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Sea Level Change Affecting the Spatial Development in the Baltic Sea Region

Edited by Philipp Schmidt-Thomé

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A collection of peer reviewed articles on the results of the
INTERREG IIIB Baltic Sea Region (BSR) project
“Sea level Change Affecting the Spatial Development
of the Baltic Sea Region – SEAREG”.

The project was co-financed by the European Regional Development
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The BSR Interreg IIIB project "Sea Level Change Affecting the Spatial Development of the Baltic Sea Region" (SEAREG) aimed at strengthening the linkages from climate change to planning and decision-making and at enhancing adaptation to climate change. In the scope of the project, existing global climate models from the International Panel on Climate Change (IPCC) were first downscaled to the Baltic Sea Region and selected case study areas, and then combined with topographical data.

The resulting scenario maps of potential coastlines changes and flood prone areas were then analysed together with various relevant actors to discuss potential impacts on the territory, referring also to the socio economic system and development. The results of this process were structured in a set of tools, the Decision Support Frame, to better bridge the gap between climate change models and spatial planning by integrated scenario interpretation.

The intensity and the sort of impacts that might affect the Baltic Sea coastal area will largely differ depending on the location of the assessed area. Generally, the northern part of the Baltic Sea Region faces a smaller problem of sea level rise as the postglacial rebound lessens its impact. Whereas northern Scandinavia still rebounds up to 9 mm/year, there is a subsidence of about 1 mm/year in some parts of the southern Baltic Sea coast. Land loss caused by inundation can be negligible in sparsely populated areas; however, for areas with a high population density and development areas for housing close to the shore, a similar land loss will be much more serious.

The Decision Support Frame aims at guiding and supporting the discussion between the relevant planner and other stakeholders in defining necessities and possibilities of mitigation strategies. The Decision Support Frame found strong support from local and regional spatial planning authorities that can thus lead to timely decisions on integrated mitigation strategies.

Key words (GeoRef Thesaurus, AGI): climate change, sea-level changes, transgression, floods, coastal environment, risk assessment, regional planning, Baltic Sea.

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FOREWORD

This publication presents the final results of the INTERREG IIIB Baltic Sea Region project "Sea Level Change Affecting the Spatial Development of the Baltic Sea Region – SEAREG". The Project was part financed by the European Union (Regional Development Fund - ERDF), and developed the steps from downscaling of climate models, regional and local scenario applications towards subsequent discussions with regional stakeholders, and finally assessing the potential impacts of sea level rise in case study areas.

The project developed around the idea to involve spatial planners and other stakeholders into the discussion and the assessment of climate change impacts. Since planners are not usually confronted with the topic of climate change, the project developed methods and materials to illustrate and communicate both the potential impacts as well as the uncertainties of climate change impact research and assessment.

The project was very successful, as it was able to start a communication process on climate change impact in the case study areas presented here. Nevertheless, this project was only a first start on an integrated climate change impact assessment on spatial development, much more activities in this sector are needed in the future. The project group hopes to have constructively contributed to the discussion and to the development of climate change mitigation strategies.

Philipp Schmidt-Thomé

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SEA LEVEL CHANGE ASSESSMENT IN THE BALTIC SEA REGION AND SPATIAL PLANNING RESPONSES

by
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The impacts of climate change on human settlements and spatial development are an important issue on the European agenda. One effect of a warming climate is the elevation of the mean sea level, which has differing effects depending on the location. To facilitate the process of applying sea level change scenarios in spatial planning in the Baltic Sea Region, the communication between involved scientists and stakeholders was structured around the task of developing a set of tools called the "Decision Support Frame", which facilitates the process of inquiry and communication. Through this process, detailed integrated assessment of climate models and sea level change scenarios can lead to an understanding of the possible impacts of climate change and support spatial planners and other stakeholders in making the necessary conclusions and defining response strategies.

Key words (GeoRef Thesaurus, AGI): climate change, sea level changes, transgression, coastal environment, risk assessment, regional planning, Baltic Sea.

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1 INTRODUCTION

Climate change adaptation, defined as "adjustments in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects or impacts" (Smit et al. 1999), has entered the arena of climate policy agenda relatively recently (Pielke Jr. 1998). Since adapting to and mitigating climate change are not mutually exclusive strategies, it has become apparent that the linkages from climate change to planning and decision-making are underdeveloped despite the growing need for appropriate strategies. This article summarizes results from the BSR INTERREG IIIB project "Sea Level Change Affecting the Spatial Development of the Baltic Sea Region" (SEAREG), co-financed by the European Development Fund (ERDF), which has explored connections between climate change induced sea level rise and planning concerns at local and regional levels in the Baltic Sea Region. In the scope of the project, existing global climate models from the International Panel on Climate Change (IPCC) were first downscaled to the Baltic Sea Region, and then combined with topographical data. The resulting scenario maps of potential future coastlines and flood prone areas were then analysed together with various relevant actors to discuss the territorial impacts. The results of this process were structured to better bridge the gap between climate change models and spatial planning by integrated scenario interpretation. The approach found strong support by local and regional spatial planning authorities and can thus lead to timely decisions on integrated mitigation strategies.

This article discusses the possibilities of applying sea level change scenarios in spatial planning with a set of tools called the "Decision Support Frame". The "Decision Support Frame" (DSF) structures research efforts and provides an interface between research and practice to demonstrate the connections between climate change induced sea level rise in the Baltic Sea Region and planning concerns on local and regional levels. The DSF also builds on an idea of a communication process, which it seeks to facilitate. It includes guidelines for communication between different stakeholders and provides information and case study examples to demonstrate the interactions between the changing global climate and local planning, showing the eventual necessity of drawing conclusions for mitigation strategies.

