1990. Comparison of the data of last 15 years was done with data of reference period. This study is part of a Nordic cooperative research project "Climate and Energy Systems" (CES).

INTRODUCTION

Researchers from different countries give a great attention to climate change. It is emphasized that main variations of climate elements – atmosphere circulation, air temperature, precipitation, snow and ice cover have been occurring since the sixth decade of the last century (Arnell, 1996; Bergstrom, et al., 2001; Reihan, et al., 2007). Such trends are recorded by Lithuanian climatologists as well (Bukantis, 2002). They forecast variations of different climate indicators – rise of air temperature, increase of precipitation during the cold period of the year, decrease of days with snow cover and increase of frequency of extreme air phenomena. These weather patterns may affect the water resource availability. The variability of river discharge was analyzed widely, for example decreasing of river discharge was determined in Northern Canada (Dery and Wood, 2005). The impact of climate change on the river discharge has been identified in the Nordic countries as well (Hisdal et al. 2007). Possible increasing of the Danish rivers discharges (by 12%) is described in (Thodsen, 2007). The changes of river runoff of the Baltic States have been also investigated in individual national studies. The Latvian studies concluded that changes of discharge are minimal and significantly increase only for the main rivers (Klavins et al. 2002). The investigations of runoff of Lithuanian rivers were done by Gailiusis et al. (2001), Kriauciuniene et al. (2006) and other researches.

The consistent patterns of variations of air temperature, precipitation and the river runoff have changed from one region to other one. Therefore the regional data series make it possible to estimate regional differences and compare both recent years and climate change scenarios with long-term historical observations. In the Nordic countries comparison of regional temperature, precipitation and runoff was done by Hisdal et al. (2007). The regional series were derived from the seven longest and most complete records from the North Patagonian Andes in the Argentina (Masiokas et al, 2008). A strong regional pattern of discharge primarily controlled by precipitation was determinate in the last century. Regional series have interesting implications for the evaluation of possible future climate changes in river runoff in the different regions.

According to different characters of rivers feeding Lithuania is divided into the three hydrological regions: Western, Central and Southeastern (Fig. 1). In the Western Lithuania the main source of the rivers feeding is precipitation (40% - 70% of the annual runoff). The type of the rivers feeding is mixed in the Central Lithuania. The snowmelt and rain contributions are from 35% to 50% of the whole runoff. The rivers of Southeastern Lithuania have a prevailing subsurface feeding (40% - 60% of the annual runoff). The annual runoff of the Southeastern Lithuanian rivers is distributed rather equally. Partition of Lithuanian territory in the three hydrological regions is the base for setting-up of regional series.

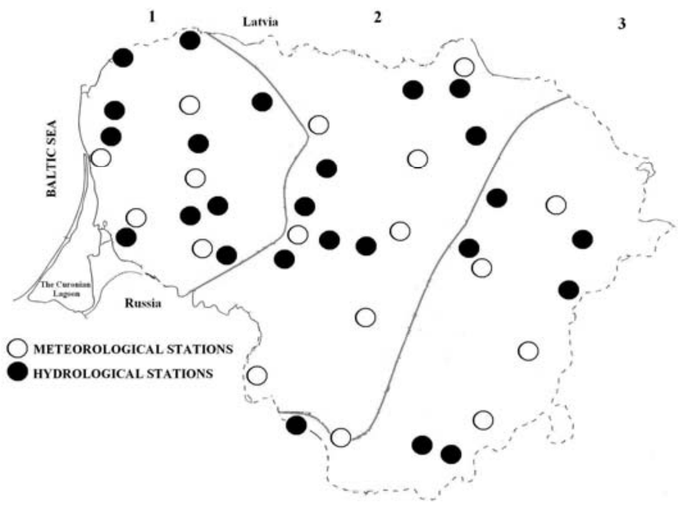

Figure 1. Network of meteorological and hydrological stations in Lithuania (hydrological regions of Lithuania: 1 – Western, 2 - Central, 3 - Southeastern).

The main task of this study is to investigate long-term regional data series of temperature, precipitation and runoff of Lithuanian rivers. The object of study is the rivers of all territory of Lithuania. The regional data series of temperature, precipitation and runoff are compared with regional series of Nordic countries.

DATA AND METHODS

The representative historical data series from 26 gauging stations is used for the calculation of regional runoff time series (10 stations from Western, 8 – from Central and 8 – from Southeastern region). Analysis of temperature (4 stations from Western, 7 – from Central and 5 – from Southeastern region) and precipitation (5 stations from Western, 7 – from Central and 5 – from Southeastern region) is done on the basis of data from 17 meteorological stations (Fig. 1). Homogeneity test was carried out for data series of the annual discharge, precipitation and air temperature of all hydrological and meteorological stations.

Long-term regional series of temperature, precipitation and runoff were normalized with reference to the period of 1961-1990. Precipitation and runoff were normalized by division with mean values, whereas temperature was normalized by subtraction with the mean and division of the standard deviation. The regional series is estimated as the average of the standardized individual series.

The integrated curves with 5-year moving average point up the cyclic behavior of regional series of air temperature, precipitation and rivers runoff. Non-parametric Mann-Kendall test with a 5% significance level, recommended by the WMO (1988), was applied for data series analysis.

REGIONAL INDEX SERIES OF TEMPERATURE, PRECIPITATION AND RUNOFF

The long-term regional series of temperature, precipitation and runoff were compiled for the three Lithuanian hydrological regions. Regional time series of annual temperature are presented in Fig. 2. There are no big differences in the regional temperature time series for three hydrological regions. Air temperatures were higher in 1991-2006 than in the reference period (1961-1990). During the last sixteen year period increasing of temperature was 0.8 ºC in the Western region and 0.9 ºC in the Central and Southeastern regions.

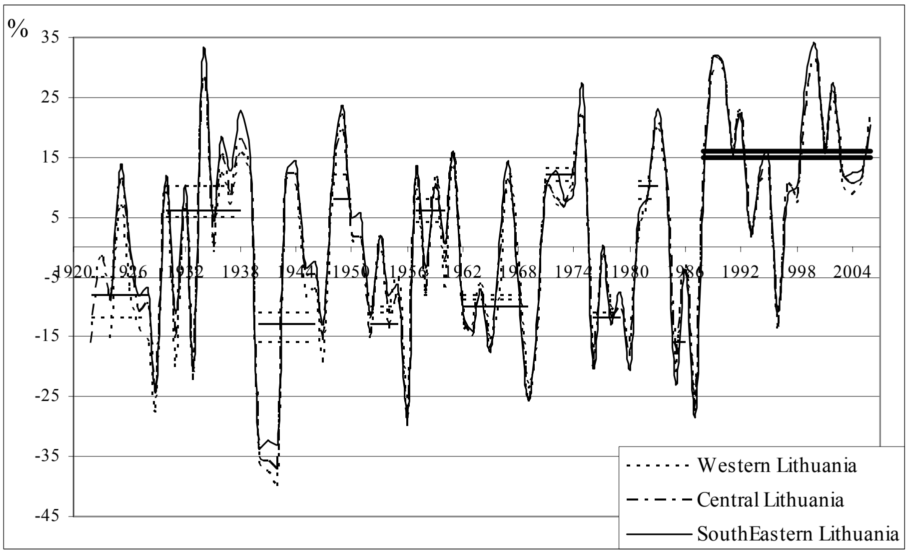

Figure 2. Regional air temperature series for 3 regions relative to the reference period 1961-1990 (%).

Cyclical variations (high and low phases of annual air temperature) are observed in long-term chronological series (Fig.2). There were observed 5 cycles from 1922 to 1984 in all regions of Lithuania. The durations of cycles are from 9 to 18 years. Duration of high phases of air temperature varies from 4 to 10 years and of low phases – from 5 to 9 years. The last cycle (1985-2006) has another character. There are only 3 years of low phase of temperature with the negative deviation (-16 - -18 %) from the average. The beginning of the phase of high temperature is from 1988 with increasing from the average in 15 - 16 %. The warmest period of air temperature has been during last 19 years. Significant increasing of air temperature could be the result of climate warming processes.

Precipitation has high variability in space and in time. During the last sixteen years period (1991-2006) increasing of precipitation was 34 mm in the Southeastern Lithuania, decreasing by 41 mm and 18 mm in the Western and Central regions comparing with the reference period (1961-1990). The long-term regional series of annual precipitation have obvious cyclical fluctuations (dry and wet periods) (Fig. 3). These cycles compounded of dry and wet periods are 25-30 years. The driest period in precipitation series was in 1963-1976 and the most wet – in 1977-1991 (Table 1).

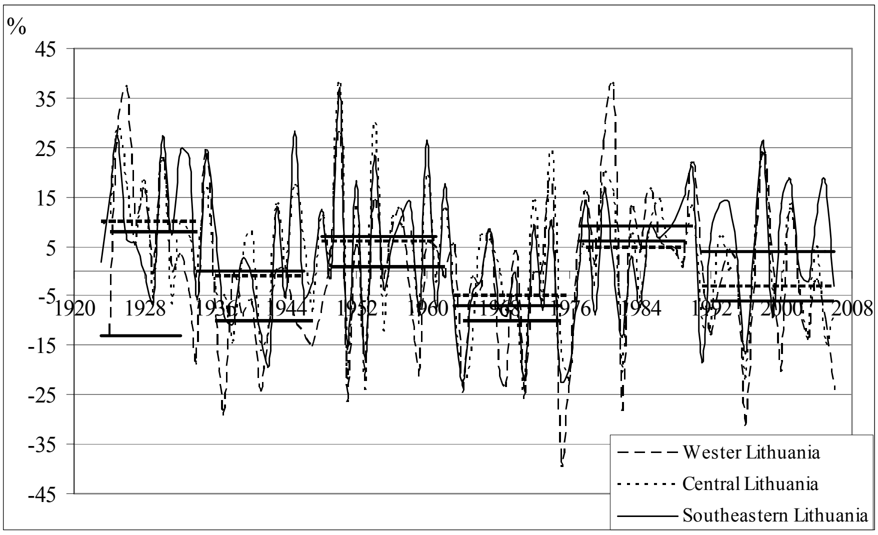

Figure 3. Regional precipitation series for 3 regions relative to the reference period 1961-1990 (%)

There are no the same tendencies of precipitation changes in the last period (1991-2006). It could be the dry period according to tendency of cyclical variations. Annual precipitation has decreased by 3 – 6 % only in the Central and Western regions. Increasing of precipitation is determinate in the Southeastern region.

Cyclical variations of long-term runoff regional series are typical for all Lithuanian regions. Durations of the cycles of rivers' runoff are similar only with the exception when dry and wet periods can differ in 1-2 years in different regions. Three cycles of runoff variation are found (Fig. 4). The average period of the cycles is 28 year including the wet period of 15 year and the dry period of 13 year (Table 2). The most wet period of the rivers runoff of the Central region was in 1977-1991 (deviation from the average is 31%). The driest period was in 1963-1977 for all regions. The average discharges of this period were less then the average of many year time series by 12 - 23%.

Table 1. Wet and dry periods of the regional precipitation series (deviation from the average in %)

Western Lithuania		Central Lithuania		Southeastern Lithuania	
Period	Devia-tion,%	Period	Devia-tion,%	Period	Devia-tion,%
1924-1935	8	1923-1935	10	1922-1933	-13
1936-1948	-10	1936-1947	-1	1934-1947	0
1949-1963	1	1948-1962	6	1948-1962	7
1964-1976	-10	1963-1977	-5	1963-1976	-7
1977-1991	9	1978-1990	5	1977-1990	6
1992-2006	-6	1991-2006	-3	1991-2006	4

Only in the last period (1991-2006) the river runoff variations have another character. It would be dry period according to cyclical variation. Through the rivers discharge of all regions has exceeded the multi-year average discharge by 2-4 %. These changes are coherent with changes expected mainly due to temperature increase in period from 1991.

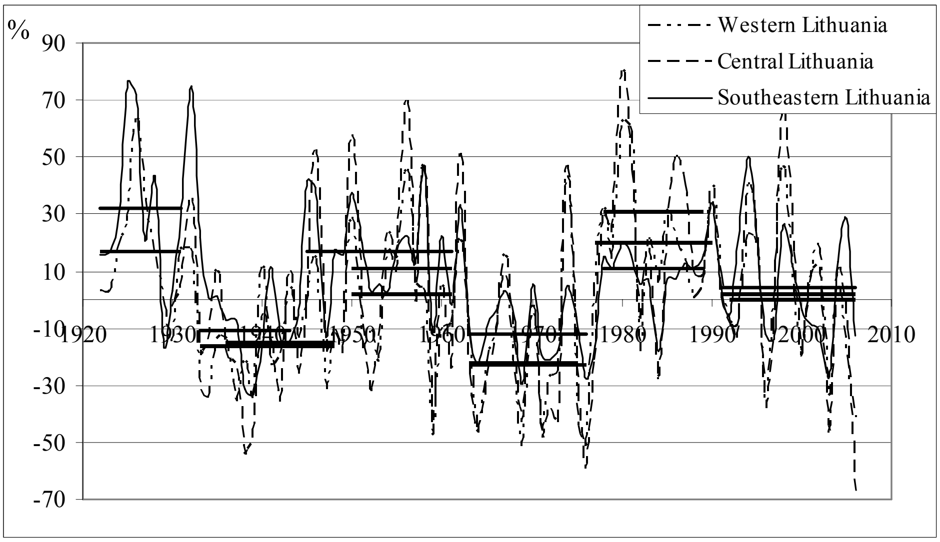

Figure 4. Regional runoff series for 3 regions relative to the reference period 1961-1990 (in %).

Higher air temperature could increase winter discharge and course earlier snowmelt floods. In the Lithuania precipitation has significant influence on the runoff quantity. However, the present study shows that correlation between precipitation and runoff regional series can be weak. Coefficients of correlation of annual variables are 0.79 in the Western Lithuania, 0.64 – in the Central Lithuanian and 0.55 in the Southeastern Lithuania.

Table 2. Wet and dry phases in regional runoff series (deviation from the average, %).

Western Lithuania		Central Lithuania		Southeastern Lithuania	
Period	Devia-tion,%	Period	Devia-tion,%	Period	Devia-tion,%
1922-1932	17			1922-1933	32
1933-1949	-16	1936-1949	-15	1933-1944	-11
1950-1962	2	1950-1962	11	1945-1962	17
1963-1976	-22	1963-1977	-23	1963-1977	-12
1977-1991	20	1978-1990	31	1978-1990	11
1992-2006	0	1991-2006	2	1991-2006	4

The results of Mann-Kendall test studies were performed for the following patterns: regional air temperature series have significant positive trends (its mean that air temperatures are raising); precipitation regional series have no trends in the Western and Southeastern Lithuania and significant negative trend in the Central Lithuania; runoff regional series have no trends in all Lithuania.

Comparison of Lithuanian regional series was done with regional series of the Nordic countries (Hisdal et al, 2007). In the years after 1990 annual temperatures were higher above the reference level in all countries. Increasing of precipitation was more significant than runoff in most regions of the Nordic countries. In Lithuania decreasing of precipitation is determinate excepting the Southeastern region. The dry period of runoff have to be after 1990. Therefore rivers' runoff variations are fixed near average.

CONCLUSIONS

Analysis of long-term regional series of temperature, precipitation and runoff was done in Lithuania. Compared to the reference period, regional series of the years of 1991-2006 have changed character. Annual temperatures were about 15% above the reference level. Precipitation decreased by 3-6 %. The runoff was insignificantly higher in 1991-2006 comparing with the reference period.

The cyclic variations in the regional runoff time series are typical for all Lithuanian regions. The average period of the cycles is 27 years, including the average wet period of 13 years and the dry period of 14 years. The last period (1991-2006) of cyclical variation of the river runoff would be the dry period. Through the rivers discharge of all regions has exceeded the multi-year average discharge by 2-4 %.

ACKNOWLEDGEMENTS

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CLIMATE CHANGE EFFECTS ON WATER RESOURCES AND REGULATION IN EASTERN FINLAND

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ABSTRACT

The effects of climate change on hydrology and water resources of eastern Finland were studied to assess the possibilities to adapt to these changes by altering lake regulation practices. The study was carried out in Finnish Environment Institute (SYKE) as a part of Finnish national WaterAdapt project and a part of the Nordic CES project. Watershed Simulation and Forecasting System (WSFS) was used to estimate the effects of climate change on four lakes in Vuoksi watershed with several climate scenarios for 2010-39, 2040-69 and 2070-99. The effects of different regulation rules to the water levels and outflows were also studied. The results show that the current regulation rules and limits with a winter and spring draw-down of water levels will not be suitable in the future on the studied lakes. By 2040-69 the spring floods will diminish considerably and the largest runoff into large lakes occurs during winter. Winter floods and occasional summer dryness will be the new challenges to which the new regulation practices have to adapt. The negative effects of climate change can be decreased by changing the regulating practices and limits.

INTRODUCTION

Climate change will have a large effect on the hydrology and water resources of Finland. By the 2080's average yearly temperature in Finland may increase 3-7 °C and yearly average precipitation may increase 13-26 % with largest increases during winter (Ruosteenoja and Jylhä, 2007; IPCC, 2007). The decrease in the amount of snow and increase in warm spells during winter will cause decreases in spring floods and increases in runoff during winter. This will severely alter the current yearly cycle of runoff and water levels in Finland's numerous lakes.

The aim of this study is first to estimate the effect of climate change on hydrology and water resources in eastern Finland. The second goal is to estimate how to adapt to these changes by altering lake regulation practices.

In Finland there are more than 300 regulated lakes, which are regulated mainly for hydropower, flood protection and recreational purposes. Lake regulation requires a legal regulation permit, which in many cases includes regulation limits that stipulate that the water level must be drawn down during spring to make room for the snow melt flood. Majority of these rules will no longer function properly when the spring flood decreases and occurs earlier than before. It has been estimated that to adapt to climate change more than half of the regulation projects may need revision (Silander et al., 2006).

This study was carried out in Finnish Environment Institute (SYKE) and it's a part of national WaterAdapt project financed by the Finnish Ministry of Agriculture and Forestry and a part of Climate and Energy Systems project financed by Nordic Energy Research.

MATERIAL AND METHODS

Study sites are four lakes in Vuoksi watershed in the lake district in eastern Finland (Fig. 1). These lakes range in size from rather small (runoff area 1 130 km^2) to the largest lake in Finland, Lake Saimaa with 61 000 km^2 runoff area. The other three lakes are all in the runoff area of Lake Saimaa. Especially the outflow of Lake Pielinen, the second largest lake in the study, has a rather small but still significant influence to the inflows and water levels of Lake Saimaa.