2 METHODOLOGY

During the Earth's approximately 4.5 billion year long history, the climate has been constantly changing. There have been both colder and warmer periods than present, and thus it is hardly possible to talk of a "normal" climate (Berner & Streiff 2000). The climate we have experienced over the last 100 years is only a certain type of climate that is perceived as "normal". Its normality is thus relative to our own temporal horizon. However, our ancestors 10 000 years ago experienced a totally different climate that was much colder than present. During the last ice age glaciers covered most areas of northern Europe. This last ice age also contained interstadials with a climate warmer than present. The climate is a product of a variety of inter-related factors, such as the atmosphere, oceans, geosphere and cryosphere (e.g. glaciers). On a regional scale, the climate has sometimes changed rapidly in merely a few decades. For example, the temperature in Northwest Germany rose 5 - 6˚C in 5 -15 years after the last glaciation period (Berner & Streif 2000).

More recent studies on climate change, for example by the Intergovernmental Panel on Climate Change (IPCC), show that there is little doubt that the Earth's climate is warming up (e.g. Church et al. 2001). IPCC also draws clear conclusions on a changing climate and rising sea levels (Church et al. 2001). Hassol (2004) analyses the environmental and socio economic effects of the warming climate of the Arctic. The publication lists the impacts of climatic changes that occurred in the last hundred years and draws scenarios on the expected warming of 4-7˚ C in the 21st Century. A rising sea level is only one of the many effects. Since the northern half of the Baltic Sea Region belongs to the boreal zone, the climate and vegetation zone neighbouring the arctic, large climatic impacts can be expected here, too.

The question is, at what speed and to what extent will the climate in the Baltic Sea Region get warmer in a certain time period, for example in 100 years. The SEAREG project provides information about the trends in climate change and thus helps to delineate the areas that could be affected by impacts like sea level rise and/or changing flood patterns in such a time scale.

In general, "modelling" means simplifying complicated contexts and/or processes to understand them better. Thus, many details of a complex system, such as the weather, are reduced to their basic functions. In this way, it is possible to understand how a system works and to analyse how changes in its basic parameters can lead to future changes in the system (Buchanan 2001).

Climate modelling uses reference climate models for future assumptions. In the SEAREG project, a "time slice" of thirty years was chosen as a reference (1961-1990). According to simulated trends in the changing climate resulting from the simulations using global coupled atmosphere-ocean models, the same time slice with its characteristics is projected 100 years into the future. Climate projections take socio economic development trends and future greenhouse gas emissions into account. According to the assumptions the model is fed with different climate change scenarios and resulting impacts are obtained, such as sea level rise trends.

When several scenarios yield similar results in different calculations, one can assume that the calculated scenarios show reliable trends. These trends give a picture on how the climate changes in the future and the possible impact on the living conditions of human beings. Due to multiple uncertainties related to the future climate, it is impossible to predict future events precisely; nobody can say how much the sea level is exactly going to rise. To address this uncertainty, the SEAREG project delivers 3 different sea level rise scenarios, ranging from "low case" to "high case". The difference between scenarios and predictions is that scenarios do not have probabilities attached to them. Thus, the "low", "middle" and "high" do not refer to points in a probability distribution. Rather, they all represent possible futures.

Within the SEAREG project, data from global general circulation models are downscaled to a regional scale. Two global circulation models (GCMs) have been used to represent the recent climate (time slice 1961-1990). These two control simulations are used as a calibration base for producing four future climate change scenarios. The climate change is assumed to be influenced by changing anthropogenic emissions of greenhouse gases. These greenhouse gas emissions are based on models of the future socio economic development and are applied to the time slice from 2071 to 2100. One of the scenarios assumes larger and continuously increasing emissions of the major anthropogenic greenhouse gases while the other scenario predicts a slower increase of these emissions. Both scenarios predict a temperature rise ranging between 2.4ºC and 3.4ºC, depending on the global general circulation model used (Meier et al. 2004 and Meier et al. 2006, *this volume*).

While the signals from climate research point to a need to take climate change into account in decision-making, sea level rise scenarios will not be automatically adopted as guidelines for planning or decision-making. To bridge the gap between climate change modelling and decision-making processes a set of tools, the Decision Support Frame (DSF), was developed. The term "Decision Support Frame" was chosen to mark a difference to the often-used term "Decision Support System". Decision Support Systems are mostly used to describe highly technical and increasingly sophisticated computer based processes that draw from multiple databases and then calculate optimal choices of action from a set of alternatives (e.g. Shim et al. 2002). The aim of the DSF structure has not been to recommend paths of action but rather to illustrate the process of learning about local and regional vulnerabilities to sea level rise.

According to Smit et al. (1999), the key to adaptation science is to address climate-related stimuli (real or expected effects) that are clearly related to the sensitivity of the systems at stake. Consequently, Smit et al. (1999), argue that, questions on *who* adapts to *what* and *how* should be asked. Answering these questions requires defining both the climate-related stimulus or stimuli and the sensitive system that needs to adapt. The how question refers to processes and methods of adaptation (Schmidt-Thomé, K. & Peltonen 2006, *this volume*).