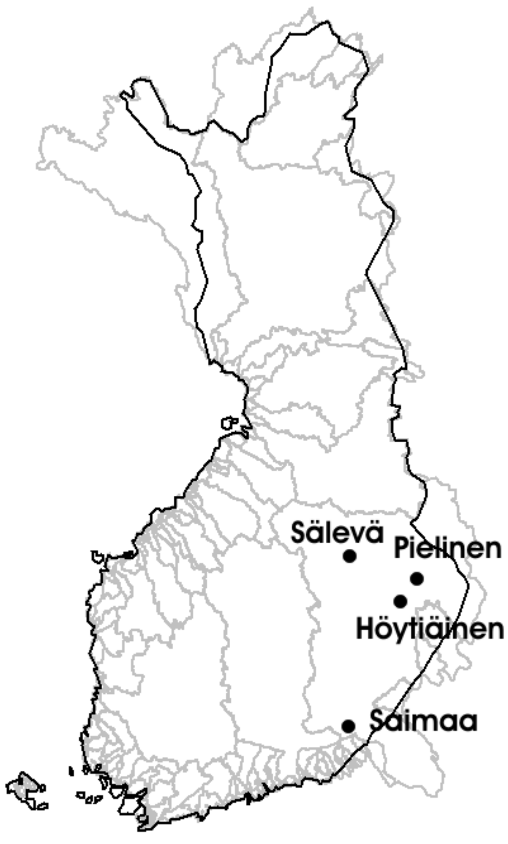

Figure 1. The location of the study lakes in Finland.

On all of these lakes the largest floods have in the past been caused by snow melt. On smaller lakes these floods occur during late spring or early summer, but due to long lake routes and time delays the highest water levels in Lake Saimaa occur typically in late summer or early autumn. Water levels of Lake Pielinen and Lake Saimaa are not regulated and thus most of the time the outflow follows the natural rating curve. On both the lakes there is however a dam with a technical possibility to alter the outflow from the lakes. Lake Saimaa's outflow is based on a release rule that is a part of a contract established with Russia. To avoid damages this release rule allows increasing or decreasing the outflow if the water level in Lake Saimaa threatens to rise too high or sink too low. On the other hand, Lake Pielinen's release rule is based on the national legislation and does not include exceptional outflows. In a threatening flood or drought situation on Lake Pielinen it is however possible to apply for an exemption permit subject to the Water Act to alter the outflow and thus avoid or alleviate damages. Exemption permits have been used on average once in every three years for several weeks at a time. Lake Sälevä and Lake Höytiäinen are regulated for hydropower and flood protection purposes.

The Watershed Simulation and Forecasting System (WSFS) was used to simulate the effects of climate change (Vehviläinen et al., 2005). It is a conceptual watershed model based on the Swedish HBV-model, but developed further in SYKE for operational forecasting and research purposes.

Several climate scenarios were used and three periods 2010-39, 2040-69 and 2070-99 were studied. Baseline period was 1971-2000. The climate scenarios were provided by the Finnish Meteorological Institute (FMI). Scenarios from three global climate models and scenarios using an average from results of 19 climate models were used together with three emission scenarios. The climate models used were ECHAM5/MPI-OM, UKMO-HadCM3 and CCSM3 (by NCAR) and the SRES-emission scenarios A2, B1 and A1B (IPCC, 2007). The so called average scenario was the average temperature and precipitation changes from 19 models with the intermediate A1B emission scenario (Ruosteenoja and Jylhä, 2007). Temperatures and precipitations were changed using the delta-change approach.

Different regulation practices were simulated by using different regulation rules, where certain water level at certain time of year corresponds to certain outflow. In the reference period the regulation rules were such that they on average corresponded to the current regulation practices. The climate change simulations were done with the same regulation rules as in the reference period and additionally with modified regulation rules. The modified regulation rules took the changed climate with shorter and wetter winter better into account and had milder and earlier draw-down of water levels during winter and spring. The same regulation rules were used for the entire

30 year simulation period and thus the rules are not optimal for every year. In reality the current regulation rules are more flexible than it appears in the model simulations since in real life there are more possibilities to take the prevailing snow amounts and weather into consideration.

RESULTS

Following are results from the simulations using the average scenario (average of 19 global climate models with A1B emission scenario). The calculation were done with 12 scenarios and there are some differences between the results from different scenarios especially in the period 2010-39 when the climate signal is not yet very strong. For most part, the different scenarios give rather similar results.

In Lake Pielinen the simulations were first done using the natural rating curve. This is similar to the current situation except that extremely high and low water levels are in reality often decreased or increased by changing the outflow from the lake. In these simulations the average water levels increase during winter and decrease during summer due to climate change (Fig. 2). By the period 2040-69 the maximum water levels are during winter and spring (Fig. 3) and they increase from the reference period. On the other hand also minimum water levels during summer and autumn decrease. Both flooding and drought problems in the lake area would seem to increase due to climate change.

The second simulations for Lake Pielinen were done by changing from natural rating curve to an operating rule where the discharges can be increased or decreased earlier when flood or drought starts (Verta et al., 2007). With this new operating rule the highest water levels can be decreased and lowest water levels increased. Thus the negative effects of climate change could be decreased by regulating the lake.

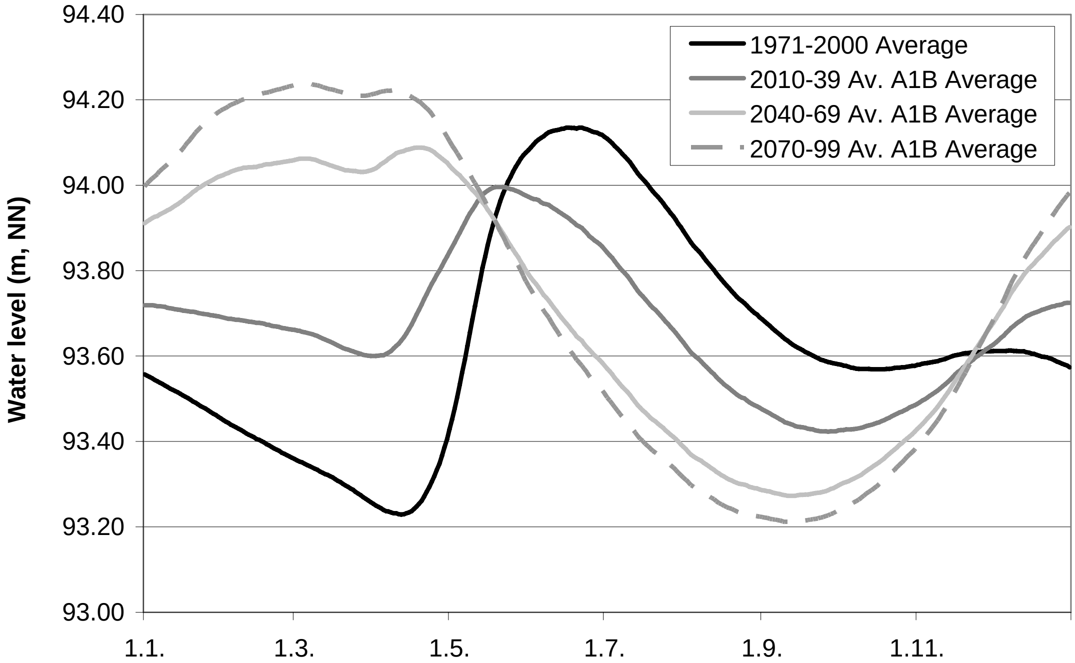

Figure 2. Average water level in Lake Pielinen during different period with the natural rating curve.

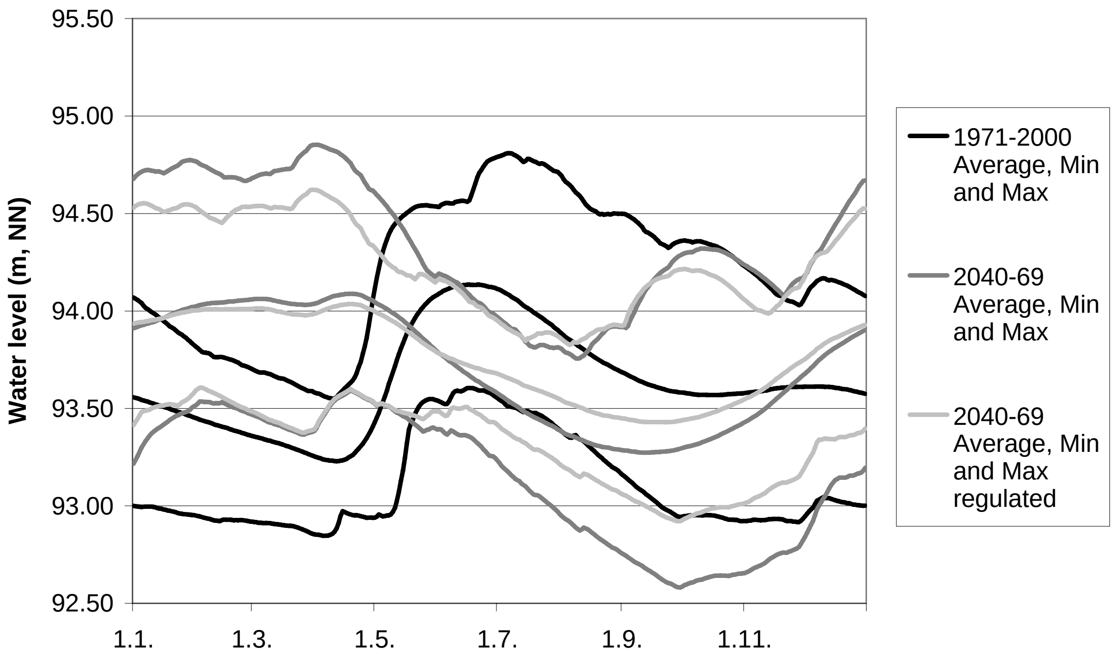

Figure 3. Average, minimum and maximum water levels in Lake Pielinen in reference period with natural rating curve and in 2040-69 with natural rating curve and an operating rule.

In the future the highest water levels in Lake Saimaa will occur during winter and early spring. Floods will increase considerably from present situation (Fig. 4). The possibilities to decrease the highest water levels are limited since discharge to the River Vuoksi, which flows to Russia, is controlled by an agreement between Finland and Russia. Increasing the outflow from Lake Saimaa above the defined maximum discharge level would cause flood damages in Russian side and would have to be agreed on by both sides.

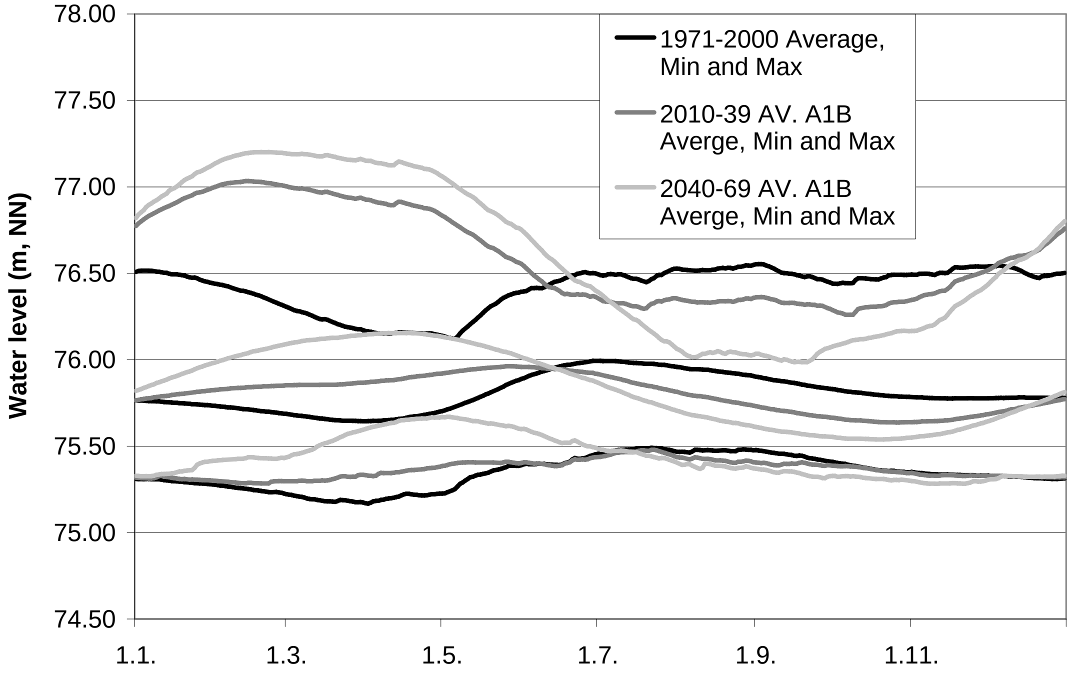

Figure 4. Average, minimum and maximum water levels in Lake Saimaa in reference period and in 2010-39 and 2040-69.

Lake Höytiäinen is a large lake with a relatively small runoff area. Therefore, the lake evaporation during the summer is large and in the future it will be larger than the inflow to the lake. Current regulation limits demand that the lake is drawn down during January-March to make storage capacity for the spring flood. If exactly the same regulation rule as in the reference period is used in 2040-69, the lake surface will remain low during the entire summer since spring floods decrease dramatically (Fig. 5). It is necessary to change the regulation rule so that the draw-down is smaller and ends earlier to reach the preferred summer water levels suitable for recreational and other uses (Fig. 6). In the new regulation rule the current regulation limits would be breached during spring.

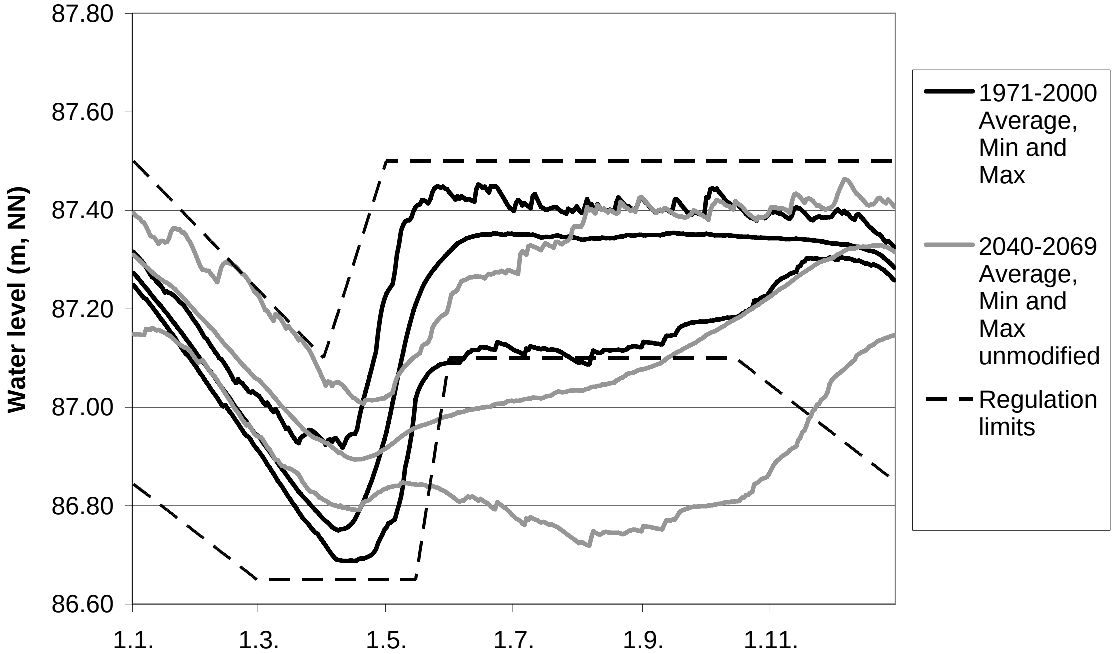

Figure 5. Average, minimum and maximum water levels in Lake Höytiäinen in reference period and in 2040-69 with the current regulation rules.

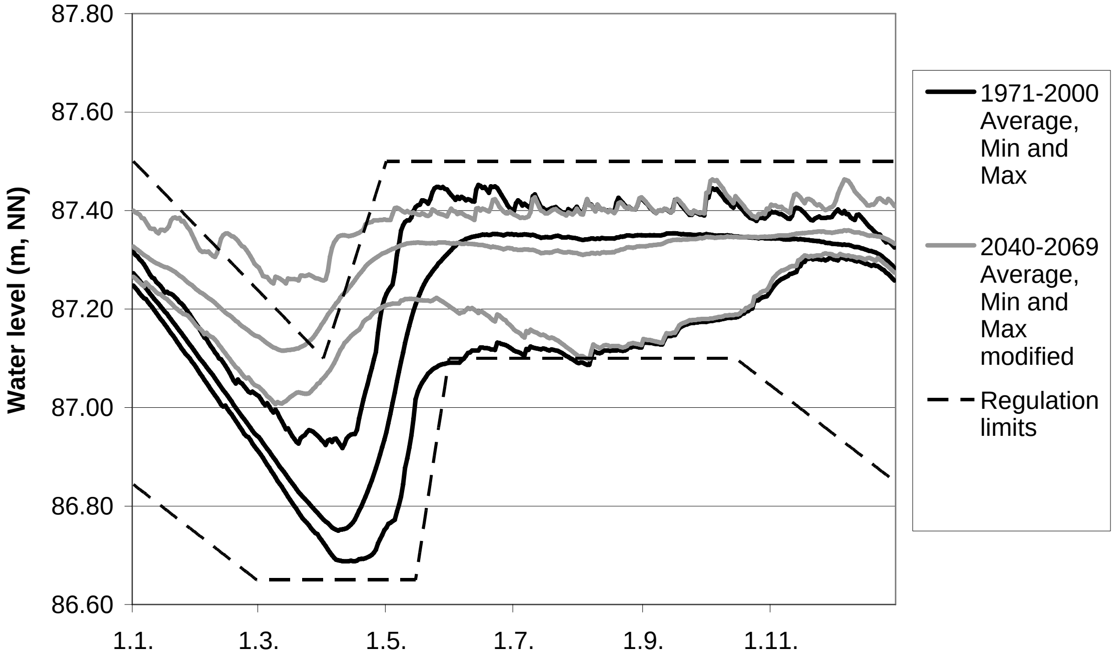

Figure 6. Average, minimum and maximum water levels in Lake Höytiäinen in reference period and in 2040-69 with the modified regulation rules.

Lake Sälevä is rather small lake with the largest floods occurring at present in spring. As in Lake Höytiäinen, the modification of the regulation rule is needed to reach satisfactory summer water levels (Fig. 7). The regulation limits however are less strict and would have to be breached only occasionally. The decrease of the spring floods means that the largest water levels and outflows and thus the flood risk decreases.