In the scope of the SEAREG project, the "adaptation to what?" question, pointing to the climate-related stimulus, was narrowed down to the effects of sea level rise due to climate change. This was done deliberately, understanding the need to focus on a clearly defined issue within a complex set of climate-related (coastal) events (e.g. precipitation and flooding in river systems). At first, the focus was mainly on mean sea-level changes but extreme events were also addressed by the project, due to their importance for local and regional planning. The "who adapts?" question was delineated through the GIS and impact studies as local and regional human settlements. The adaptation of ecological systems, for instance, was secondary. Initial answers to the third question on adaptation – "how adaptation should occur?" – were given through analysing system sensitivities, for example, the "hotspots" identified in the vulnerability assessments in different case study locations. Even if direct recommendations where not made, the analysis served to link different stakeholders to the hotspots, thus pointing to networks which actually or potentially hold knowledge for adaptation (Schmidt-Thomé, K. & Peltonen 2006, *this volume*).

The SEAREG Decision Support Frame (DSF) thus came to serve three main purposes. First, it provides a framework to answer the who-adapts-to-what-and-how questions. Second, within the project organisation, it provides an umbrella for integrating the multidisciplinary research within the project. Local case studies, despite their heterogeneity, followed the overall structure of the different DSF elements. Third, the DSF is used as a format for presenting the project results. It serves as a "user interface" between research and practice, providing easy-to-access information on SEAREG to planners, decision-makers and other interested parties in the Baltic Sea Region.

The DSF is structured in a four-pillar matrix, representing the main tasks and tools that are necessary to communicate the sea level scenario building and analysis on a scientifically interdisciplinary basis; in cooperation with spatial planners, as well as decision makers and other stakeholders. The key factor to address the socio economic system of an area and mitigate negative impacts of climate change is determined by the coping capacity. The Knowledge Base element includes available background information of legal and planning aspects. As well, it gives precise, short overviews on the current stage of climate change studies and serves as a platform to find examples of other study areas and best practices in climate change impact mitigation strategies. The fourth column, the Discussion Platform, is the tool that supports co-operation by providing examples and methods of the roles and interests of the involved actors and networks.

3 APPLICATION OF THE DECISION SUPPORT FRAME

During the project, multidisciplinary components were integrated as follows: First, sea level change scenarios were plotted into topographic and land use maps, creating thematic Digital Elevation Models (DEMs) with sea level rise and flood scenario data. The researchers in the project then analysed these jointly with planners and other stakeholders to assess vulnerabilities of the spatial systems. This interdisciplinary dialogue supported an interactive communication process among the involved parties who gained knowledge on other stakeholders' concerns. Scientists, for example, improved their understanding of the kind of information needed in planning and decision-making and how it should be communicated. On the other hand, stakeholders were able to broaden their insights into the possibilities and constraints of climate change scenarios and their applicability in planning. The steps from climate modelling via spatial vulnerability assessment to planning support are displayed in the DSF structure (See Figure 1).

Considering that all involved parties have different approaches and interests, both in their professional field and in shaping the living environment, the DSF approach is transparent to all views and flexible enough to facilitate mutual understanding. While climate scientists may be mostly interested in the outcomes of climate models and cannot make definite conclusions about the future impacts of climate change, planners and decision-makers prefer to have clear values and probabilities of sea level rise, for example, in mm/year to draw up the next stage of land use plans. Other stakeholders, such as repre-

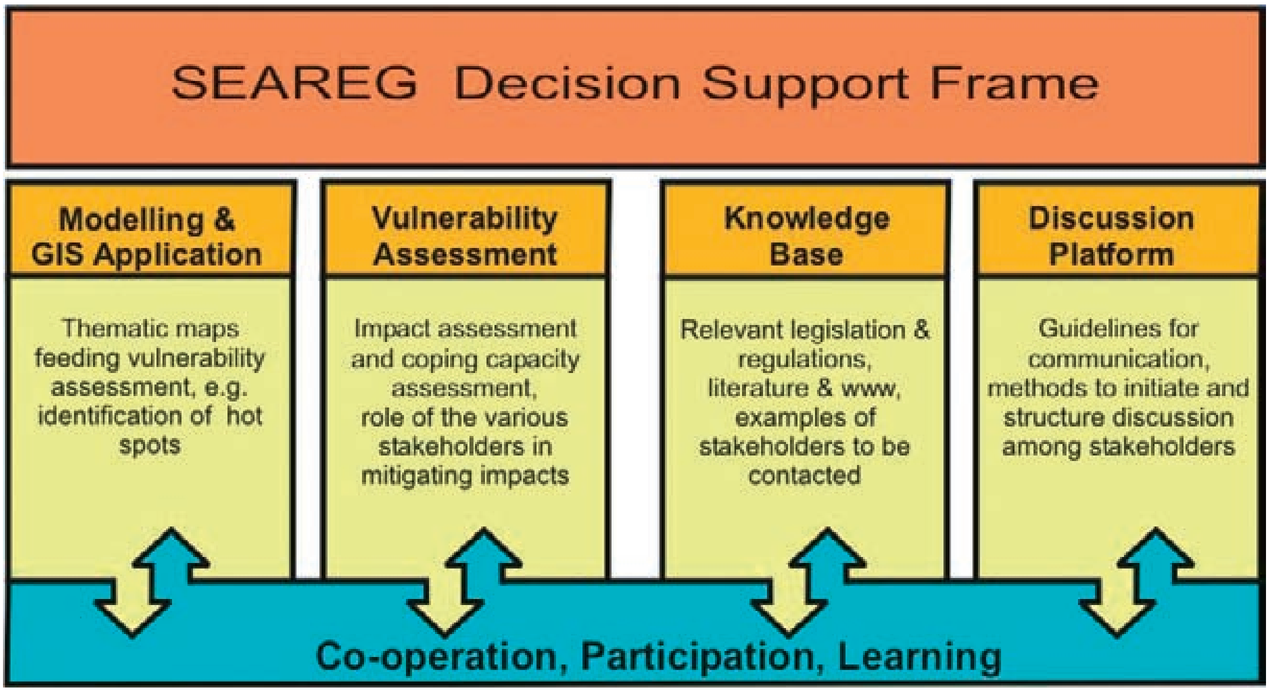

Fig. 1. The Decision Support Frame (L. Peltonen, P. Schmidt-Thomé & J. Klein).

sentatives of the tourist industry, must know about the safety of investments while decision makers might be more concerned about infrastructural aspects and the overall development of a region. The SEAREG project did not enter the discussion of producing information for legally binding local land use plans. The intention was first to raise awareness among planners and to discuss how sea level change information could be added into the planning perspective on a general level. The further development of the DSF to define, for example, new minimum construction elevations above mean sea level, has to be further discussed among stakeholders.

The results of the research carried out under the DSF structure were rearranged as a user interface for planners and other interested parties for easy access to the project results (www.gtk.fi/slr). The elements of the DSF were interlinked using an interactive format resembling a www-page. The interface combines climate modelling results and GIS applications, providing the visual basis for the communication process on sea level change. The elements derived from the vulnerability assessments display actual land use patterns and the environment of an area, which serves to evaluate the impact of sea level changes. The DSF interface also allows for easy comparisons between different case study locations.

The ensemble of different DSF elements thus provides an integrated research frame and user interface that helps planners and decision-makers from the participating case study areas to learn about their respective situations and compare them with other areas around the Baltic Sea Region. The SEAREG DSF is also a pedagogical tool, which can be used to demonstrate different aspects of climate change, sea level rise and related planning problems to decision-makers and the broader public (Schmidt-Thomé, K. & Peltonen 2006, *this volume*). It can be seen as a tool for organisational learning (Bhatt & Zaveri 2002). As such, it allows for bridging between expert and lay views and thus helps communicate the problem between different stakeholders.

In the case of sea level rise discussion, it is vital to present the scenarios in maps to obtain spatial overviews of the territorial extent of changing shorelines and flood prone areas. The visualization of the sea level rise scenarios and its probable impacts adds a spatial dimension to the current discussion on climate change and thus supports the decision making process of cities and regions. Due to the spatial variation of climate change effects, it is crucial for any adaptation strategy that spatially specific scenarios can be used.

The set of sea level change maps that is used depends on both the availability of data and the research target. While topographic maps show the extent of low lying areas and delineate, for example future flood plains, land use maps can reflect the impacts on the environmental and socio economic system. By displaying current land use patterns, it is possible to spatially assess the present socio economic system of the living environment. For example, it is possible to estimate the impact on coastal nature protection zones that might be inundated in the future. These nature protection zones could be important for the local economic structure (e.g. tourism) and it may be appropriate to delineate future coastal protection zones at an early stage, before potential areas are assigned to other land use types. Another example is the location of aquifers used for drinking water. Water wells might have to be closed because of decay in quality due to seawater intrusion. This type of information can have an important impact on the land use plans of an area, as climate change impacts can be taken into account at a early stage. The analysis of local and regional assets at stake is summarized in the vulnerability assessment of the SEAREG project (Klein & Schmidt-Thomé 2006, *this volume*).

To give a full picture on the extent of sea level change scenarios, the SEAREG project produced three different map sets on each case study area. These map sets contain information on the extent of sea level change in “low case”, “ensemble average” and “high case” scenarios. It is important that all three map sets are analysed in parallel to maintain the entire picture of possible sea level changes. Even though it might appear as the most appropriate solution, the SEAREG project does not recommend the single use of any scenario. The scenarios show a range of possibilities but not probabilities. The high range of uncertainties in global climate change modelling impedes the calculation of probabilities.

4 ASSESSMENT OF SEA LEVEL RISE SCENARIOS WITH STAKEHOLDERS

Spatial planners and other stakeholders of the case study areas were first contacted with general information material on the project, followed by more detailed questionnaires. When the first interview rounds started, it became clear that the approach to first send questionnaires was time saving from an organizational point of view but impractical in the applied approach. As most planners were confronted with climate change issues for the first time, it was of great importance to explain the scenarios and the contents of the questionnaires in detail before being able to start the discussion on a more detailed level. The SEAREG project has experienced a wide range of reactions towards these scenarios, as described in the case study area articles in this volume. Meanwhile some planners rapidly said that they would like to apply the high case scenario to have the "highest probability" of being above the future sea level, other planners consistently asked for probability calculations because it would not be feasible to talk about mitigation on the base of three different scenarios. The goal of the SEAREG project, to contribute to the climate change discussion and offer a tool for communication, was thus achieved. In practice, the DSF has to be developed further within the case study areas to take sea level rise into account in spatial planning. It has to be evaluated on a very local scale which mitigation options are politically and economically most viable.

Once the framework of the project and the constraints of the scenarios were clarified, the interest and cooperation of the planners increased as the main understanding of the perspectives and the opportunities of the scenarios became clearer.

The experiences from the first interview rounds revealed the need for a more structured approach in discussing sea level change scenarios with spatial planners and other stakeholders. A solid communication process structure is important, especially with regards to the large amount of assumptions and uncertainties in scenario building. In this way, climate change scenarios can be communicated to a broader audience to find possibilities of applying the results in spatial planning practices.

Spatial planning involves a large amount of different interest groups. Financial issues play an important role, as monetary values and investments are important for the socio economic development of regions. While some investors might only be interested in short term profit, planning in general has to be oriented towards long-term sustainability. Climate change issues are especially sensitive because the time frame of impacts is extensive (100 years in the SEAREG projections) and difficult to verify at an early stage. Even if the long time scale does not necessarily comply with the time scales of investment (and profit) and political decision-making, the 100 years perspective is relevant for spatial planning, due to the durability of physical infrastructure and its path-dependent character, providing a "scaffolding" for other constructs.