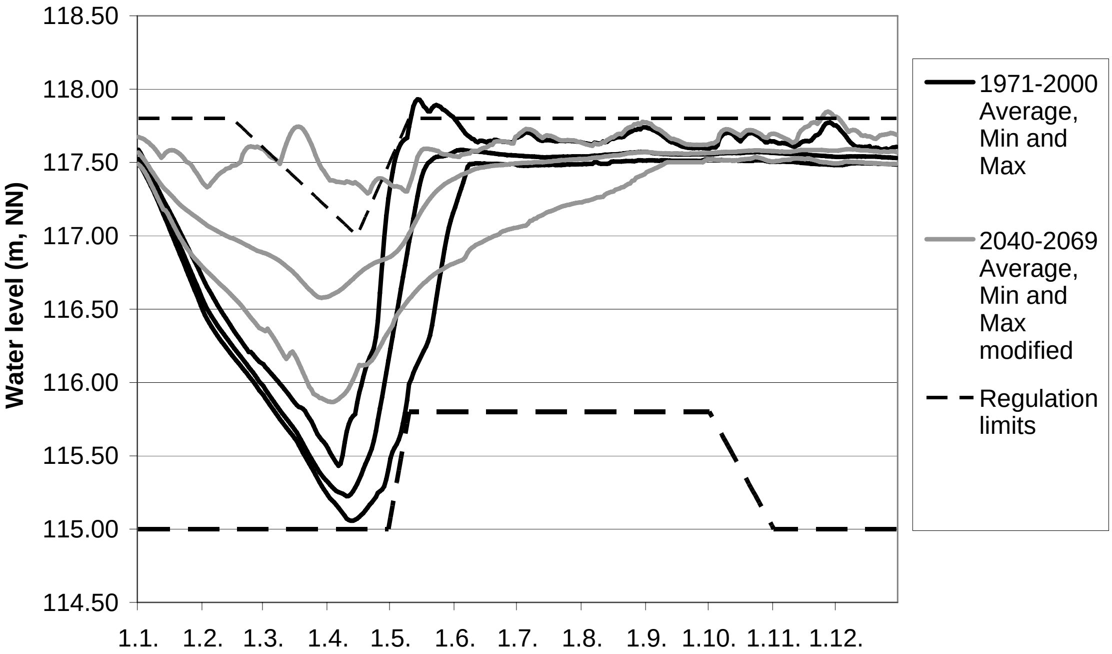

Figure 7. Average, minimum and maximum water levels in Lake Sälevä in reference period and in 2040-69 with the modified regulation rules.

DISCUSSION AND CONCLUSIONS

The results show that on some lakes the current regulation rules and to some extent regulation limits with a winter and spring draw-down of water levels will not be suitable in the changed climate. Instead of snow melt floods, the largest challenges in eastern Finland will in the future be winter floods and occasional summer dryness. To adapt to these changes and to decrease the negative effects of climate change, many of the regulation practices and limits have to be changed.

The new regulation rules should be flexible to function properly in a variety of conditions. Winters with large amounts of snow will still occur especially during 2010-39 and in these years there will still be need to be prepared for the melt waters during spring. On the other hand winters with very small amount of snow and large runoffs will become common and the new regulation practices should take this into account. Decreasing and earlier spring floods and longer summers also increase the risk for dryness during summer and autumn and make it important to ensure that the lakes will be high enough during spring and early summer. On some lakes such as Lake Pielinen starting the regulation of the lake may be the only way to counterbalance the negative effects of climate change. On Lake Saimaa the possibilities to change the water levels are limited due to restrictions of the outflow and regulation and these restrictions are not easily changed.

Water level fluctuations affect many social, ecological and economic objectives. These effects should be taken into account when establishing new operating rules in changing climate. In the WaterAdapt project, estimation of the impacts of water level fluctuations has been started by calculating several indicators from the simulated water levels and discharges of Lake Pielinen. The methods will be developed and extended to other lakes in future work.

The last two winters were mild in Finland and in southern Finland it has already become clear that some of the regulation permits are not suitable for these kinds of conditions. Changing the legally binding regulation permits, limits and practices is a large and time consuming work. Therefore, the analysis of the suitability of the current regulation rules in changing climate has to be started as soon as possible to avoid the situation where the unsuitable regulation will aggravate problems caused by climate change.

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MODELING PRECIPITATION OVER COMPLEX TERRAIN IN ICELAND

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ABSTRACT

An orographic precipitation model has been used to estimate the spatial distribution of precipitation in Iceland with a horizontal resolution of 1 km and time scales ranging from a day over the period 1958 to 2006. This model combines airflow dynamics with a simple parameterization of cloud physics (cloud water formation time, hydrometeor fallout time, condensed water advection and lee-side evaporation). The model is forced with large-scale atmospheric variables taken from the European Centre for Medium Range Weather Forecast (ECMWF) (Re-)analysis and the model parameters have been optimized using rain-gauge and glaciological data. The results suggest that the model behaves reasonably well in the complex terrain of Iceland and offers a suitable solution for providing detailed estimates of precipitation for various purposes ranging from hydrological and glaciological applications to climatology.

INTRODUCTION

Estimating the spatial distribution of precipitation in complex terrain remains a challenging problem. Traditional approaches based on a geo-statistical description of the spatial variability of precipitation are difficult to apply in Iceland because rain-gauge observations are sparse and affected by wind-induced undercatch. An alternative approach based on the linear model of orographic precipitation (LT-model) proposed by Smith and Barstad (2004) has been selected. This model includes crude representations of the main physical processes involved in orographic generation of precipitation, namely airflow dynamics and cloud physics. The LT-model is forced with large-scale temperature, wind and precipitation data obtained from the ECMWF (Re-)analysis, following a methodology defined in Crochet et al.

(2007) and further improved in Jóhannesson et al. (2007). The resulting 6-hourly precipitation estimates are then accumulated over a day or longer. The parameters of the LT-model were optimized over the period 1995-2000 using precipitation observations from a rain-gauge network and precipitation derived from mass-balance measurements made on 3 large ice caps. These parameters were then kept constant over the entire simulation period. Daily, monthly, annual and 30-year averaged gridded precipitation datasets have been produced with a horizontal resolution of 1 km over the period 1958-2006.

CASE STUDIES

As an example, Figure 1 shows the simulated precipitation field on 27 March 1994 when the main wind direction in Iceland was from the SE. Orographic enhancement of precipitation on the windward side of mountains and a precipitation shadow or dry areas on the lee side of mountains are clearly visible. The wet and dry areas are rather well detected despite the complexity of the precipitation pattern, especially in the northern part of Iceland. The comparison between simulated precipitation and wind-corrected rain-gauge observations is presented in Figure 2. Precipitation is systematically slightly overestimated for this day at most locations, and at a few locations where no precipitation is observed, rather large amounts are simulated, revealing the difficulty to delineate accurately the wet and dry areas in complex terrain.

Figure 3 shows simulated precipitation on 21 March 1998 when the main wind direction in Iceland was from the SW. The wet and dry areas are rather well detected but a lack of lee-drying is observed in a region located north of the Vatnajökull ice cap in SE Iceland. The comparison between simulated precipitation and rain-gauge observations is presented in Figure 4. Precipitation is rather well simulated for this day, but the largest amounts are underestimated.

A detailed verification of simulated daily precipitation fields over a 10-year period reveals that the model estimates agree quite well with observations in a large number of cases, but systematic over- and/or underestimation of precipitation may occur due to model shortcomings and to some aspects of the practical model implementation. Inconsistencies between the time windows of the large-scale forcing and the precipitation measurements have also an impact on the quality of the comparisons.

When precipitation is accumulated over a month or longer, the results indicate good model performances most of the time against both rain-gauge observations located in lowland areas and precipitation derived from mass-balance measurements on 3 large ice caps. As an example, Figure 5 presents a comparison between simulated and observed precipitation on the Hofsjökull ice cap, central Iceland, for the winter 2000-2001.

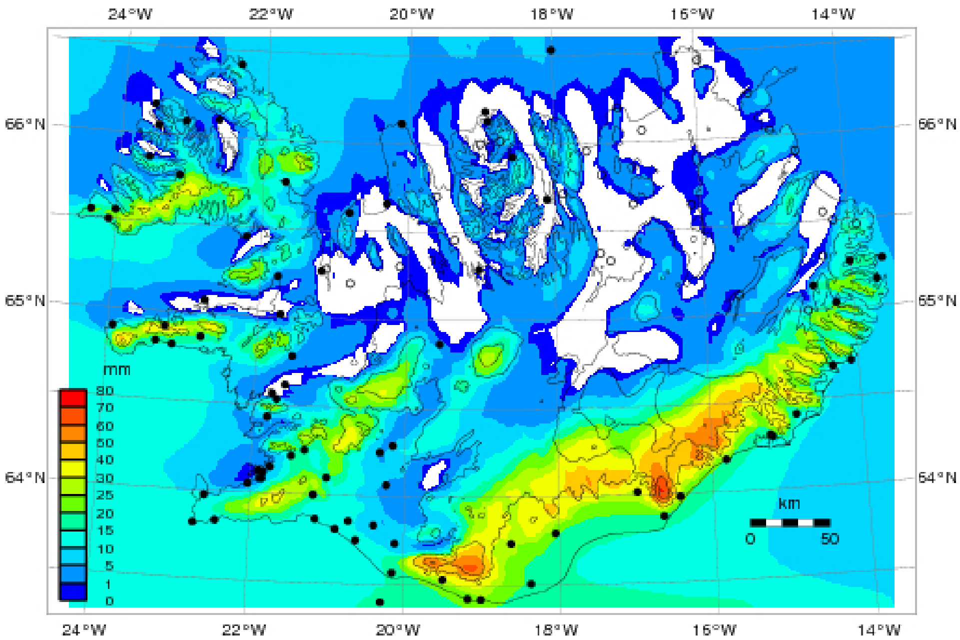

Figure 1. Simulated daily precipitation on 27 March 1994, when the main wind direction in Iceland was from the SE. Filled (open) symbols denote rain-gauge stations where precipitation was observed (not observed).

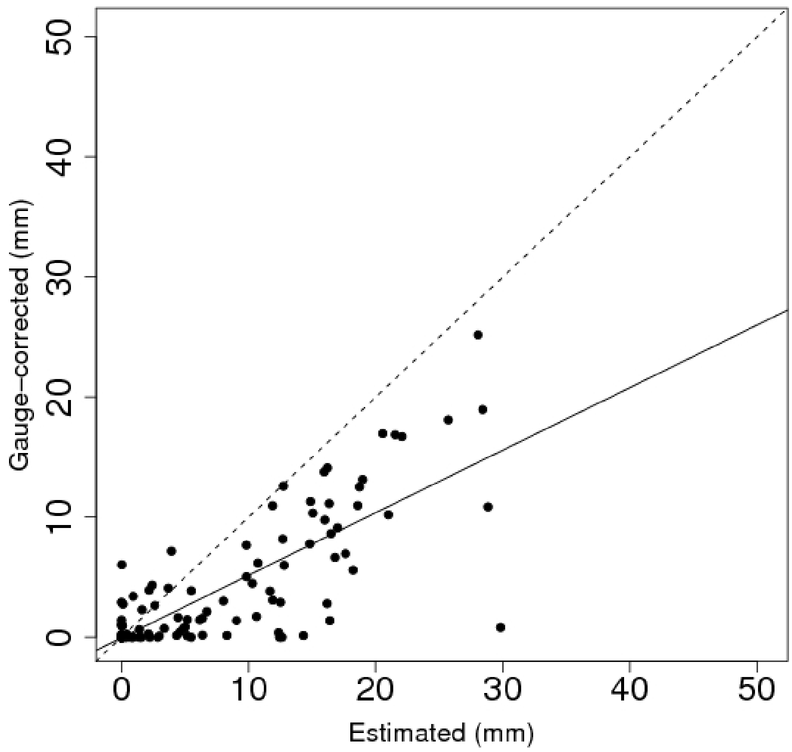

Figure 2. Estimated precipitation versus observed precipitation for 27 March 1994. The solid (dashed) lines are the regression (1:1) lines.

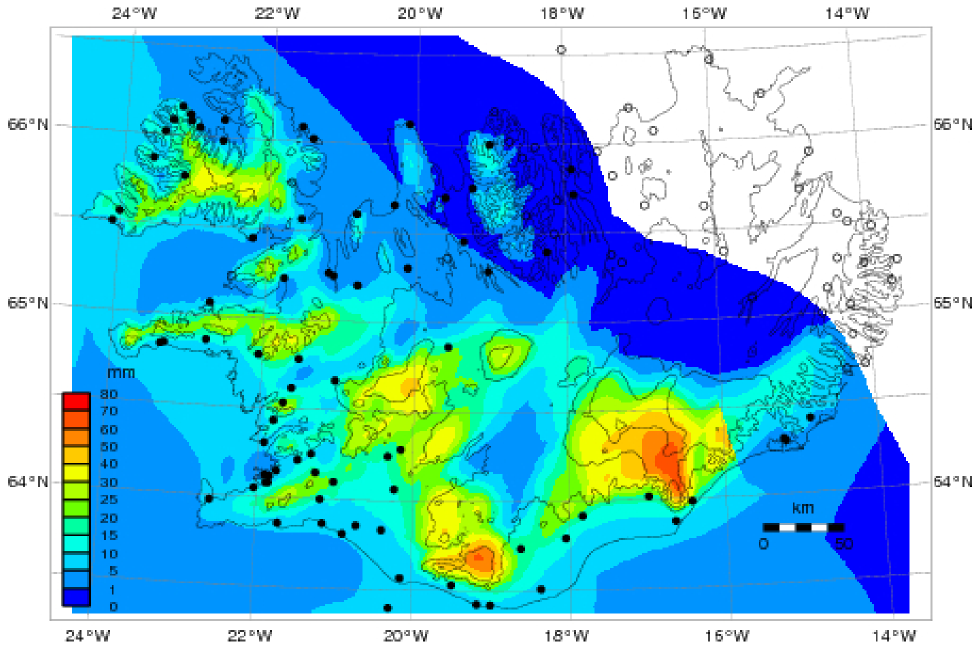

Figure 3. Simulated daily precipitation on 21 March 1998, when the main wind direction in Iceland was from the SW. Filled (open) symbols denote rain-gauge stations where precipitation was observed (not observed).

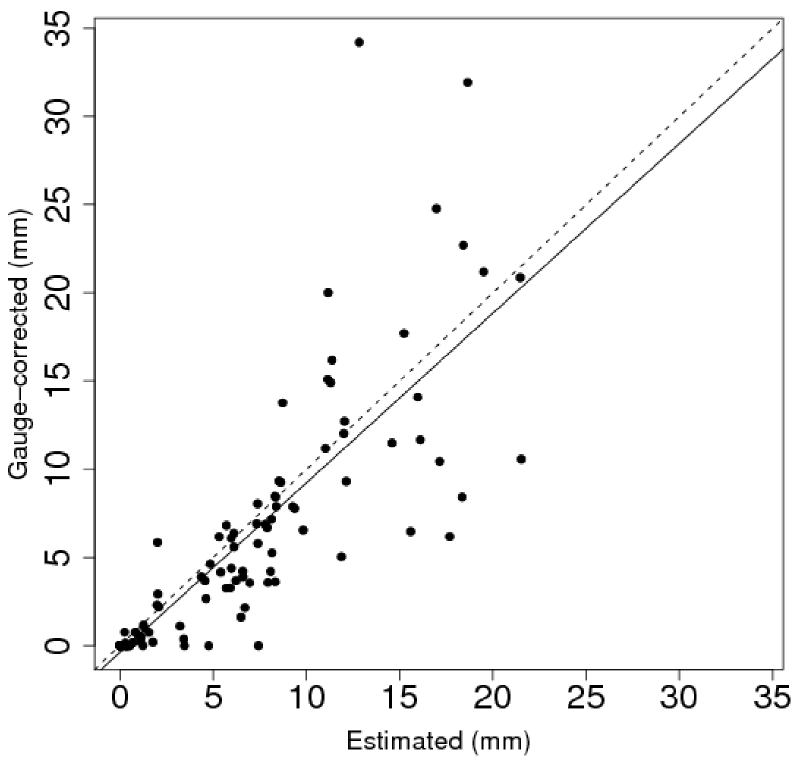

Figure 4. Estimated precipitation versus observed precipitation for 21 March 1998. The solid (dashed) lines are the regression (1:1) lines.

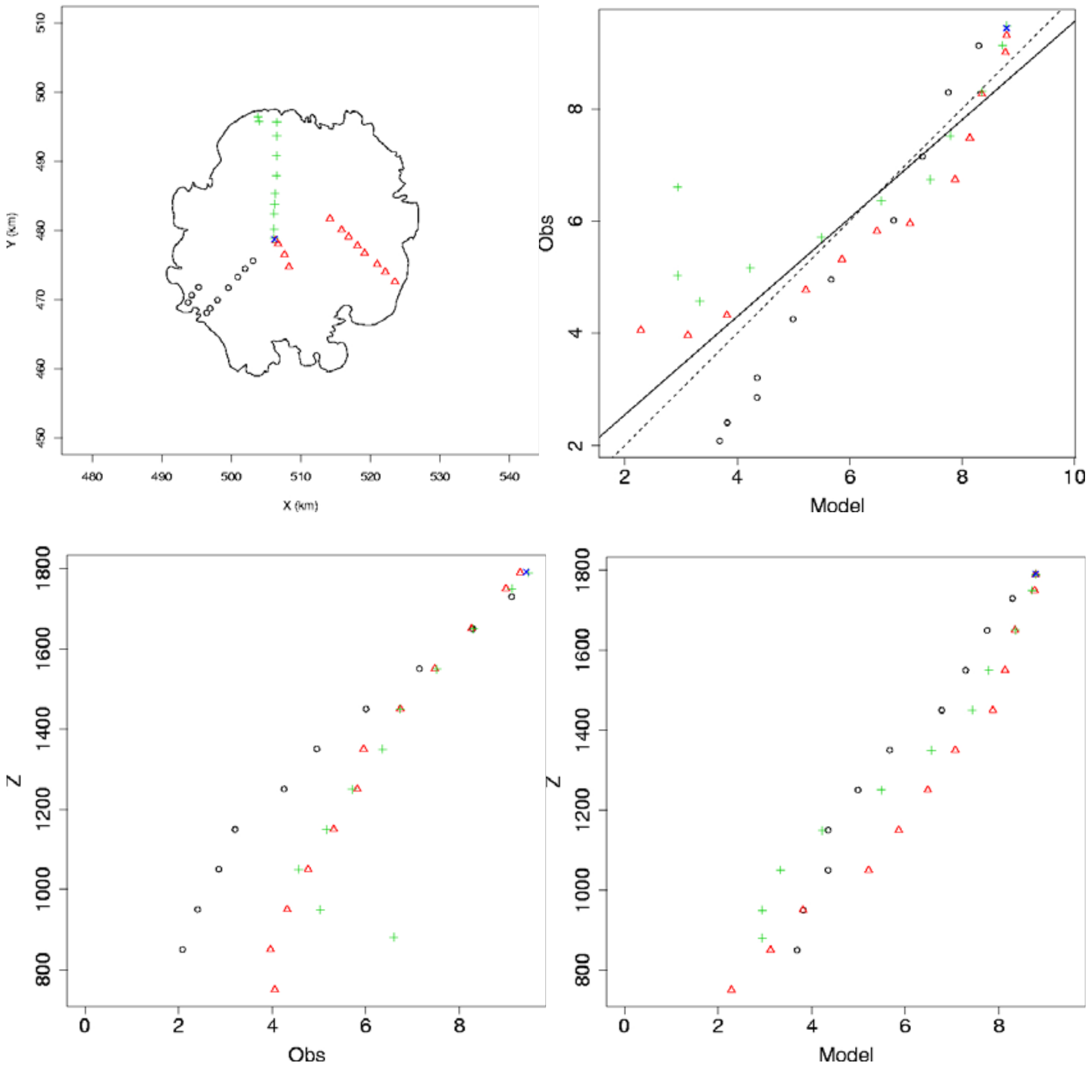

Figure 5. Precipitation on Hofsjökull ice cap from October 2000 to April 2001. Top left: snow-stakes location. Top right: averaged observed precipitation versus simulated precipitation (mm/day). The solid (dashed) lines are the 1:1 (regression) lines. Bottom left: stake elevation (m.a.s.l) versus averaged observed precipitation (mm/day). Bottom right: stake elevation (m.a.s.l) versus averaged simulated precipitation (mm/day).