Dealing with the uncertainties of climate change poses challenges for the communication processes concerning sea level rise. For instance, if the results of sea level change scenarios are communicated in a "worst case scenario" way only, investors might rather withdraw from development projects. On the other hand, the "worst case scenarios" should be taken into account to allow preparing for the worst. Not to give the "worst case scenario could" also be seen as withholding information that is crucial for public safety. Cities and regions that are currently starting to lay out new coastal development areas should do so with state-of-the-art of sea level information. The sensitivity of climate change and sea level information can be easily understood when thinking of areas that have recently invested in coastal development but neglected climate change as an issue. In such situations, new information on sea level rise may even be seen as a threat that could jeopardize ongoing development.

Issues such as these were the topics of discussions organised by the SEAREG project around the Baltic Sea in coastal cities and regions. The results and methods of these discussions have been formulated as an element dealing with communication issues under the Decision Support Frame. This element has been fully developed and applied in Helsinki, where multiple rounds of discussions were held with different participants (Lehtonen & Peltonen 2006, *this volume*). In the other case study areas, smaller rounds of discussions and interviews were held, which always involved spatial planners.

During all interviews and discussion rounds, the feedback to the project's approach was considered innovative and welcome. Many stakeholders and planners who participated in the round table discussions and interviews had earlier knowledge of climate change as a discussion topic, but this was first time that they encountered a deliberate attempt to find interrelations between global climate change and local realities concerning spatial planning. Most of the interviewed actors were confronted with climate change scenarios from a professional point of view and not via the media for the first time. For some stakeholders, it was also a first encounter with sea level rise impacts in their respective region. Sea level changes in the Baltic Sea Region are quite common. The sea is rather young, as it was formed after the last Quaternary glaciation period (Kallio 2006, *this volume*).

Discussions with stakeholders and decision makers while developing and applying the DSF were manifold and very helpful to better understand the possibilities of applying climate scenarios in decision-making processes.

There was a very positive approach in the case study area of Itä-Uusimaa to the SEAREG project and the DSF from the start. The area has a comparatively low population density, and the planners expressed the opinion that they would prefer the "high case" sea level rise scenarios for future development plans. Thus it could be ensured that if further investments and construction were allowed only above the projected sea level of the "high case" scenario, these would be "on the safe side", and planners would not have to fear any advert sea level rise consequences in the future. In general, Itä-Uusimaa can expect rather low impacts from sea level rise as most of the area is high enough above sea level. Nevertheless, there are certain hotspots, especially in connection with contaminated soils, but the local coping capacity to deal with these problems appears to be rather high (Virkki et al. 2006, *this volume*).

In Helsinki, regulations to meet probable sea level rise effects have already been taken into account with regards to future building projects. The renewed versions of the building code have set increasingly strict limits for minimum construction heights above sea level. Excluding the old settlements in Helsinki and the surrounding Uusimaa region, the area expects rather low impacts, as the coastal morphology is not very vulnerable to sea level rise. Structural problems might arise during winter storms, especially concerning sewage and the heating systems. These problems were mentioned in interviews with local stakeholders while applying the DSF. The DSF was welcomed by stakeholders and decision makers and the project was contacted by the City of Helsinki after the winter storms in January 2005, which nearly flooded some new housing construction sites (Lehtonen & Luoma 2006, *this volume*).

The results of the DSF for Stockholm and the Mälaren County were that the entire area would not have any severe problems from sea level rise. As Graham et al. (2006, *this volume*) report, the climate change problems for Stockholm lie rather in an expected increased runoff from Lake Mälaren rather than sea level rise. Climate change might lead to more precipitation in northern Europe (Meier et al. 2006, *this volume*). The runoff from the Lake Mälaren into the Baltic Sea is strongly regulated by sea locks in downtown Stockholm. The locks reach their discharge maximum during higher runoffs in winter so that a reconstruction of these locks should take increased runoff patterns into account. The Mälaren Flood Group was rather open to the DSF approach and the cooperation with Swedish planners worked well (Viehhauser et al. 2006, *this volume*).

The problems of sea level rise might have stronger impacts in Pärnu (Estonia), as the area is low-lying. The effects of winter storms were studied in January 2005, when the storm surge reached 1m above the 100-year flood level (Klein & Staudt 2006, *this volume*). This flood led to severe erosion problems along the regional coastline. One beach was eroded up to 12m inland. The city could also face infrastructural problems by sea level rise as many inhabitants have wells for their drinking water supply and are not connected to the sewer system. Some of the aquifers have already been shut down due to increasing salinity (Klein 2004). The application of the DSF found local interest to identify possible mitigation strategies.

In Gdansk (Poland), the DSF found strong support from the local city planning administration once the sea level change scenarios were plotted into digital elevation models. The local geologists were concerned about the effects of sea level rise at a very early stage, as Gdansk is a low lying area that has already suffered strongly from flash floods from the hilly areas towards the hinterland. If these flash floods coincided with storm surges on an elevated sea level, the problems for the city might increase dramatically. The rising sea level also endangers the local beaches and the aquifers that lie in the vicinity of the shoreline (Staudt et al. 2006, *this volume*).

The Region of Vorpommern might also face strong impacts from sea level rise if this occurred. The area is very low lying in many places. This leads to extreme flooding scenarios that might threaten many areas that have recent investments. The DSF was challenged in the local application of planning systems as it is based on scenarios and does not forecast the exact sea level rise or development of the coastline. The DSF tools were useful to assess the local planners and decision makers coping capacity and the trends of future investments (Röber et al. 2006, *this volume*).

5 DISCUSSION

According to research results from the Arctic, climate change seems to be occurring even quicker than previously expected (Hassol 2004). Therefore, an integrated analysis of climate change and subsequent sea level rise effects, in cooperation with spatial planners and other stakeholders, seems to be appropriate to integrate in future spatial planning. A cooperative and transparent analysis of the scenarios is recommended in the DSF structure. The following section gives an overview of the DSF's applicability according to the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis.

Strengths

The Decision Support frame is a transparent and flexible tool that operates on an interdisciplinary basis. During the SEAREG project, most planners, decision makers and other stakeholders were informed about climate change issues directly by scientific experts and could discuss all the aspects in an open forum, receiving direct answers. This interactive discussion opened new possibilities of understanding on the possible effects of sea level rise and the possibilities of scenario building. In general, the feedback towards the project was very positive because the sea level rise scenarios gave a local or regional visual dimension to the topics that are presently an important issue in the media. The data input is not restricted to any normative data sets with minimum requirements; a DSF can be performed with only a few data available. A DSF can be started on an expert opinion basis and the input data set can be enhanced when more data is available. In this sense, the DSF is also a suitable tool to identify missing data sets.

Weaknesses

The DSF can give an overview of the range of scenarios of sea level change effects, providing information on the constraints of the models. The climate models used in the SEAREG project are based on research results from the Intergovernmental Panel on Climate Change (IPCC), which is the most international and most accepted platform on climate change research. The main weakness of all models aiming to create scenarios of future developments is, of course, the impossibility to foresee the future. The SEAREG project encountered the limits of the DSF for spatial planners, as decision-making upon scenarios is difficult, especially when large investments and/or strong interest groups are involved. The SEAREG project's results are based on scenarios, not forecasts or predictions. Climate change and sea level rise issues are so complex topics that absolute numbers of inundated land and exact dates of inundation, for example, are simply impossible to deliver. As a result, the lay out of spatial plans will always be based on political decisions. These might take climate change scenarios into account, but they also might not, depending on the day-to-day or short to medium term interests.

Opportunities

The DSF offers the opportunity to discuss the impact scenarios of sea level change and possible mitigation strategies in a transparent manner and with sound expert background. The structure of the DSF offers broad participation from scientists and actors as well as the involvement of examples from other study areas. This provides an opportunity to involve all major stakeholders, mainly spatial planners, and make decisions at an early stage. In this way, existing funds can be used to face the advert consequences of sea level change and influence, for example, the future use and direction of investments. The DSF could be considered a prototype for a more developed decision support tool, which could include planning and decision-making alternatives and would allow for simulating choices in relation to different future sea level rise scenarios.

Threats

Attracting investments might suffer from a negative image, if sea level change issues are being explicitly addressed. This may, at worst, lead to an aversion to climate change information in local and regional planning contexts. Therefore, the use of the DSF must be very careful and the information given to the broader public must be well balanced. Since the time frame of the scenarios goes beyond liability claims, decision makers must take long term consequences of land use planning into account and be sure to make conscious decisions with a good understanding of the different sea level scenarios.

6 CONCLUSION

The SEAREG project developed a tool, the Decision Support Frame (DSF) for integrated discussions on sea level rise effects between scientists, planners and stakeholders. The DSF was used to show the effects, assess the impacts and discuss vulnerability aspects of sea level change in regional and local case study areas in the Baltic Sea Region. Many planners and stakeholders were confronted with climate change scenarios on a professional level for the first time and despite certain limitations of the scenarios for planning and decision-making, the overall response was very positive. Currently, the aim is for the DSF to be applied in different regions with varying impact scenarios, different natural settings and different planning and decision-making structures. The DSF is a dynamic tool, which is intended to be further developed along the assessment process and it gains strength as more people are informed and more knowledge is continuously incorporated into the tool. Further development of the DSF could take national, regional and local factors better into account. It could also cover the whole range of climate change effects, which could then be integrated into planning.

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Sea Level Change Affecting the Spatial Development
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THE EVOLUTION OF THE BALTIC SEA – CHANGING SHORELINES AND UNIQUE COASTS

by
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Kallio, H. 2006. The evolution of the Baltic Sea – changing shorelines and unique coasts. Geological Survey of Finland, Special Paper 41, 17–21, 2 figures.

Climate change has been one of the main forces changing oceanic water quantity during the history of the Earth. The evolution of Baltic Sea started from the last deglaciation and has gone through different stages (Baltic Ice Lake, Yoldia Sea, Ancylus Lake, Litorina Sea and finally Baltic Sea). The widely shifting shoreline has been the result of melting glaciers, changing outlets and uplift of the Earth's depressed crust. The land uplift continues, especially in the northern part of the Baltic Sea, where it causes the coastline to retreat noticeably within a human generation. The coasts of Sweden and Finland are highly fretted and generally rocky. The typical landscape is a hilly, smooth, outcrop terrain and archipelago with hundreds of small islands and skerries. In the south, the Baltic Sea makes constant attempts to re-conquer low-lying land. There erosion caused by wave action and sea level rise rapidly changes the shape of sandy coasts.

Key words (GeoRef Thesaurus, AGI): Baltic Sea Stages, Baltic Ice Lake, Yoldia Sea, Ancylus Lake, Litorina Sea, sea level changes, shorelines, Baltic Sea.