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SESSION 9: ECO HYDROLOGY

HYDROLOGICAL EFFECT OF WATER MANAGEMENT ON WATER REGIME RESTORATION IN THE DOVINĖ RIVER BASIN, LITHUANIA

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ABSTRACT

The Žuvintas Lake, located in southern Lithuania in the basin of the Dovinė River is one of the biggest lakes and oldest nature reserves of the country. However, the changes in the hydrology of the Dovinė River Basin, caused by large scale melioration and water management works carried out in the 20th century, have resulted in significant decrease in biodiversity of Žuvintas Lake and surrounding wetlands. In order to prevent the ongoing deterioration of the lake and wetlands solutions have to be found at the basin level. Therefore, various scenarios have been analyzed to evaluate the impact of water management alternatives in the Dovinė River basin. For these scenarios the physically-based model SIMGRO was used. The results have shown that entire restoration of water dynamics and flow pattern of the Dovinė River to its original state is impossible. However, the blocking of drainage ditches and the removal of scrubs and trees in the wetlands can be a highly successful measure to improve hydrological conditions.

Keywords: The Doviné River, water regime restoration, Lithuania

INTRODUCTION

The objectives of the EU Water Policy as described in the Water Framework Directive (2000/60/EC) identify a need for greater integration between factors such as water quantity, quality, water use and environmental protection. The Directive is to be implemented focussing on the river basin scale. Furthermore it aims to protect and enhance the status of aquatic ecosystems. One implication with respect to water management is that there should be an objective to maintain flow regimes as close to natural as is feasible. The flow regime is generally considered the primary driving process in the river ecosystem. Wetlands due to their influence on controlling peak flows and droughts as well as on removing pollutants and recycling nutrients and accumulating sediment, can play an important role in governing processes between terrestrial and aquatic environments. The significance of wetlands in landscape ecology is crucial concerning biodiversity. Therefore, naturalization the flow regime as well as restoration of wetlands has received increased attention in river basin management during recent years.

During the second half of the twentieth century, large-scale agricultural expansion, has posed a thread on the natural water conditions in river basins, like in the Dovinė River basin, Lithuania. The water regime of the river was significantly altered, sluice-gates were built at the outlets of some lakes and natural peat lands were changed into agricultural land. The land reclamation and associated drainage works caused the peat land to subside. As a result the neighbouring wetlands suffer too dry conditions and as a consequence a rapid encroachment by scrubs. Therefore the changes in hydrology have caused biodiversity to decline.

Spatially distributed hydrological models have become useful tools to support the design and evaluation of river basin management. The dynamics of flow between aquifer systems and interconnected streams are explored using coupled stream–aquifer interaction models that are capable of accounting for the interdependence of groundwater and surface water functioning. To analyse the complex Dovinė basin with its wetlands and lakes requires the use of a combined groundwater and surface water model and predict the effect of measures on a regional scale. Therefore the regional distributed parameter hydrological model SIMGRO (SIMulation of GROundwater and surface water levels) was used. The model simulates the flow of water in the saturated zone, the unsaturated zone and the surface water (Van Walsum et al., 2004). The model is physically-based and therefore suitable to be used in situations with changing hydrological conditions.

This paper addresses the measures to improve the river regime, the conditions in the Žuvintas Lake and the adjacent wetlands, using the model SIMGRO. Measures were judged on their merits to improve stream flow conditions and in particular increase the low flows. Further improvements of the groundwater conditions in the wetlands were considered (removal of scrubs and trees) and how this measure influences the stream flow in the basin as well.

DESCRIPTION OF THE DOVINĖ RIVER BASIN

The Dovinė River Basin covers an area of 588 km² and is located in the southern part of Lithuania (Fig. 1). The basin is the right tributary of the Šešupė River consisting of a network of streams and a number of through-flowing lakes (Dusia 23 km^2, Žuvintas 9 km^2, Simnas 2.4 km^2, and Amalvas 2 km^2). The Dovinė River basin holds one of the most important and meanwhile most threatened nature reserves of Lithuania, the Žuvintas. In the past the lake was a good example of an eutrophic lake but in the current situation only small parts of the lake qualify to be designated under the EU Habitats Directive and its conservation status is far from favourable (Zingstra et al, 2006).

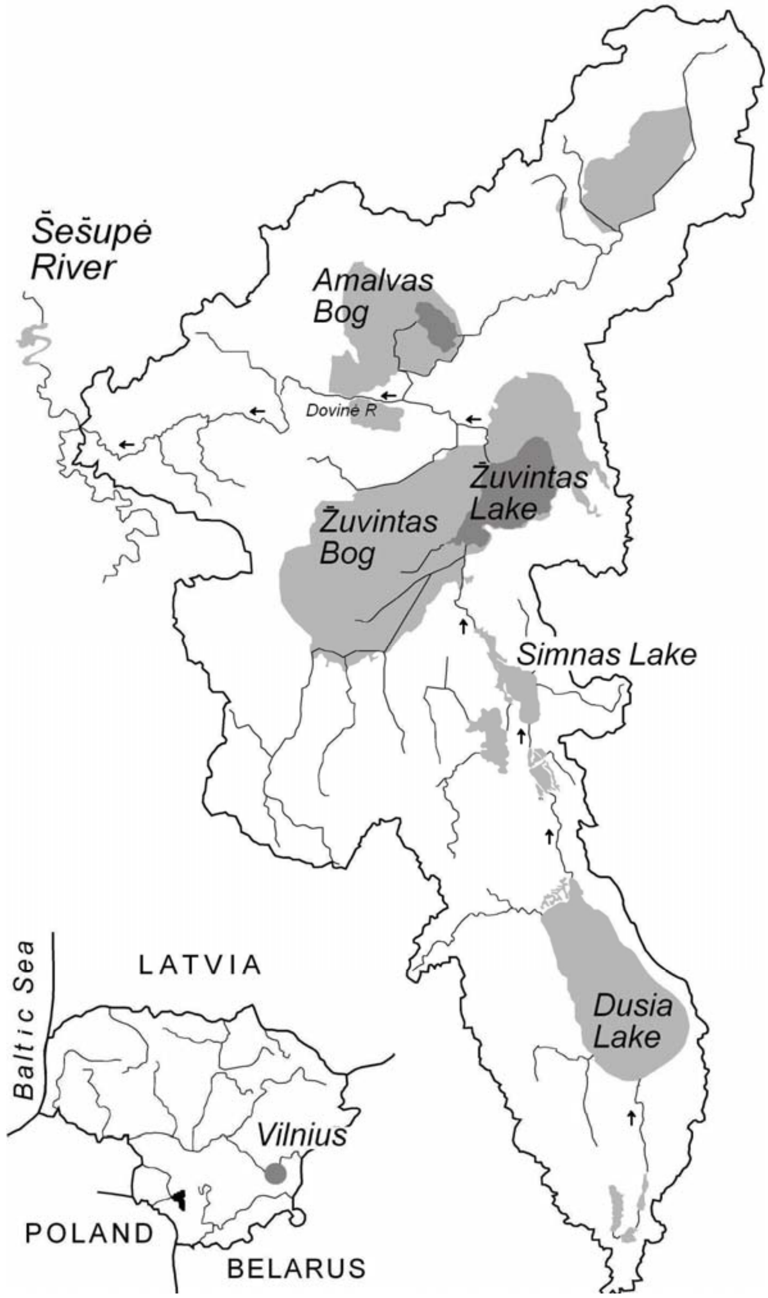

Figure 1. Location map of the Dovinė River basin.

Adjacent to the Žuvintas Lake are extensive bog and fen areas of the Amalvas wetland complex. Both the Žuvintas and Amalvas wetland makes up the Žuvintas Biosphere Reserve. The Amalvas wetland is influenced by human activities to an even higher extend. Draining ditches cover almost half of the original wetland complex, excavated in the late 80-ties of the last century, when the area was transformed from a bog area into pastures and hay-producing meadows. The relief of the northern part of the Dovinė River basin is rather flat (80-100 m a.m.s.l.). In southern direction it changes into low glacial hilly landscape (100-190 m a.m.s.l.). Land use is predominantly agricultural, about 46% is arable land, 16% is pasture and meadows, 14% is natural wetlands (including wet forest), 12% are lakes, 9% is forested and 3% is urbanized. The dominant soils are Haplic Luvisols covering one third of the basin while Gleyic Luvisols cover more than 20% of the territory. Sandy loam soils prevail in hilly southern part of the basin, light clay loam and peat soils dominate within the Žuvintas Biosphere Reserve.

The predominantly fertile soils in the Dovinė River basin stimulated the extension of agriculture. During the second half of the twentieth century, the water regime of the river and its basin was significantly altered. Sluice-gates were built at the outlets of Dusia, Simnas, Amalvas and Žuvintas Lakes to accumulate spring runoff. After the arrangement of sluices average water level in the lakes has increased in the order of 0.2-0.8 m. Due to intensified drainage activity about 36% of the Žuvintas drainage basin was ameliorated. Nowadays Žuvintas Lake, being quite shallow as well, is rapidly shrinking in size due to the massive overgrowth by water plants. Obvious, that the change of hydrological regime has had a negative impact on the biodiversity of the Dovinė River Basin and on Žuvintas Lake in particular.

INPUT DATA

A SIMGRO model application has been build for the entire Dovinė River basin with a size of approx 600 km^2 (Povilaitis and Querner, 2006). The finite element network covering the basin comprised of 4370 nodes spaced about 400 m apart. The peat layer of the Amalvas and Žuvintas bog was considered as an aquitard ranging in thickness of 2-4 m. The resistance of this peat layer is in the order of 400 days. The aquifer below covers the whole basin and has a thickness of 40-80 m and a transmissivity of about 20-65 m^2 day^{-1}. For the modelling of the surface water the basin was subdivided in 460 sub-basins and the schematization further included the sluice-gates. For the modelling of spatially distributed features in the Dovinė River Basin, the available digital data were used. This included topography (scale 1:10000) along with the boundaries of the river basin and sub-basins, together with land use; soil type; geological layers and hydro-geological parameters; hydrographic network and positions of hydraulic structures. The SIMGRO model was calibrated using the available data on water levels measured in Dusia and Žuvintas Lakes, groundwater levels, and measured discharges for the period 2000-2005.

The comparison of measured and simulated discharges, groundwater levels and lake water levels revealed that there were differences. However, in spite of some inaccuracies, the SIMGRO model showed to be a useful tool to predict groundwater movement and its interactions with surface water in the Dovinė River basin.

MITIGATION MEASURES AND THE IMPACT

The water management measures are focused on the entire Dovinė basin, with particular attention for the Žuvintas Lake and its wetland complexes.

Given the aim of making the Dovinė River runoff regime more natural, different scenarios were analysed to ascertain the impact of changes on the river regime and on the water levels in Žuvintas Lake and adjacent wetlands. Model simulations were performed for the period 1994–2005. Therefore, three scenarios (Table 1) have been analyzed to get insight in the impact of the measures. Simulations with the model were carried out using a daily time step and meteorological conditions.

Table 1. Management scenarios simulated with the SIMGRO model.

Scenario	Description (main features)
0	Present situation used as reference
1	Replacement of sluice gates by overflow spill-weirs
2	Removal of trees in part of the Amalvas and Žuvintas wetlands
3	Blocking drainage ditches around Žuvintas and Almalvas wetland

Scenario 0 reflects the present water management situation in the Dovinė Basin and was used as the reference for the other scenarios. It gave the possibility to judge the impact of different water management practices on water regime. In scenario 1 the sluice gates were replaced by overflow weirs. Preliminary simulations showed that *it is impossible to restore the water regime in Žuvintas and other lakes entirely by removing the sluice-gates downstream*. Such a measure would lower the water level in Žuvintas Lake by more than one metre and consequently destroy it (Povilaitis and Querner, 2007). Therefore, to improve the hydrological situation along the Dovinė River, the scenario analysed involved replacing the sluice gates by overflow weirs designed so as to release an environmental flow during dry periods whilst ensuring that the water level does not fall so low that large areas near the shore are too shallow. In scenario 2 the effect of the encroachment of scrubs and trees on the bog area was analysed. Higher groundwater levels are needed and the loss of water to adjacent reclaimed land should be reduced as much as possible. In scenario 3 the blocking of drainage ditches was considered. The rise of groundwater level at the outskirts of Žuvintas and Amalvas wetlands can be achieved by raising the water levels in the draining ditches by means of small dams or bars. The height of the dams corresponds to the water level in the ditches according to the 10% probability discharge (10-year return period). The damming is considered at 23 locations, only in those ditches, which are part of the Žuvintas Biosphere Reserve Management Plan.

In the model the situation for *scenario 1* was reached by adjusting the stage-discharge (Q-h) relationship of the lake outlet. For the case of Žuvintas Lake this was considered to be an effective measure for achieving partial naturalization of hydrological regime and for minimising the impact of human interventions. The simulations showed that the complex-shape designed overflow weirs would raise the water level in Žuvintas Lake by 0.05 m on average. During dry periods the rise is expected to be in the order of 0.1 m, compared to the reference scenario. The groundwater level in the Žuvintas wetlands would also rise. The changes in water levels would also affect outflow. Though the average daily outflow from the lake would remain about the same (Fig. 2), the average outflow during the driest 30-day period would increase by 45%. Maximum peak outflows are expected to decrease by 10% on average. Seasonal outflow conditions would also be affected: in winter and during the spring floods, the outflows would be 6% and 10% smaller, respectively. However, during summer and autumn the outflows would increase by 17 and 11%, respectively.

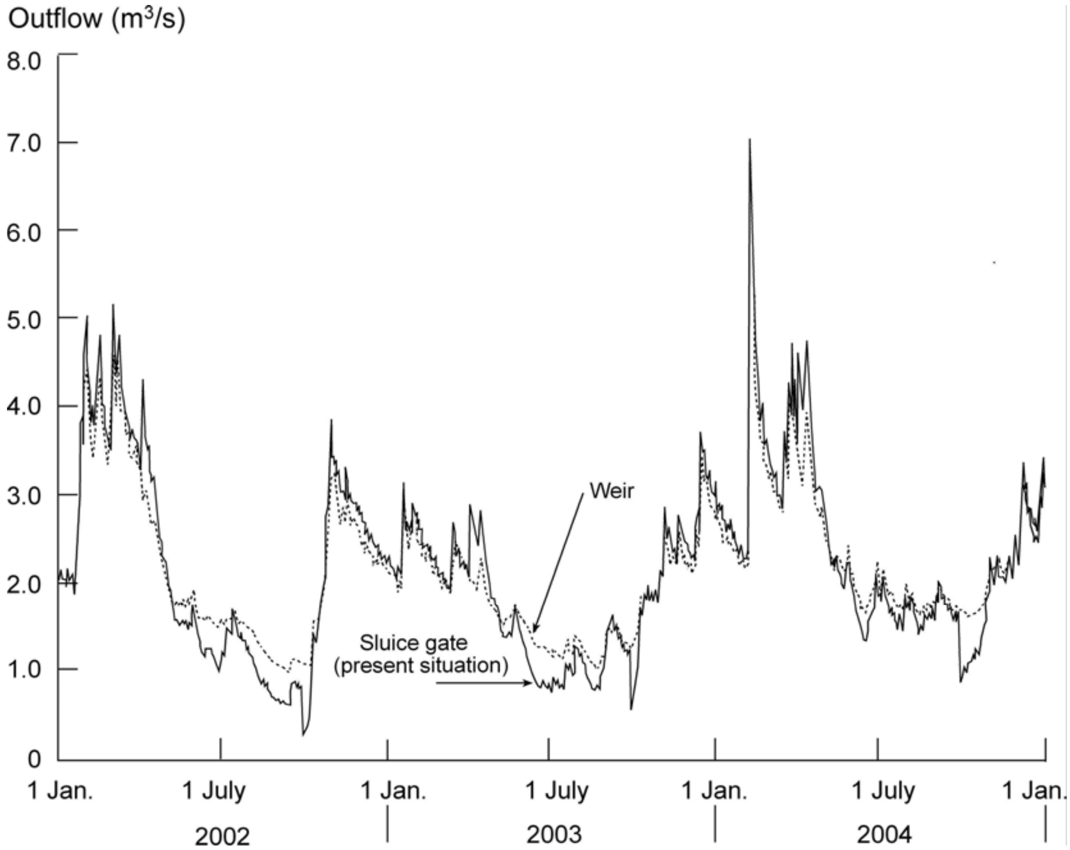

Figure 2. Comparison of outflows from Žuvintas Lake

The complex of wetlands around Amalvas Lake covers an area of 18.3 km^2, the largest part of which is covered by raised bogs (15.1 km^2) situated on the both banks of the Dovinė River. A large area (94%) of the bogs is overgrown with forest. Wetlands around Žuvintas Lake cover an area of 57.9 km^2, of which 80% is covered by forest. The possible influence of the total removal of scrubs and trees in the wetlands upon the groundwater levels in them was evaluated under *scenario 2*.