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1 INTRODUCTION

In the long-term perspective, the sea surface height is a subject of constant changes. Its variability depends on a combination of global, regional and local factors and time scale. Climate change has been one of the main forces changing the oceanic water quantity during the history of the Earth. During the last glaciation, enormous fresh water masses were stored in ice sheets in northern Europe and North America. The global sea level rise since the last glacial maximum (18 000BP) is estimated to have been between 90 and 130 meters (Pirazzoli 1996). A brief review of the evolution of the Baltic Sea is necessary to understand the mechanisms behind changing shorelines and the unique landscapes created by sea level changes. This article provides a general overview of the principle stages in the evolution of the Baltic Sea and examines the regional influence of the shore displacement phenomena within the Baltic Sea Region.

2 DEVELOPMENT OF THE BALTIC SEA

The Baltic Sea is very old and very young at the same time. While the Baltic Sea is a depression of three billion year old primary bedrock, it is also the creation of the last glaciation as the ice retreated 14 000-10 000 years ago. An almost 3 km thick ice sheet covered large parts of Scandinavia and northern Europe until it started to retreat northwards because of global warming. During these thousands of years beginning with deglaciation, the Baltic Sea has changed a number of times. First, it was a lake at the edge of the ice sheet then it became a salty sea and then again a lake, finally turning into a brackish water sea as we know it today. While the melting ice sheets released more fresh water causing sea level rise (a postglacial "glacioeustatic" transgression), land uplift took place in the area. The heavy load of ice depressed the Earth's crust at least 600-700 m below its present position (Tikkanen & Oksanen 2002). As soon as the pressure started to decrease, the crust slowly began to rebound back to the normal level. The majority of this rebound took place as the ice melted, and the rate became slower as the ground surface was exposed (Tikkanen & Oksanen 2002).

2.1 Baltic Ice Lake

The first stage in the evolution of the Baltic Sea is called the Baltic Ice Lake. Glacial melt waters accumulated beneath the ice front, forming successively greater and greater lakes. This lake was bounded to the north by the ice sheet, forming a frozen reservoir during most of the year. The Baltic Ice Lake existed from 13 000 to 11 590 calendar years ago (Saarnisto & Saarinen 2001), successively increasing its area as the Scandinavian ice-sheet melted. The end of the Baltic Ice Lake phase was extremely dramatic. A rapid marine regression took place in central Sweden when the low-lying terrain could no longer hold the rising water and a strait were opened to the Atlantic. The sea level quickly fell some 25 m (Björck 1995). Such considerable changes resulted in a dramatic migration of the coastline. The rate of sea level fall was 0.3-3 m per year, and for example, the coastline in Poland shifted northwards 30-40 km at that time (Uścinowicz 2003).

2.2 Yoldia Sea

During the period of 11 590 to 10 700 years BP, the Baltic basin was connected to the ocean, allowing waters to be mixed. This phase is named the Yoldia Sea after a mussel (*Yoldia arctica*) that inhabited the sea at that time. The Baltic Sea region looked very different in those days. The level of the sea surface was 35 metres below the present level in the southern part of the sea and all of Denmark for instance, was one united terrestrial area (Jensen et al. 2002). In the northern part of the sea, big areas of Sweden and Finland were exposed under the retreating ice but were still lying under water. The ocean level rapidly rose due to continuous ice sheet melting and the sea level in the southern part of Baltic Sea rose by about 10-12 m or for example 15-20 mm/year (Uścinowicz 2003). Due to a rapid uplift of the Scandinavian area – faster than the ocean-level rise, the Baltic basin lost its connection with the Atlantic about 10 700 years BP, and the Yoldia Sea turned into a fresh-water lake, the Ancylus Lake.

2.3 Ancylus Lake

The Ancylus Lake stage lasted from 10 700 to 9 000 BP (Björck 1995, Ojala et al. 2005). It is called Ancylus after a fresh water snail found in the clay sediment at this time. At the beginning of the Ancylus stage, transgression took place about 300 years (Björck 1995). During this time, the rising water level caused extensive areas of land to be inundated once more, especially along the south coast of the Baltic, where practically no land uplift took place. The water level rose at a rate of 5-10 centimetres a year, and the transgression as a whole is estimated to have been 15-25 metres (Björck 1995). However, around the Gulf of Bothnia, the land