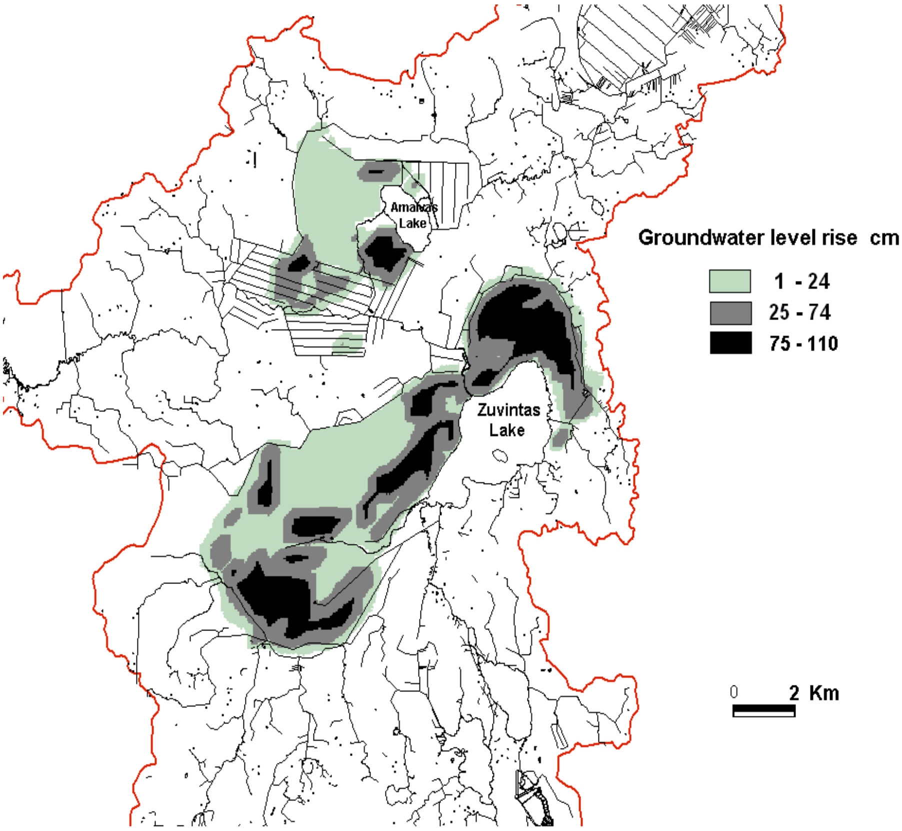

Figure 3. The impact of the removal of scrubs and trees on groundwater level changes in Žuvintas and Amalvas wetlands.

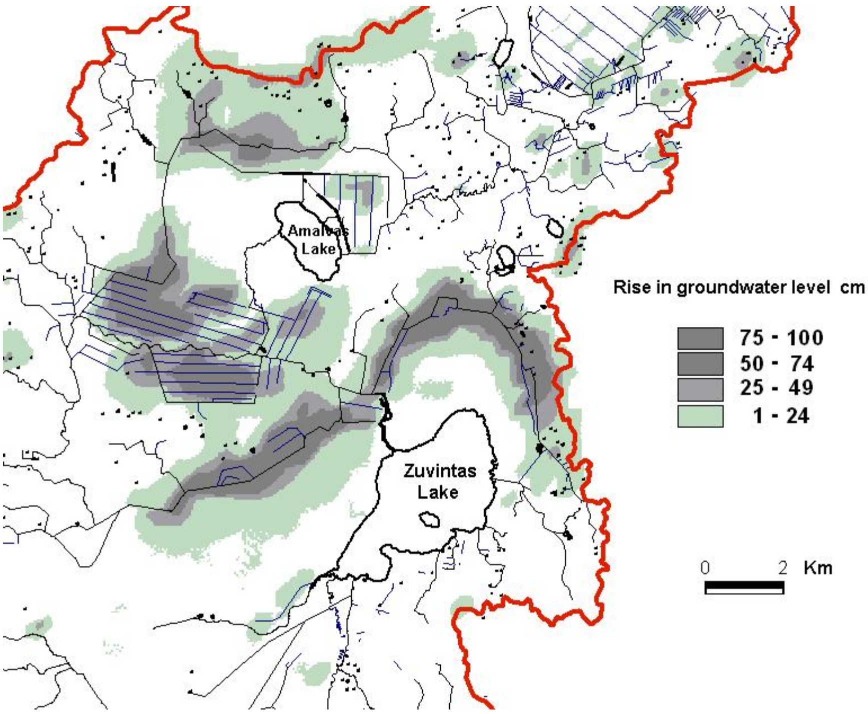

Figure 4. Average annual rise of groundwater level around Žuvintas and Amalvas wetlands after blocking of drainage ditches.

The results have shown that the most susceptible changes would appear in summer season (Fig. 3). The groundwater level can rise up to 1.1 m. In large parts of the area the rise would be in the order of 0.30 m. The most vivid changes can be expected in the northern and eastern wetlands of Žuvintas Lake, where dense woodland, mainly pine trees, is situated. The largest changes in the wetlands around Amalvas Lake would be observed in the drained raised-bog (right bank of the Dovinė River) and south of the lake. There, the groundwater level would rise by 0.2-0.9 m on average. During winter the rise in groundwater levels in both wetlands is expected to be less than in summer.

The results under *scenario 3* revealed that on the northern, north-western and north-eastern outskirts of wetlands surrounding Žuvintas Lake the damming of water in the ditches would raise the groundwater level by 0.60-0.70 m on average (Fig. 4). The small dams can affect a large area as far as 1000 m away from the dams. The small dams in the ditches would affect an area of the drained Amalvas raised bog (to the south-west from the Amalvas Lake) in particular. There the groundwater level would rise by 0.60 m on average.

DISCUSSION AND CONCLUSIONS

Dams have major impacts on river hydrology, primarily through changes in the timing, magnitude, and frequency of low and high flows, ultimately producing a hydrologic regime differing from the pre-impoundment natural flow regime. Restoration of an unregulated flow regime has been cited as a necessary, and often sufficient, condition for restoration of the ecosystem. However, many of the physical changes are irreversible and have to be taken for granted when assessing the quality status of the river. This necessitates the use of combined groundwater and surface water models to evaluate the effect of the changes.

Simulations using SIMGRO model revealed that for the case of the Dovinė River basin the removal of sluice-gates would be followed by 1.2-2.4 times higher fluctuations of water level in the lakes in comparison with dammed conditions. However, restoring the water dynamics and flow pattern of the Dovinė River to its original state appeared to be impossible. The restoring would result in undesirable water level decrease. The entire naturalization of the hydrological regime in Žuvintas Lake is impossible. Such measure would decrease the surface area of the lake by 20%. Consequently, the necessity of the damming in the lakes remains in order to prevent drying out of the lakes and to prevent undesirable lowering of the groundwater table in adjacent wetlands. This makes clear that the Dovinė River has been modified to such degree that the changes are irreversible. When striving for at least partial flow naturalization the reconstruction of the sluice-gates is necessary. Therefore, some partial naturalization of outflow pattern from Žuvintas Lake might be achieved by reconstructing the sluice-gates and installing a specially designed overflow spill-weir. This would raise the water level in the lake and surrounding wetlands and make outflow conditions more natural. If accompanied by agro-environmental measures in the basin, the partial flow naturalisation would be a feasible measure to improve the situation in the lake.

It is well recognized that land cover and land use change have significant effects on hydrological processes such as evapotranspiration, soil moisture and groundwater recharge. Forest cover leads to higher transpiration rates and interception of rainfall, therefore, clear cutting on wetlands can result in a rise of the groundwater table (Pothier et al., 2003; Laiho, 2006). These findings have been proved out under the clear cutting scenario in Žuvintas and Amalvas wetlands. It shows that when the prevailing grassy peat-moss (*Oxycocco Sphagnetea*) cover is reinstated, a significant rise in the groundwater level can occur. Scrubs and trees lower the groundwater level and therefore the peat layer can dry up leading to intensified mineralization of organic matter and subsequent degrading of wetlands. Therefore, the highest impact is estimated in the areas with pine trees during summer season. Based on this knowledge it is recommended to remove trees and scrubs in the wetlands.

A significant threat to peatland sustainability in Žuvintas and Amalvas wetlands has been the installation of artificial drainage ditches. However, recent restoration schemes have pursued drain blocking as a possible strategy for reducing degradation. The results from simulation scenario have shown that the rise of groundwater level at the outskirts of Žuvintas and Amalvas wetlands can be achieved by raising the water levels in the draining ditches by means of small dams and bars. Such small dams in the ditches would raise the groundwater level by 0.6-0.7 m on average on the northern, north-western and the north-eastern edges surrounding Žuvintas wetland. The introduction of the small dams can affect the territories situated at a distance from 100 m to 1.0 km. The dams in the ditches would affect the area of the drained Amalvas raised bog in particular. There the groundwater level would rise by 0.6 m on average. It is expected that small dams in the ditches on the outskirts of wetlands would have a positive impact on bird habitats as well.

ACKNOWLEDGEMENT

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ANCHOR ICE FORMATION AND ITS INFLUENCE ON HABITAT USE OF ATLANTIC SALMON (*SALMO SALAR* L.) PARR IN STEEP STREAMS

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ABSTRACT

Recent studies report an overall decline in northern populations of Atlantic salmon. Beside their biological significance, the Atlantic salmon generates major income nationally and internationally by recreational and industrial fisheries. Therefore, research aiming at preserving sustainable populations of the specie is evident. As the winter has been suggested to be a critical period for juveniles, interdisciplinary studies focusing on physio-biological interactions are thus needed. In this study, a multidisciplinary approach has been used focusing on (1) formation of anchor ice in steep streams, and (2) habitat use by juveniles in anchor ice affected streams. Results show that anchor ice has profound impacts on the stream environments, and may be differentiated between two ice types according to its formation process and density (I: less dense; II: dense). Observations of habitat use by parr affected by the two types demonstrate two strategies: Type I demonstrate no effects on the habitat use by parr, whereas Type II, display habitat exclusion leading to high movement activity by parr increasing their energetic costs. Finally, results indicate that winter may not necessarily act as a bottleneck, whereas in contrast, the spring ice break-up implies a critical period for parr.

Keywords: *Salmo salar* L.; winter habitat use; dynamic ice formation; steep streams

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INTRODUCTION

Research reports of an overall decline in Northern populations of Atlantic salmon (*Salmo salar* L.) (ICES, 2007). As streams play a vital role of the salmon life cycle providing spawning and rearing habitats (Schaffer, 2004), the importance of conducting studies in these environments is evident. Furthermore, with future climate scenarios of increased temperature and precipitation (Corell, 2006) northern streams and ecosystems will be put under pressure. Especially the winter period, fluctuating discharge and variable water temperatures will increase the freezing-thawing shifts (Frauenfeld et al., 2007) and amplify the dynamics of in-stream conditions. Today, winter conditions in streams including river ice are known to have both physical and biological implications (Prowse, 2001), however, limited knowledge exist on the matter and further attention is needed. Particularly, the knowledge of habitat use by juvenile salmonids in ice covered streams (Huusko et al., 2007) is scarce. Previous studies suggest that juveniles are sensitive towards changes in stream conditions during the cold season as energy conservation, access to cover and food availability are important aspects of suitable winter habitats and for their survival. Nevertheless, winter as a "bottleneck" has recently been discussed as the literature at hand is both limited and disparate (Huusko et al., 2007). To determine the effect of winter on northern populations of Atlantic salmon, the cold stream environments needs further focus. New and innovative studies conducted in natural environments will be essential, both on a spatio-temporal scale and in a multidisciplinary manner.

In the following, an interdisciplinary study focusing on steep streams and habitat use of Atlantic salmon parr in ice covered streams is presented. A particularly focus on dynamic ice formation and its influence on the habitat use of parr is given. The study has two main parts: (1) Investigation of anchor ice formation in streams and its influence on the physical stream habitat, and (2) the influence of anchor ice on habitat use by Atlantic salmon parr in steep streams. By this, emphasize towards data collection under natural conditions has been made. Studies conducted in natural environments are especially lacking within the literature, most probably due to difficulties of collecting data under such conditions, but are nevertheless essential if we are to understand the dynamics of natural systems. Findings should be of value towards those that work and deal with cold climate freshwater fisheries and/or development of existing and future hydraulic/habitat modeling tools.

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METHODS

Study area

Anchor ice formation and its influence on habitat use of Atlantic salmon parr was studied in three different streams located in the northern hemisphere (between 48º - 63º N, Figure 1). These streams have similar coastal climate conditions, but different physical characteristics (Table 1). The winter, here defined as a period from first appearance of ice to complete removal of ice in the spring, usually lasts for 6 months from the freeze-up in late October to the thermal ice break-up in April. In the following, the study sites are described.

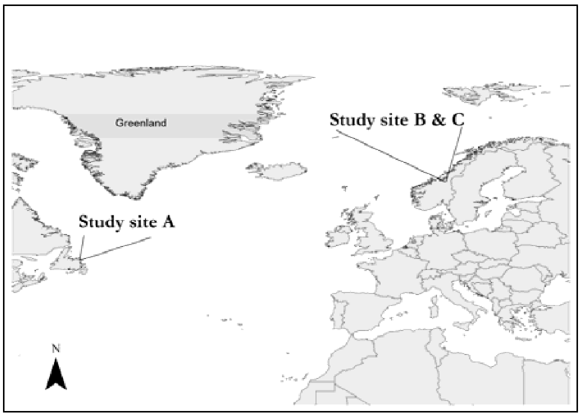

Figure 1. Location of the three study sites A, B and C (see Table 1for physical features). Study site A: Southwest Brook, Newfoundland Canada; B: Sokna River, Norway, and C: Orkla River, Norway.

Study site A, Southwest Brook, is an unregulated stream located in the Terra Nova National Park (48º36’ N, 53º58’ W) on the northeast coast of Newfoundland, Canada. The Southwest Brook is a small stream with an average winter discharge of 0·4 m^3s^{-1}. The selected study section was approximately 300 m long, with a steep stream gradient favoring dynamic ice formation. In ice-free conditions, the reach is riffle dominated with sections of slow flowing shallow and deep (pools) areas. Study site B, Sokna River, is an unregulated stream located in Mid-Norway (62º98’ N, 10º23’E). It is a small (average winter discharge of 2 m^3s^{-1}), steep stream favoring anchor ice formation. The field study was carried out in a 350 m long stream reach, consistent of predominantly riffle with a smaller section of slow flowing shallow area. Study site C, Orkla River, Mid-Norway (63°17’ N, 9°50’E), is a regulated stream with a mean winter flow of 50 m^3s^{-1}. Due to the local climate, regulation regime and its steep stream gradient, the river system has high production of frazil and anchor ice. The selected study site was located in the middle portion of the river system, approximately 10 km downstream of nearest power plant outlet (Grana outlet). The study site is 250 m long, representing riffle, glide, and slow flowing shallow sections, and is largely influenced by severe anchor ice formation in winter.

Table 1. Summary of physical characteristics in the study sites given by their average winter discharge (Q), stream gradient (I), maximum water depth (Y_{Max}), average wetted width (WW), and dominant substrata (D_{50}).

Study site	Q (m^3s^{-1})	I (%)	WW (m)	Y_{Max} (m)	D_{50} (mm)
A	0·4	1·3	11·5	2·0	97
B	2·0	1·8	23·5	1·0	165
C	50·0	0·5	45·0	2·0	72

Data collection of physical characteristics

To describe the effect of dynamic ice formation on the physical habitat in steep streams, a number of physical characteristics have been collected. The data collection can be distinguished by two parts: (1) monitoring of changes in the hydraulic heterogeneity caused by river ice, and (2) monitoring of anchor ice formation and its formation process. In (1) changes in the hydraulic heterogeneity were observed measuring changes in discharge (pressure sensor and manual measure), water depth and water velocity (Sontek Flow meter, 10-MHz ADV, Acoustic Doppler Velocity profiler) and by using a hydro-morphological unit (HMU's) classification system according to Borsányi et al. (2005). In latter, four classes were implemented: 1) shallow riffle (water depth, $Y < 0·7$ m, velocity, $U > 0·5 ms^{-1}$); 2) shallow glide ($Y < 0·7$, $U > 0·5$); 3) walk ($Y < 0·7$, $U < 0·5$) and 4) pool ($Y > 0·7$, $U < 0·5$). Substrata were measured by the b-axis (shortest axis) and classified using the Wenthworth scale. The substrata embeddedness was measured according to the method by Schälchli (2002) by visual determination using five classes: 0-20%, 20-40%, 40-60%, 60-80% and 80-100%, in which low values reflect low degree of embeddedness (i.e. high degree of interstitial spaces). In (2) anchor ice formation was monitored measuring spatial and temporal distribution (total station (Sokkia SET 600 or Leica TS 306, or DGPS (Differential GPS)), thickness, density and its formation process, both on a micro (< 10 m) scale and on a meso (10 – 100 m) scale. Photo, video and underwater video recording was also conducted. In addition, high resolution temperature sensors (SeaBirds Electronics, SBE39, ± 0·002 C) was used to survey temporal distribution of anchor ice according to its formation process, and underwater light meters (Onset Computer Corp., HOBO RH) to investigate underwater light changes due to ice formation (both surface- and anchor ice). Finally, measurements (Sontek ADV, 10 MHz, velocity range 250 ms^{-1}) of turbulence (here defined as velocity fluctuations around its mean over during two minutes) were made to investigate its effect on anchor ice formation and density.

Monitoring of Atlantic salmon parr

Atlantic salmon parr monitored in the present study ranged from 75 – 170 mm (fork length, L_F). Two different techniques were used to monitor Atlantic salmon parr: (1) Radio telemetry and (2) Passive Integrated Transponder (PIT) technology. In the respective studies, a number of salmon parr were caught by electro fishing within the study sites using a 24 V backpack electro fisher (Smith Root Inc., model 12-B). Salmon parr were kept in a bucket for observation of any potential effects before tagging using radio transmitters (Model Lotek MBFT 7M; 7.3·18 m, 1.4 g in air, and 9M; 8.2·19 mm, 1.8 g in air, Lotec Wireless) and Passive Integrated Transponders (Texas Instruments, RI-TRP-WRHP; length: 23·1 mm; diameter: 3·9 mm; weight: 0·6 g in air). As the size of tags have been discussed to have potential effects on fish behavior (Jepsen et al., 2004), procedures suggested by Roussel et al. (2000) and Robertson et al. (2003) has been followed to ensure minimal impacts of tagging. Furthermore, in all cases salmon parr were kept for 24 hours before releasing them into their respective habitats where they had been captured. No post-mortality was observed in any of the conducted studies.

Tracking of salmon parr were conducted using radio telemetry (Lotek Wireless) and PIT technology (Texas Instruments Inc.; TIRIS S-2000 RI-CTL-MB2A), following procedures described by Scruton et al. (2005) (radio transmitters), Roussel et al. (2000) and Linnansaari et al. (2007) (PIT). When using PIT technology, manual in-stream tracking was performed concurrently with two sets of hand-held antennae. Maximum reading distance (70 cm) and spatial accuracy (± 15 cm in x-y-direction, Linnansaari et al., 2007 and personal experiences) were tested on each survey using a test tag on the stream bank. Water, ice, substrata, metal seemed to have no impacts on the reading distance whatsoever. All tracking, both radio and PIT, was done in an upstream direction to reduce the possibility of driving individuals from their positions. When an individual was detected, a marker was dropped and its position (x-, y-coordinate) was subsequently geo-referenced (morning positions were geo-referenced in the afternoon, and afternoon/night positions were geo-referenced in the morning after) using a theodelite (total station; Leica 307, Sokkia SET 600; spatial accuracy = ± 2 cm). For further details, see (Stickler et al., 2007; Stickler et al., 2008; Stickler et al., in press)

RESULTS

In the following, main conclusions from the present study are summarized by five main points:

i. The formation of anchor ice may have profound impacts on the steep stream heterogeneity, and should be considered when evaluating physical conditions in such environments.

ii. Anchor ice may be distinguished by two types (Fig. 2): i) Type I: Less dense, forming on top of substrata, ii) Type II: Dense, forming between substrata filling interstitial spaces. The two anchor ice types may further be expressed by the Reynolds number.

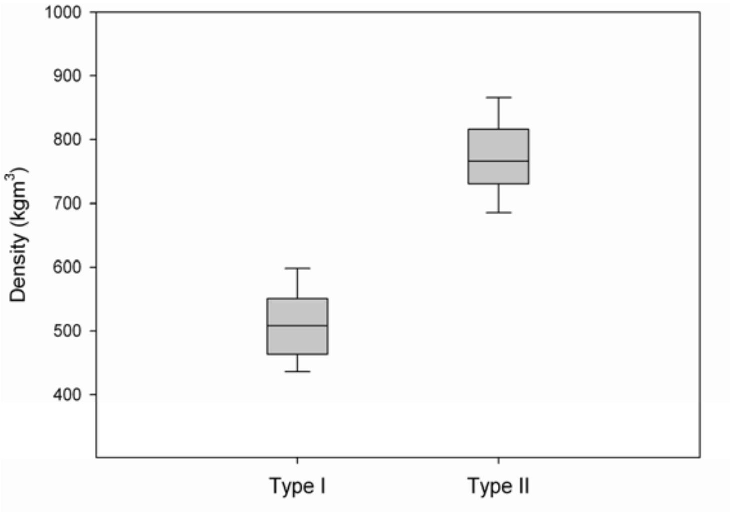

Figure 2. Two types of anchor ice according their densities. Boxes imply the inter-quartile range, whiskers the 90th percentile and the solid line median value.

iii. The effect of dynamic ice formation on habitat use of Atlantic salmon parr may depend on the type of anchor ice. Type I has small/no impact in which habitat choice by parr are less affected. In contrast, Type II demonstrates negative effects in terms of habitat exclusion with increased movement activity and enlarged home ranges (Fig. 3).

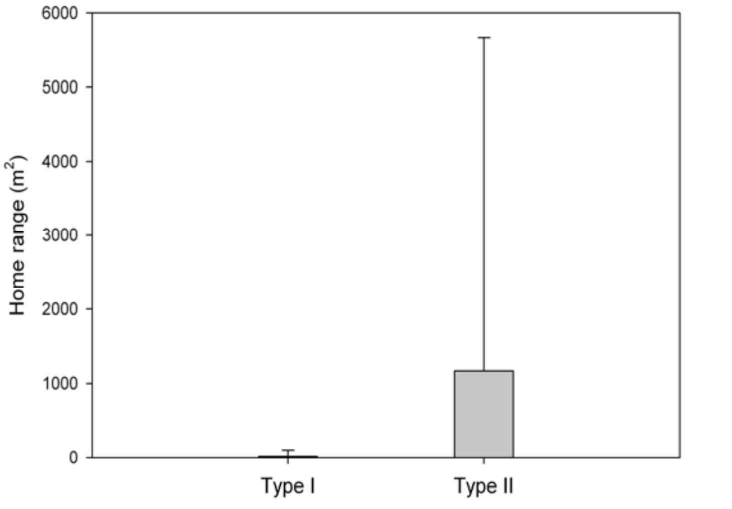

Figure 3. Size of home ranges by Atlantic salmon parr in areas affected by anchor ice type I (median = 16 m^2) and Type II (median = 1163 m^2). Bars represent median value and whiskers the 90th percentile.

iv. Riffle habitats may be suitable habitats for Atlantic salmon parr during winter, whereas pools are less utilized. However, the degree of dynamic ice formation should be considered.

v. Winter may necessarily not be a limiting factor in parr performance (i.e. growth) in steep streams, whereas in contrast the spring ice break-up can lead to a decrease in body mass and hence act as a potential bottleneck (Figure 4).

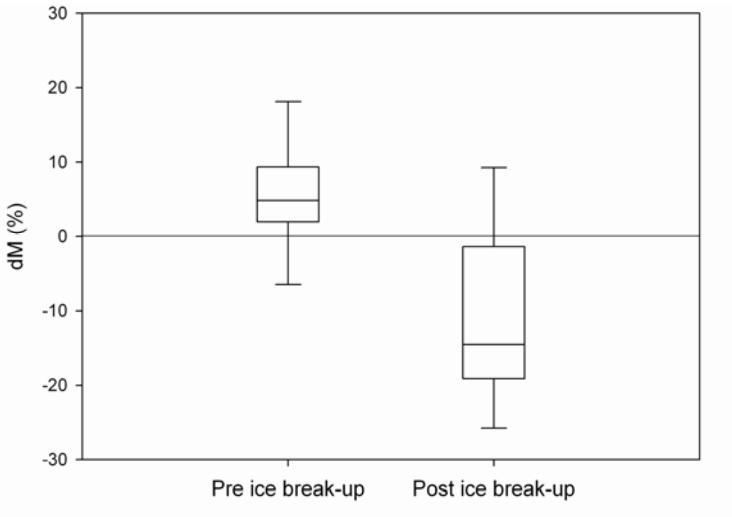

Figure 4. Change in body mass (dM, %) of Atlantic salmon parr before (pre, median = 4·8%) and after (post: median = -14·5%) the thermal ice break-up (April/May). Boxes imply inter-quartile range, whiskers the 90th percentile and the solid line the median value.

DISCUSSION

The importance of conducting multidisciplinary research to increase the understanding of aquatic ecosystems should be clear on the basis of direct linkages between the physical environment (living space; habitat) and the living species (biota). In the present study, an interdisciplinary approach has been used to investigate habitat selection and performance of juvenile Atlantic salmon in steep streams during winter. Findings demonstrate profound effects of dynamic ice formation on stream environments, and that juvenile salmon may be negatively affected through habitat exclusion and/or entrapment, although dependent on the severity of dynamic ice formation. Furthermore, the winter may necessarily not be a limiting factor in juvenile salmon performance, whereas in contrast, the spring ice break-up may lead to a lower performance.

In northern streams, ice is commonly observed during the winter. Dependent on local climate and physical conditions (flow, stream-gradient, morphology), various types of river ice may form, and hence change the in-stream environment (Devik, 1944; Prowse, 2001). Since ice affect the stream heterogeneity independent of discharge, characterization and quantification of these changes on the physical habitat is important, both in relation to freshwater management and to understand the dynamics of cold climate streams (Alfredsen and Tesaker, 2002; Shen, 2003; Morse and Hicks, 2005; Huusko et al., 2007). In particular, steep stream environments may be dynamic throughout the winter by the formation of bottom (anchor) ice formation. The formation of anchor ice and anchor ice dams may significantly alter the in-stream environment, however, the phenomena is mainly qualitatively described in the literature. In the present study the formation of anchor ice were observed and quantified in three different streams. Findings imply that anchor ice significantly affect the in-stream heterogeneity by increasing the wetted area and changing riffle areas into pools, even on a short (< 12 hours) temporal scale. These findings are in line with previous descriptions of the effect of anchor ice on stream hydraulics, but difficult to compare as no quantitative data exist. Nevertheless, discharge as the controlling factor for alteration of hydraulic heterogeneity may therefore call for a modification in streams that experience seasonal ice formation, and in particular in areas with dynamic ice formation.

Arden and Wigle (1972) and Tsang (1982) notes that the formation process of anchor ice may cause differences in ice density. In the given study, densities and the formation process of anchor ice under various physical conditions were investigated. Observations support the hypothesis by Arden and Wigle (1972) and Tsang (1982), and reports of significant density differences according to its formation process. Two types were implied: Type I was “soft” (density mean ± SD: 506 ± 63 kg·m^3) forming only on top of the substrata, whereas Type II was dense (density: 768 ± 65 kg·m^3) forming between the substrata filling interstitial spaces. Furthermore, the two anchor ice types were linked to the Reynolds number indicating a direct relation between anchor ice types and the level of turbulence. The level of turbulence on anchor ice density has also been recently demonstrated in a laboratory experiment (Qu and Doering, 2007), although the density values were significant lower compared to reported values from this study.

The potential of different anchor ice types according to its density should have both physical and biological implications, but has given less, if any, focus. From literature, anchor ice is known to cause local flooding, storing of water within the water course leading to decreased water power production, and freezing of the riparian zone (Eythorsson and Sigtryggsson, 1971; Prowse and Gridley, 1993). Anchor ice formation is also known to have negative affects on stream fish populations and invertebrate communities by direct freezing or migratory behavior (Prowse, 2001). However, previous winter studies on stream salmonids demonstrate discrepant findings questioning the importance of anchor ice (see latest review by Huusko et al., 2007). In the presented study the differences in formation process and density of anchor ice were investigated in relation to habitat use of juvenile Atlantic salmon. The findings showed a potential affect between the density and formation process of anchor ice and behavioral responses of salmon. Juvenile salmon affected by anchor ice Type I (low density) seemed to be little or not affected, whereas in contrast, salmon affected by Type I (high density) were excluded from their habitats, or even entrapped in ice, leading to large home ranges and high activity, both night and day. Thus, anchor ice Type II may have negative impacts on the performance, and potentially survival, of juvenile salmon as energy minimization in winter is crucial.

Pool habitats and other in-stream low flow velocity areas have been suggested to be important winter habitats for juvenile salmonids (Huusko et al., 2007). During winter, these habitats may provide shelter against diurnal predators and energy demanding flow velocities, while in contrast, riffles and steep stream environment has been cited as less preferable. In the presented studies, interesting findings were made. In all cases, pool habitat was less preferred by salmon parr, and high site fidelity was demonstrated towards riffle habitat if present. However, as noted above, the behavior of juveniles may be affected by the degree of dynamic ice formation and should be considered. In the regulated steep stream (case D) salmon parr avoided the riffle habitat. However, the salmon parr did not seek shelter in pool habitats, but preferred stream margins. Nevertheless, the observations made in this study exemplify how harsh winter conditions can be in such regulated systems. Altered flow and water temperature regime lead to highly unstable stream environments, and hence a changed ice regime. Further, this may increase the possibility of increased dynamic ice formation, and thus pose a potential threat against fitness of juvenile stream fish. Increased activity and hence increased energy expenditure may lead to reduced growth, and eventually reduced performance.

A potential explanation for parr using riffles can be the linkage between coarse, low embedded substrata and shelter availability. Coarse, low embedded substrata provide refuge against energy demanding water velocities and potential diurnal predators. Thus, low embedded substrata may be the controlling factor in habitat choice by parr during winter in steep streams, and thus offset the need to change habitat, even in dynamic environments caused by dynamic ice formation. The access to low embedded areas may further be important for the juveniles performance (growth, survival), which is also indicated in this study. Measurements of growth of salmon parr demonstrated a stable body mass throughout the winter (November – April). However, it was also observed that the spring ice break-up had a negative effect on the body mass of parr. The ice break-up caused a decrease in body mass of maximum 24%, indicating a critical period. A potential explanation could be the harsh conditions that parr experience during the spring and the thermal ice break-up. Ice runs and increased discharge may exceed the holding-velocities for parr and may cause unsuitable conditions with respect to increased energetic costs.

ACKNOWLEDGMENTS

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THE SALMON IN THE REGULATED ALTA RIVER. ARE CHANGES IN THE HYDROLOGY THE REASONS FOR THE IMPROVED CONDITIONS?

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ABSTRACT

The Alta power station came into production in 1987 after some years with strong resistance against the power scheme. An important part of the following-up program has been research on the salmon in the Alta River. This salmon has for a long time been famous for its size and the river is an attractive fly-fishing river. During the 1990-ies there was a marked decline in the salmon stock. A new set of manoeuvring rules were introduced, aiming to lower the winter water temperature and increasing the ice-cover on the upper part of the river. The findings, both from research and from experience, are that the winter water temperature and the river ice cover are critical hydrological factors. These factors are probably more important for the salmon in the Alta River than in e.g. rivers in South-western Norway. During the last years is seen an increase in both the number of spawning salmon and in the density of parr. The answer to the question in the heading is a conditional **yes**. It shall, however, not be forgotten that other factors may have been important too, like the introduction of "catch and release fishing"

INTRODUCTION

The history and conflicts behind the Alta hydropower (HP) station is well known to most Norwegians and probably also for many people in the Nordic countries. The purpose of his paper is not to go into that story, which led to the most intense and long-lasting demonstrations and civil disobedience in modern Norwegian history. This background is, however, necessary for understanding the many following-up investigations and the detailed operations rules that Statkraft has to follow when operating the Alta power station.

The location of the Alta River and the general outline of the HP development is shown in Figure 1. The power plant has only one reservoir (named Virdnejavri) with a volume of 133 mill. m^3 that can only store 6 % of the annual inflow. It is important to note that there are two intakes in the dam; one intake

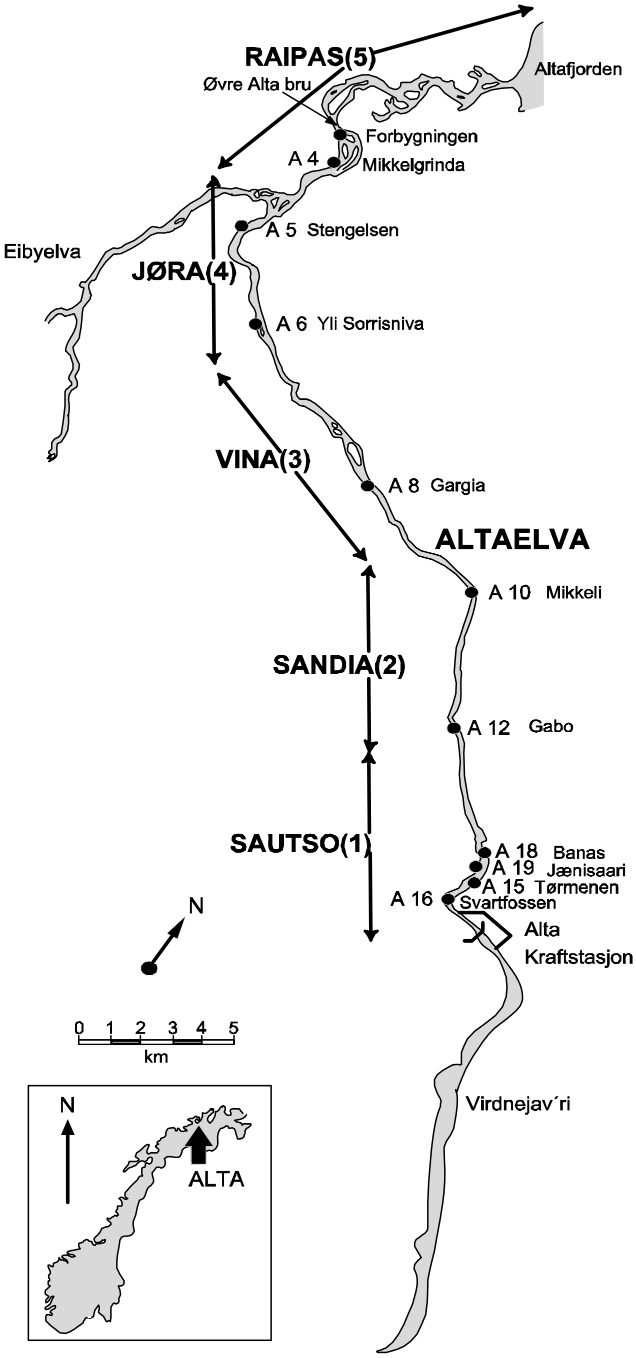

Figure 1. Location map. The names with capital letters to the left of the river are the different fishing stretches. Note the location of the Sautso stretch.

at 5-10 m depth (the upper intake) and another intake at 80 m depth (the lower intake). In the planning stage it was thought that the upper intake should only be used in the summer months to avoid releasing colder water from the bottom layer of the reservoir. The lower intake was planned to be used for the rest of the year.

The power station has a capacity of 99 m^3/s separated on two turbines. The station started producing electricity in 1987. The water is released from the power station back to the Alta River, 47 km upstream from the fjord. This river stretch is the same that was used by the wild salmon also before the HP development.

THE HYDROLOGY OF THE ALTA RIVER

The discharge of the Alta River is presented in Figure 2 with graphs for the unregulated period (1971-87) and for the regulated period (1988-05). The graphs show that the regulation has not resulted in any drastic changes in the discharge pattern. The important changes are:

1. The winter discharge has increased, most in the last part of the season
2. The spring flood is lowered and the time for the peak is a couple of weeks later

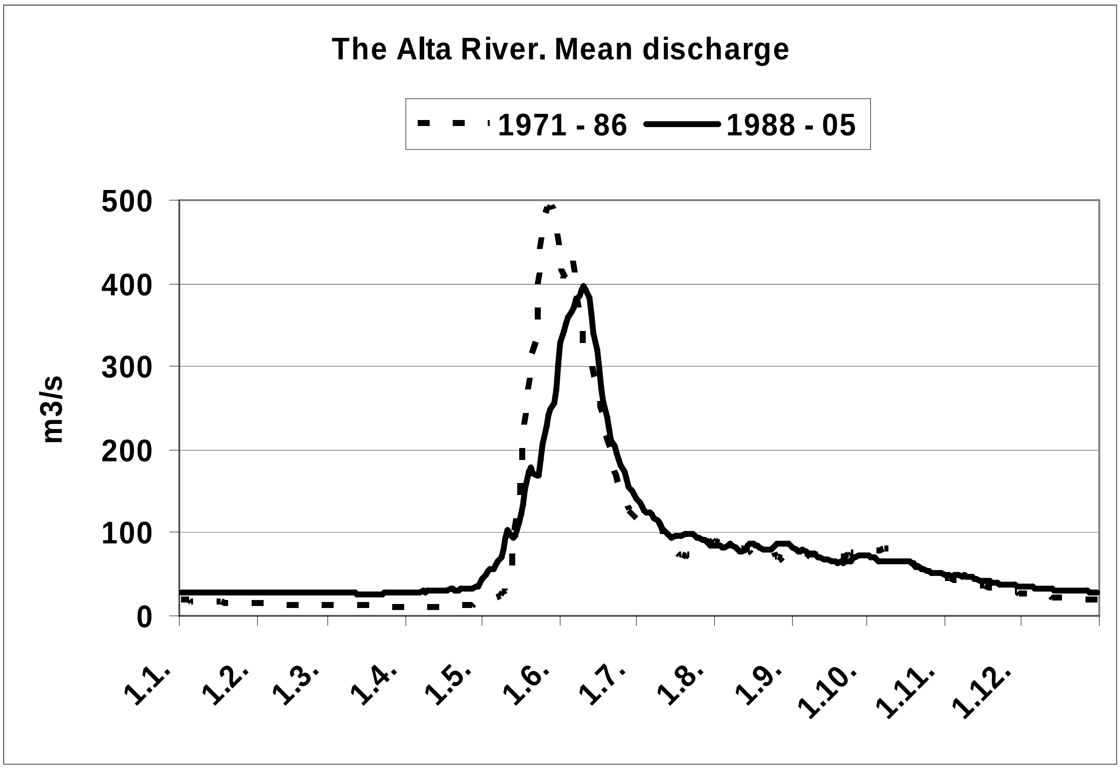

Figure 2. The discharge in the Alta River at the Kista measuring station.

The water temperature of the river has also been monitored since early 1970-ies. Before regulation the winter temperature was very close to 0 ^oC and the summer temperature was varying between 10 and 16 ^0C. After the regulation, the winter temperature increased by 0,5-1^0C and the summer temperature decreased by 0,5 -1,5 ^0C, most in the early part of the summer. In the fall months the temperature has increased. The winter increase, both in the discharge and in the water temperature, resulted in an ice-free river stretch from the outlet of the power station and circa 10 km downstream. The rest of the river down to the fjord has only seen minor changes in the ice conditions. The water temperature and the ice conditions in the Alta River are summarized by Pytte Asvall (2007)

THE SALMON

The salmon in the Alta River is, and has for a long time been, famous for the large sizes (up to 30 kg) and for the challenges it offers to the sport fishers. The development of the salmon catch by sport fishing is presented in Figure 3. There have been periods with ups and downs, both in the number and in the weight. This is a pattern found in nearly all salmon rivers and can be caused by several factors, both natural and man-made.

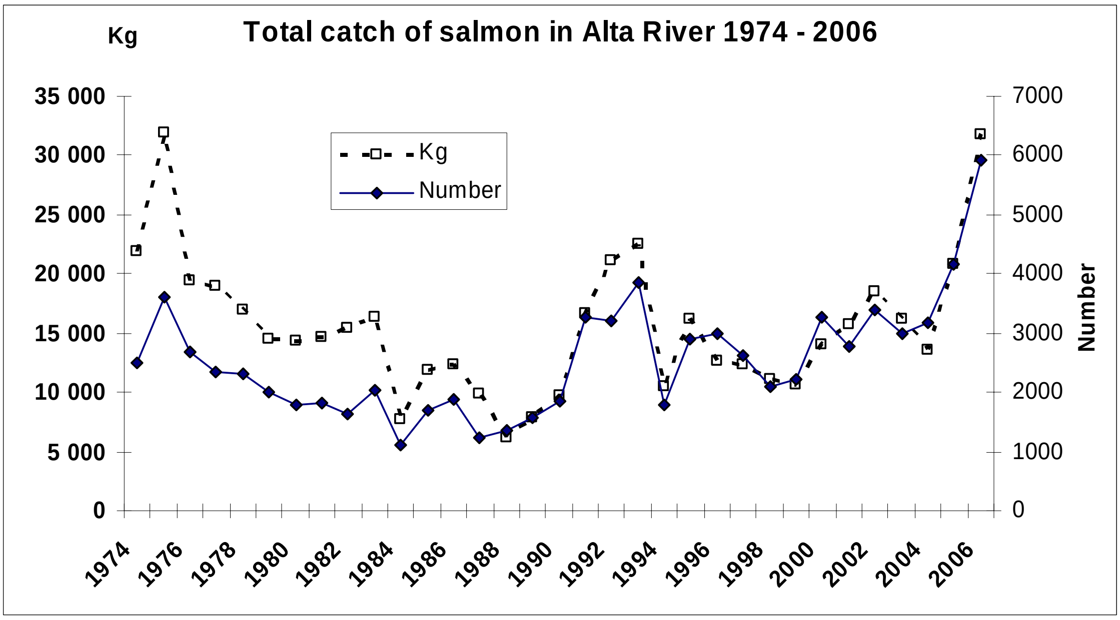

Figure 3. The total catch of salmon in the Alta River in numbers of fish and their total weight in kgs. Data from the webpage of the Alta Fishing Right Assosiation.

For the Alta River it was special worrying in the 90-ies when the number decreased, both for the parr, the presmolt and the old spawning salmons. The decrease was largest in the upper part of the river, named the Sautso stretch. The Sautso stretch became an ice-free stretch downstream from the power station. The investigation program was intensified and focused towards identifying the most important factors controlling the life cycle of the Alta River salmon. An overview of the program is presented in Table 1.

Recommendations from a seminar in 1997, summarized by Næsje (1998), pointed out some important mitigations to be tested out:

1. Change the manoeuvring rules so that the upper part of the river again can have an ice cover, like the before-regulation situation.
2. Introduce “catch and release” fishing rules in the Sautso stretch.

The Norwegian Water and Energy Directorate (NVE) asked Statkraft to find out practical ways to get more ice cover on the river. Tests and calculations were done and the result was a recommendation to change the use of the upper intake in the reservoir. If the upper intake was to be used in most parts of the winter, in combination with a lower discharge, the water temperature would decrease sufficient to allow for ice formation on most of the Sautso stretch. In order to maintain the annual power production, a switch to using the lower intake was necessary from around 1. April.

New manoeuvring rules, based on these principles, were introduced from the winter 2002/03.

Environmental Monitoring program: The Alta River Project in 2005 and earlier years

Hydrology and climate	Invertebrates	Water vegetation	Salmon and trout	Birds
Discharge 4 stations	Flies, several types, amounts and distribution	Algae - several types, amounts and distribution	Fries – time for swim-up	Birds of pray – types, numbers and reproduction rate (not in 2005)
Water stage	“Small crawfish”, several types, amounts and distribution	Mosses -several types, amounts and distribution	Parr - amount and distribution. Winter survivial	Ducks (in spring)
Water temperature 13 stations			Smolt - amount, distribution and time of migration to the sea	
Ice condition Maps and video			Returning adults- date, amount and distribution of catches	
Erosion/sediment transport (not in 2005)			Spawning - number and distribution of spawning pits	
Water chemistry (not in 2005)			Smolt – migration in the fjord	
Local climate – air temperature, wind and humidity (not in 2005)			Trout – number and distribution	
Ground water stage (not in 2005)				

Table 1.

THE EFFECTS FROM THE NEW MANEOUVERING RULES

The new manoeuvring rules have now been in operation for 5 years and the results are promising. The water temperature effect is seen on figure 4. The temperature in the early winter is circa 0,5 ^{0}C lower when using the upper intake, compared to when the lower intake was used. This also resulted in a larger percent of the Sautso stretch now gets an ice-cover. The ice is, however, seldom thick enough to last through midwinter periods with mild weather. All the winters since 2002 have been milder than normal, we still have not been able to test through a really cold winter. In Figure 5 are presented examples of different ice coverage situations on one of the river parts continuously surveyed by video cameras.

The situation for the salmon in the Alta River has also been positive, see figure 3. The number of salmon caught has increased and the surveys of the presmolt in Sautso show an increase, even if it is still below the preregulation situation, see Ugedal et al. (2008). The total number of parr and presmolt in the Alta River in 2006 was, however, higher than ever monitored.

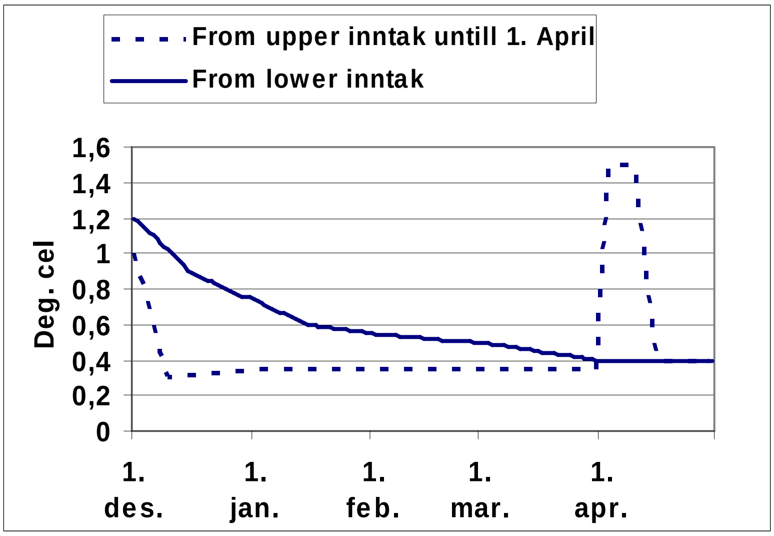

Figure 4. Temperature measured in the water from the power station when using the lower intake (up to 2002) and when using the upper intake (after 2002).

Figure 5. Video pictures of the Tørmenen pool, just downstream the power station. Different degrees of ice coverage.

The development of the electricity production from the Alta power station is presented in Figure 6. When planned, the mean production was calculated to be 625 GWh (this number is still used by the media as a measuring stick when illustrating energy production = “1 Alta”). For the period 2003 -07, the mean production was 750 GWh or 20% higher than planned. This increase is clearly a result from the increasing discharge experienced in this region.

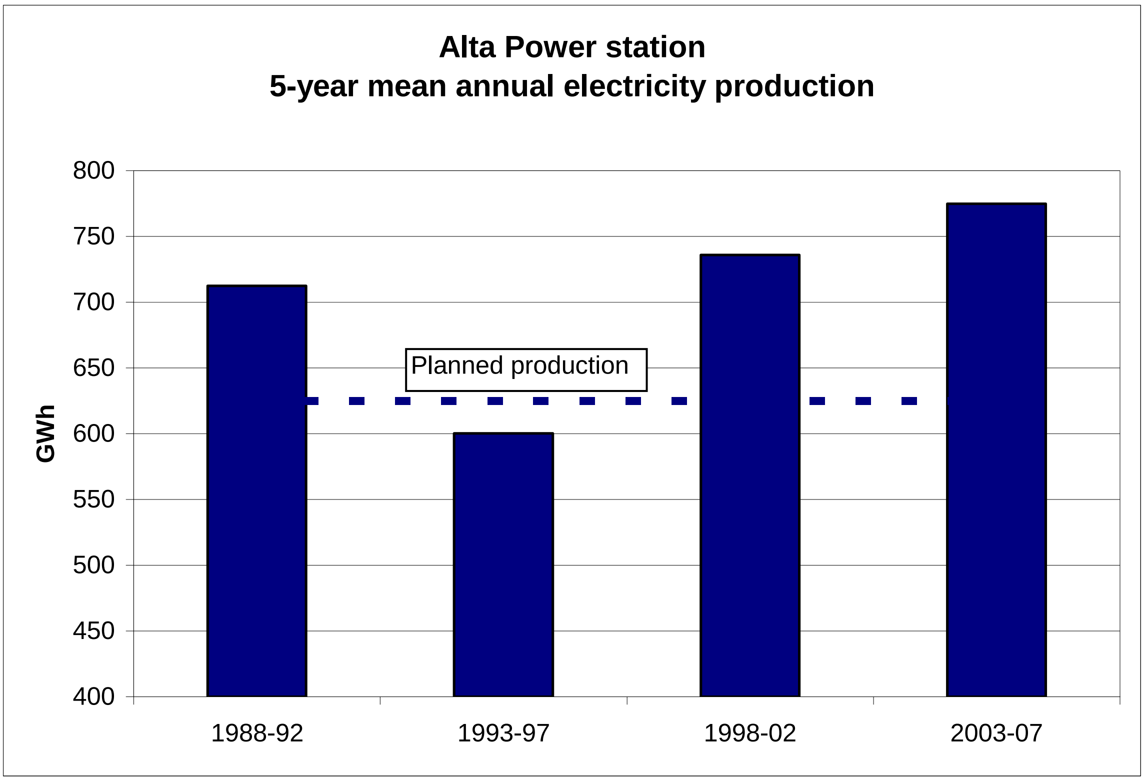

Figure 6. 5-year mean of annual power production at the Alta power station.

CONCLUSIONS

The research on the salmon in the Alta River has concluded with that hydrological factors are important for the well-being of the salmon in its different parts of the life cycle. Some of these factors are general and are important for all salmon rivers. For the Alta River, the findings, both from research and from experience, is that the winter water temperature and the river ice cover are critical hydrological factors. These parameters are more important for the Alta River than for e.g. rivers in South-western Norway. Adjusting the manoeuvring rules so as to lower the winter temperature, and to increase the ice cover below the power station, has been proved to help in the winter survival of salmon in the parr and presmolt stage. So, the answer to the question in the heading is a conditional **yes**. It shall, however, not be forgotten that other factors may have been important too, like the introduction of “catch and release fishing”.

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THE ROLE OF THE HYDROLOGICAL FACTORS IN THE FORMING OF BIOLOGICAL QUALITY OF THE MEDIUM-SIZED LOWLAND STREAMS

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ABSTRACT

The development of biological communities is an important research topic, especially in regard to the biological quality elements prescribed by the EC Water Framework Directive (Directive 2000/60/EC, 2000) – algae, macrophytes, benthic invertebrates and fish. At the same time it is still uncertain how different organism groups are affected by different environmental variables. For this purpose study of high-quality sites of medium-sized lowland streams, typical for Latvia, Ecoregion - Baltic province, was carried out with the emphasis of hydrological characteristics. We found that level of saprobity according benthic macroinvertebrates was linked mainly with substrate type. The development of benthic diatoms on a soft substratum was connected with altitude, distance from the source and also stream width. There were no significant correlations between macrophyte trophic indices and environmental factors connected with stream hydrological conditions. European Fish Index was influenced mainly by stream width and distance from the source that agree with results of other researchers. In general, direct or indirect role of hydrological factors was evident in the forming of biocenotic elements structure that characterizes stream biological quality.

INTRODUCTION

The EU Water Framework Directive (Directive 2000/60/EC - Establishing a Framework for Community Action in the Field of Water Policy, WFD) defines the aim to reach good status of European waterbodies till 2015. For this purpose the assessment of biotic indicators (macrobenthic fauna, fish fauna and aquatic flora) as main water quality elements was put into focus for all hydroecosystems, including rivers and streams. Stream ecosystems are structured by abiotic (e.g. physico-chemical), biotic (e.g. predation) or by a combination of abiotic/biotic factors, and the role of hydrological factors is of primary importance. At the same time it is still uncertain how different organism groups are affected by natural hydrological variables.

The aim of this study was to analyse results obtained in the project "Standardisation of River Classifications: Framework method for calibrating different biological survey results against ecological quality classifications to be developed for the Water Framework Directive" (STAR) from high-quality sites of medium-sized lowland streams, typical for Latvia, Ecoregion 15 (Baltic province). In total, for this study 27 sites with an utmost high ecological status from three river basins were sampled. About 40 environmental parameters, including stream hydrology, were analysed. For the assessment of biological quality a lot of different indices were calculated.

In this study we analyzed the role of hydrological factors in the forming of biological quality elements in the high quality stretches of streams.

MATERIAL AND METHODS

27 sampling sites were selected considering criteria for reference sites selection according STAR field protocols (Furse et al., 2006). From about 40 parameters of the STAR Site protocol we analysed discharge, and also stream width, altitude, gradient slope, distance from source and substrate that are strongly connected with stream hydrological regime.

Sampling and sample processing was done according to STAR protocols (http://www.eu-star.at/frameset.htm). Sampling of benthic invertebrates and diatoms was performed during spring to early summer in 2003. Macrophytes were sampled in July 2003, and fish from July to September 2003.

Laboratory processing of benthic macroinvertebrates, benthic diatoms, macrophytes and fish were carried out according STAR approach (Furse at al., 2006), and metrics of macrophytes, benthic invertebrates, benthic diatoms on soft (sand, silt) and hard (pebbles, cobbles etc.) substrata were calculated centralized by STAR project groups. European Fish Index (EFI) developed by the FAME project was provided by FAME project (http://fame.boku.ac.at). In this study, Mean Trophic Rank (MTR) (Dawson et.al., 1999) and Macrophyte Biological Index for Rivers

(IBMR) (Haury et.al., 2002) were used as macrophyte trophic metrics, and also macrophyte coverage was analysed. For benthic diatoms Trophic Diatom index (TDI) (Kelly and Whitton, 1995), for benthic invertebrates - Saprobic Index (SI) (Zelinka and Marvan, 1961), and for fish - EFI were selected as indices characterizing stream biological quality.

The links between biological and hydrological characteristics were evaluated by Pearson correlation coefficients calculated by SPSS 12.0.1. Streams were grouped for width (1 = <1m, 2 = 1-5m; 3 = 5-10m; 4 = 10-20m; 5 = >20m) and substrate (1 = pebble/gravel; 2 = sand; 3 = silt).

RESULTS AND DISCUSSION

The importance of environmental variables for the biological quality elements is investigated quite largely, and it is stated that the strength of observed patterns depends on the extent to which various mechanisms act in concert; clear patterns arise when several processes act in one direction, and in general observed patterns can have multiple explanations (Gaston, Blackburn, 1999). Different taxonomic groups show different relationships to environmental gradients, leading to relatively low levels of concordance (Muotka et al., 2004). Thus the question is what a relative role of each environmental factor is (Soininen, 2004). It is found, that the impact of environmental variables to biodiversity indices is stronger for small-bodied organisms (benthic diatoms, benthic macroinvertebrates), followed by large bodied organisms (macrophytes and fish) and differed by basins (Briede et al., 2004).

Not many investigations exist in high quality sites of medium sized lowland streams that are typical for Eastern Europe concerning all biological quality elements – fish, macrophyte, benthic macroinvertebrates and diatoms - demanded by WFD.

In our study we summarized information on indices characterizing stream trophic and saprobic level by all these organism groups (Table 1).

Table 1. Values of biological quality indices - European Fish index (EFI) Mean Trophic Rank (MTR), Macrophyte Biological Index for Rivers (IBMR), Saprobity index (SI), Trophic Diatom index on soft (TDI_S) and hard (TDI_H) substratum - in high quality reaches of medium sized lowland streams.

Groups of organisms and biological quality indices	Range	Mean ± Standard Deviation
Fish - EFI	0.2 – 0.6	0.4 ± 0.1
Macrophyte - MTR	28.3 – 60.0	41.9 ± 7.4
Macrophyte - IBMR	8.1 – 15.0	10.7 ± 1.4
Benthic macroinvertebrates - SI	1,3 – 2.7	1,9 ± 0,3
Benthic diatoms – TDI_S	48.1 – 76.8	64.3 ± 7.3
Benthic diatoms – TDI_H	25.9 – 76.8	56.7 ±13.8

The structure of benthic invertebrate communities is recognized as a conservative measure of water quality (Leland, Fend, 1998), and opinion exists that discharge (channel width, depth, current velocity) frequently plays an overriding role in the regulation of development of benthic organisms in general (e.g. Hart and Finelli, 1999). Species distribution of macroinvertebrates in running water of Finland is also mostly related to channel width as well as conductivity and pH (Soininen, Könönen, 2004). Our previous study shows that biodiversity of macroinvertebrates could be connected with such parameters as water hardness, alkalinity, chloride, slope, stream velocity and oxygen that are linked with river basin genesis (Springe et al., 2006). In this study we found that correlation exists between Saprobity Index that characterizes organic pollution and substrate composition (Table 2). That is not surprising as larger content of organic matter is typical for slower river stretches where sediments are represented mainly by silt or silty sand.

The development of benthic diatoms (phytobenthos) in streams is determined by discharge and other complex of local and larger scale regional (catchments, ecoregions) factors (e.g. geology, topography, climate) (Poff 1997). In general, diatoms are considered to be good indicators of changes mainly in water chemistry (Steinberg and Schiefele, 1988; Soininen and Könönen, 2004), but variation in diatom species are also found to be closely attributed to such geographical factors as latitude and altitude (Potapova and Charles, 2002). This investigation confirms that in general the most obvious connection was between TDI on soft substratum and altitude and distance from the source (Table 2). On soft substratum stream width also has some impact to TDI. It corresponds with findings of Potapova and Charles (2002) as well as our previous study (Springe at al., 2006) revealing that diatoms biodiversity had stronger correlations with environmental factors than that of other biological quality elements.

According the presence and development of macrophytes in unshaded lotic systems the hypotheses is proven that they are primarily controlled by the hydrologic regime (Biggs, 1996, Riis and Biggs, 2003). Hydrological conditions and substrate can be major determinant for many taxa (Dawson, 1988, Westlake, 1975; Haslam, 2006). Hydraulic patterns affect macrophyte growth and morphological phenotypes directly, and also indirectly (e.g., at low flow rates). Higher discharges and wider reaches are associated with species richness (Baatrup-Pedersen et al., 2006). In our case, we didn't find significant correlations between macrophytes trophic indices and environmental factors connected with stream hydrological conditions (Table 2). It could be explicable that all of analysed sites belong to an utmost high ecological status and are poor in macrophyte species (from 1 to 20 per stretch). At the same time there was some relationship between macrophyte coverage and type of substratum like as for diatoms.

Investigations of fish community in relation to environmental variables reveal a role of different factors contributing to fish distribution such as altitude, distance from the source, stream width, substrate (Jowett and Richardson, 2003), flow (Lammert and Allan, 1999). Distance from the source, altitude and surface of catchment area (km^2) could explain 70% of the total variation in fish species richness (Mastrorillo et al., 1998). Our previous findings linked fish biodiversity mainly with stream morphometry (slope, altitude, maximum depth) and substrata (Springe et al., 2006). This study revealed that EFI in high-quality sites is influenced mainly by stream width and distance from the source (Table 2) that agree with results of other researchers.

In general, direct or indirect role of hydrological factors was evident in the forming of biocenotic elements structure that characterizes stream biological quality.

Table 2. Pearson linear correlation coefficients among biological quality indices (Saprobity index, Trophic Diatom index TDI, European Fish index EFI, Mean Trophic Rank MTR, Macrophyte Biological Index for Rivers IBMR) and parameters linked with stream hydrology.

	Altitude (m)	Width	Slope (%)	Distance of source (km)	Discharge (l/s)	Substrate	Saprobity index	TDI HS[1]	TDI SS[2]	EFI	IBMR	MTR
Altitude (m)	1											
Width (m)	-0,172	1										
Slope (%)	0,338	-0,272	1									
Distance of source (km)	-,603(**)	,502(**)	-0,252	1								
Discharge (l/s)	-0,126	,394(*)	-0,379	0,302	1							
Substrate	-0,193	0,103	-,508(**)	-0,058	0,127	1						
Saprobity index	-0,21	-0,264	-0,238	-0,074	-0,262	,485(*)	1					
TDI HS	-0,339	-0,009	-0,231	0,325	0,014	0,054	0,054	1				
TDI SS	-,581(**)	0,38	-0,16	,471(*)	0,217	0,264	-0,04	,439(*)	1			
EFI	-0,28	,445(*)	0,067	0,299	0,188	0,07	-0,086	0,31	,475(*)	1		
IBMR	-0,12	0,114	-0,029	0,091	0,013	-0,012	-0,244	0,255	0,192	0,348	1	
MTR	-0,103	0,171	0,002	0,112	0,098	-0,028	-0,286	0,162	0,221	,424(*)	,946(**)	1
Macrophyte cover %	-0,265	0,081	-0,172	-0,213	0,101	0,226	-0,084	-0,324	0,008	-0,017	0,019	0,027

*) $p < 0.05$; **) $p < 0.01$. N = 27

[1]HS - hard substratum
[2]SS - soft substratum

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PROPOSALS FOR RESTORATION OF REGULATED DOVINĖ RIVER, LITHUANIA

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ABSTRACT

In year 2003 PIN/Matra project “Management and Restoration of Natura 2000 sites through an Integrated River Basin Management Plan of the Dovinė River”, financed by the Netherlands Ministry of Agriculture, Nature and Food Quality, was started in Lithuania. The main project objective was to produce an Integrated River Basin Management (IRBM) and Restoration Plan as a framework for tuned and co-ordinated planning and design of water management, river and wetland restoration activities, nature management, the development of sustainable agriculture and fish breeding in the Dovinė River Basin (total area 588.7 km^2). Being a modified river (dams, canalised and large-scale melioration works in the 80-ties of the last century) the Water Framework Directive (WFD) requires the restoration to the reference conditions. Both the obligation to maintain the favourable conservation status of the Žuvintas Lake, adjacent wet grasslands and bogs (based on the Habitats Directive) and the obligation to restore the reference situation of the Dovinė river (according to the WFD) make the area an excellent pilot for integrating of the protection and restoration of nature values of European significance into integrated river basin management. IRBM Plan of the Dovinė River was finalized in the year 2006. The programme of measures is presented in the article.

INTRODUCTION

The implementation of the Birds and Habitats Directive and the Water Framework Directive has a far reaching impact on both nature management and water management in the EU member states. Although all three Directives aim at improving ecological conditions the implementation of the Birds and Habitats Directive on the one hand and the Water Framework Directive on the other hand is often poorly coordinated which can result in conflicting objectives and management measures for water bodies in particular. The management objectives for the EU WFD are based on ecological reference situations for similar water bodies across the country, while the management objectives for the EU Birds and Habitats Directive are based on maintaining or achieving the so called “favourable conservation status”. The following report describes the results of a demonstration project in the Dovinė River Basin in Lithuania where an effort was made to elaborate management recommendations to achieve both favourable conservation status for habitats and species as required by the Birds and Habitats Directive and to achieve good ecological status of water bodies following the Water Framework Directive. The Dovinė River Basin was selected as demonstration area because it is a relatively small basin and it holds one of the most important and meanwhile most threatened Nature Reserves of Lithuania, the Žuvintas Lake.

In 2003 the PIN/Matra project “Management and Restoration of Natura 2000 sites through an Integrated River Basin Management Plan of the Dovinė River” (Lithuania), financed by the Netherlands Ministry of Agriculture, Nature and Food Quality, started. The overall purpose of the project was to produce a Management and Restoration Plan for the Dovinė River Basin (total area 588.7 km2) as input to the Integrated River Basin Management Plan of the Nemunas River Basin District. The Integrated River Basin Management Plan of the Dovinė River was finalized in the first part of year 2006 (Zingstra et al., 2006).

Both the obligation to maintain the favourable conservation status of the Žuvintas Lake, adjacent wet grasslands and bogs (based on the Habitats Directive) and the obligation to restore the reference situation of the Dovinė river (according to the Water Framework Directive) make the area an excellent pilot for integrating of the protection and restoration of nature values of European significance into integrated river basin management. But most importantly the project provided a base for the long-term protection of the Žuvintas Lake, the re-naturalisation of the Dovinė River and the restoration of drained wetlands. Execution of the proposed plans will be partly secured through a UNDP/GEF project “Conservation of Inland Wetland Biodiversity in Lithuania”.

PROJECT SITE AND METHODICS

The Dovinė River is the right tributary of the Šešupė River in the southern part of Lithuania. Its length is 47.0 km and its basin covers a total area of 588.7 km² (Fig. 1). The Dusia Lake is the source of Dovinė River, The Dovinė flows through the lakes Simnas and Žuvintas while the other lakes are in the basins of the tributaries of the Dovinė River. Most of the surrounding areas are productive agricultural lands (productivity is higher than the average of the country). The forest cover is scarce, i.e. approximately 16 % of the area. Žuvintas Biosphere Reserve was established on the basis of

Žuvintas State Nature Reserve (founded in 1937), both Žaltytis and Amalvas botanical-zoological reserves, during the implementation of the international Biosphere monitoring program in 2002. The total area of the Biosphere Reserve is 18489 ha.

Figure 1. Location of Dovinė River basin.

To implement the tasks of the project four working groups (WG) were established: WG on Hydrology, WG on Ecology and WG on Information and awareness raising and a GIS WG. The members of all working groups worked in close cooperation under the supervision of Project Management Team.

The Hydrology working group task was to give recommendation for adjusting the water management of the Dovinė River in order to improve the water quality of the water flowing into the Žuvintas Lake and to naturalize the flow pattern of the Dovinė River as much as possible, as a contribution to achieve the good ecological status as required by the EU WFD.

To produce the outputs the Hydrology group carried out various activities including the gathering and analyses of water quality data and water quantity data (discharge data and groundwater data). Experts of the work group were trained in the application of the SIMGRO model (Povilaitis and Querner, 2006). To evaluate the measures for water quality improvement the Žuvintas Lake the PCLake model (Janse and van Liere, 1995) was applied. After the evaluation of collected material basic decisions and proposals were presented (Povilaitis, 2006).

PROBLEM DESCRIPTION

During the second half of the twentieth century, the water regime of the Dovinė River and river basin was significantly altered. Many rivulets were channelled, a number of dams were built, and extensive bog and fen areas were drained and meliorated.

With the growth of industry in the second half of the twentieth century a shortage of clean and fresh water in the Šešupė River near the town of Marijampolė appeared in the 1960’s. In Marijampolė, located downstream of the Žuvintas lake, the Dovinė River discharges into the Šešupė. In order to solve the lack of water in the summer, sluices-regulators were built in the

Figure 2. Hydrotechnical objects in Dovinė River Basin.

Dovinė River at the outlets of the Dusia, Simnas and Žuvintas lakes to retain and store part of spring-flood water (Fig. 2). This happened in 1968 for Žuvintas, and in 1972 for Dusia and Simnas lakes. In the lowest reaches of the Dovinė River an electric power station was built. The dams for the Dusia, Simnas and Žuvintas lakes were meant as the first stage of a water management plan for the entire area. Fortunately, other stages (redirection of water from other basins) remained unrealised. In 1992, after introduction of a sewage treatment plant, the system of retaining water in the lakes lost its value for the Marijampolė town (Gulbinas et al. 2007).

In the 80-ties of the last century, the hydrology of the area again was altered due to the execution of large scale amelioration works: a northern and southern part of the Amalvas wetland complex were drained, big sections of the Dovinė and Kiaulyčia Rivers canalised, and fish ponds established near the Simnas settlement. In addition the impact of the agricultural activities in the river valley on the water quality became more and more evident. Pollution from the Simnas town and the other villages, as well as dispersed pollution sources further deteriorated the quality of the water and accelerated the eutrophication of especially the Žuvintas and Amalvas lakes and wetland complexes.

After the construction of the water sluices-regulators, the water level fluctuation in the Žuvintas Lake has decreased from 1.2 m to only 70 cm. The average water level has decreased after the damming with about 30 cm. Now the lake is rapidly shrinking in size due to the lower average water level and the massive overgrowth of both the shore and the lake bottom. More than half of the lake surface area is covered with aquatic plants. The high nutrient concentration in the sediments is the main reasons for the massive growth of vegetation. Clearly the overgrowth of the lake is a natural process that started after the Ice Age, but it is clear that the recent nutrient pollution (especially in the 70-80'ties) and the decreased water level has speeded the process significantly.

Another process reducing the biodiversity values of the Žuvintas Biosphere Reserve was the overgrowth of the wet meadows and fens with shrubs. Through this process specific plant species and the habitat for meadow birds is disappearing. Overgrowth of the bogs with pine trees and birches is posing a threat to the specific biodiversity values of this habitat also induced by interference in the hydrology.

RESULTS

The main project objective indicated in the project proposal was to produce an Integrated River Basin Management and Restoration Plan as a framework for tuned and co-ordinated planning and design of water management, river and wetland restoration activities, nature management, the development of sustainable agriculture and fish breeding in the Dovinė River Basin.

The prepared Management and Restoration Plan for the Dovinė River Basin include:

- Proposal to stop the eutrofication and to improve the hydrological and ecological conditions of the Žuvintas Lake as a contribution to achieving the ”Favourable conservation status” of key Natura 2000 habitats and species through achieving ”Good ecological status” of the Dovinė River;
- Proposal for achieving ”Favourable conservation status” of the Žuvintas wetland areas (mire and fen areas) adjacent to the Lake and other wetlands and water bodies designated as Natura 2000 sites in the catchment of the Dovinė River;
- Proposal for the restoration of drained Amalvas wetland;
- A Geographical Information System of the Dovinė River Basin.

The Hydrology Working Group was charged to design a proposal for adjusting the water management of the Dovinė River to achieve improved water quality of the water flowing into the Žuvintas Lake and to naturalize the flow pattern of the Dovinė River as much as possible as a contribution to achieve the good ecological status as required by the EU WFD. The working group produced the following outputs: a) Proposal for adjusting water management practices (including the management of the sluices) of the Dovinė River to stop the eutrofication of the Žuvintas Lake and to achieve good ecological status and support achieving favourable conservation status of the Lake and adjacent Natura 2000 sites; b) Proposal for improved management of the Simnas fishponds to reduce the outflow of nutrients and to improve natural flow dynamics of the Dovinė River combined with the proposal to designate one of the ponds as purification pond to reduce the nutrient loads of the outflow of the pond; and c) Proposals for adjusting the water management of the Amalvas area in order to improve the ecological status of the Amalvas Lake and wetlands and optimize the restoration possibilities for the drained peatlands. The Hydrology Working Group assessed a number a scenarios to evaluate the options for achieving the goals mentioned before (Povilaitis and Querner, 2007). More detail conclusions and recommendations are presented below. All proposed measures have cartographical expression and is a part of Integrated Geographical Information System of Dovinė River Basin (Pileckas, 2006).

CONCLUSIONS AND RECOMMENDATIONS

1. Replace the three-hole sluice-gate built on the Spernia River downstream Dusia Lake with the overflow-type spill-weir along with the deposit deflection walls. The movable gate should be additionally

arranged in the middle opening for the release of environmental discharge as well as for the supplement with water of the ponds of Simnas fishery enterprise (FE) during dry periods.

2. In order to avoid accidents it is necessary to repair the main drop inlet spillway as well as small water intake structures at Kalesninkai pond.
3. For the improvement of ecological situation in the Spernia River the water discharging from the Simnas FE should be treated. For that purpose it is recommended to re-arrange the two fishery ponds into sediment and nutrient retention ponds. The Spernia watercourse should be deepened in the strip till the cemetery of the Simnas town for the release of water downstream these ponds. The watercourse downstream the cemetery should be left natural.
4. To replace the three-hole sluice-gate built on the Bambena River downstream Simnas Lake with the overflow-type spill-weir by additionally arranging fish-ladder for fish migration. The environmental discharge should be released through it.
5. In order to improve water quality in Simnas Lake it is necessary to make reconstruction of waste water treatment facilities in the town of Simnas.
6. To arrange 2 stone riffles in the strip of the Bambena River in between Simnas Lake's sluice-gates and Azuoliniai village. Such measure should be effective in particular during spring floods – the water would overflow into the river's floodplain and increase nutrient retention processes. The partition of the watercourse with riffles wouldn't be an obstacle for fish migration.
7. For the continuous measurements of water discharge in the Bambena River the automatic water level recording station should be arranged upstream the trapezoidal weir at Azuoliniai village.
8. To arrange 3 wood-made blocking walls in the 250 m long strip of the Bambena River in between Azuoliniai village and Zuvintas Lake (upstream the Kiaulycia river outlet) where the river crosses small forested area. This measure would be effective during all seasons – the water would outflow into the surrounding wetlands and would reduce the inflow of sediments and biogenic substances into Zuvintas Lake.
9. To replace the three-hole sluice-gate built on the Dovine river downstream Zuvintas Lake into the overflow-type spill-weir by additionally arranging the fish-ladder The environmental discharge should be released through it. Within the strip of 200 m downstream the sluice-gate the riverbed should be cleaned.
10. In order to create favourable outflow conditions from Zuvintas Lake as well as to improve flow hydrodynamics in the lake it is necessary to regularly remove floating vegetation in the north-western part of the

water area (near the outflow). The most proper time to do it is the end of July and August. The removed vegetation should be taken out of the water.

11. To replace the three-hole sluice-gates built on the Amalve River downstream Amalvas Lake into the overflow-type spill weirs by additionally arranging the fish-ladder. The environmental discharge should be released through it. In the strip of 50 m upstream it the riverbed should be cleaned.
12. While reconstructing sluice-gates the priority should be given by the following order: 1) The Žuvintas Lake sluice-gate; 2) The Simnas Lake sluice-gate; 3) The Dusia Lake sluice-gate and 4) The Amalvas Lake sluice-gate.

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