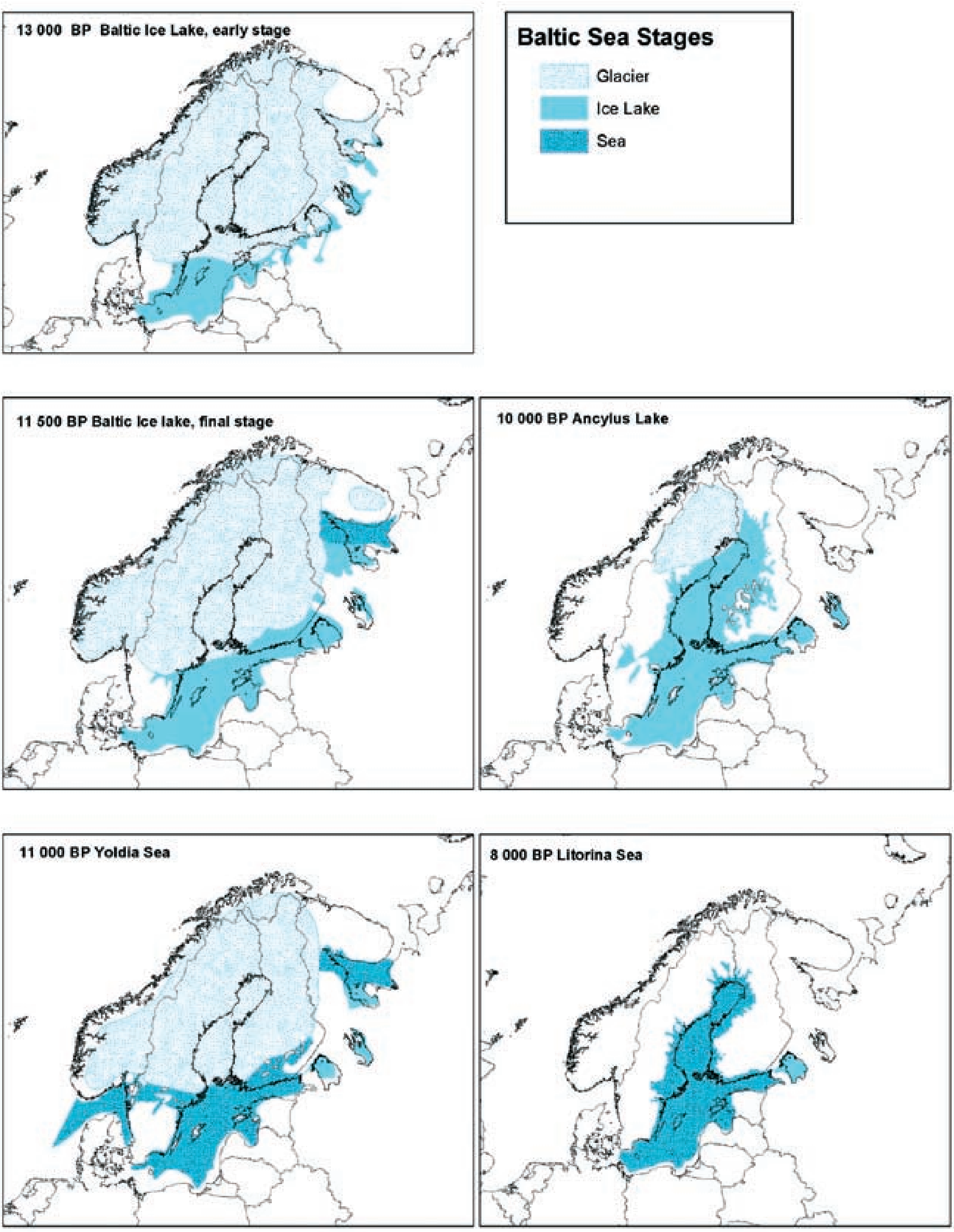

Fig. 1. Evolution of the Baltic Sea. Source: M. Saarnisto/GTK.

uplift rate consistently exceeded the sea level rise, and new land areas emerged even during this transgressive period. At the end of Ancylus Lake stage, the rising water level resulted in a big channel opening through the Danish Straits to the ocean. Through this new connection, fresh water ran with massive force to the ocean. During the Ancylus regression, large expanses of dry land emerged in the area of Finland.

2.4 Litorina Sea

After a brief Mastogloia transition phase, a great influx of saline water began to take place through the Straits of Denmark, marking the Litorina Sea stage (around 8 000-4 000 BP) (Berglund et al. 2005, Tikkanen & Oksanen 2002) to be followed by a somewhat less saline stage known as the Limnea Sea. The eustatic rise in ocean levels led to a transgression at the beginning of the Litorina Sea stage. As a result, water levels on the southeast coast of Finland rose by a few metres (Tikkanen & Oksanen 2002). In the southern Litorina Sea area, the sea level rose faster and reached a level about 2-3 metres lower than the present level. When the rise in ocean levels came to an end between 6000 and 5000 BP, the transgressive phase of the Litorina Sea also finished. However, in the southern parts of the Baltic Sea some marks of even younger transgressions have been identified (Tikkanen & Oksanen 2002). During the last 7 000 years, the coastal zone was created under the influence of slow sea level rise, with many oscillations (Musielak et al. 2004). After a transgressive period in the early Litorina Sea stage, shoreline displacement in Finland has proceeded at a steadily declining rate (Tikkanen & Oksanen 2002).

3 BALTIC SEA AND ITS COASTS TODAY

Finally, the Baltic Sea became the brackish water sea it is today but still the continuous transition goes on in this dynamic system. There are various kinds of coastal types in the Baltic Sea area. Present Baltic coasts have evolved from the primary landscape in contact with the deglaciation and Holocene transgression of the sea. The uplift of land still continues, especially in the northern part of the Baltic Sea, where the coastline retreats noticeably within a human generation. On-going uplift creates unique, constantly changing 'young' coastal environments not to be found anywhere else in the world (EEA 2002). In these areas, shallow sea bays are gradually transformed into lakes and eventually to mires and forests. The coasts of Sweden and Finland are highly fretted and generally rocky, and a typical landscape type is a hilly, smooth, outcrop terrain and archipelago with hundreds of small islands and skerries. The most representative example of an archipelago is the one between Åland and the Finnish mainland. A large archipelago is located in front of Stockholm. Another appreciable Baltic landscape type in Sweden, especially in the Västernorrlands region, is the fjord coast. Typical fjords are long, narrow and deeply U-shaped mountain valleys. Erosion is not a threat to the infrastructure of these northern Baltic coastal areas because of the rocky and clayed coasts.

In the southern Baltic coastal areas, the sea is making constant attempts to re-conquer low-lying land. Erosion caused by wave action and sea level rise shapes the coastline, creating coastal landscapes and habitats typical for the accumulation and abrasion of shores. Since the end of the ice age, the southern coastline of the Baltic Sea has changed notably as a result of changing land settlements and elevations as well as constant erosion. The rapid development of southern areas is possible because of the sandy, erosion-prone materials of the coasts. The on-going and accelerating sea level rise will complicate existing problems along the south coasts by increasing the speed of the coastal processes (Fenger 2000). Chang-

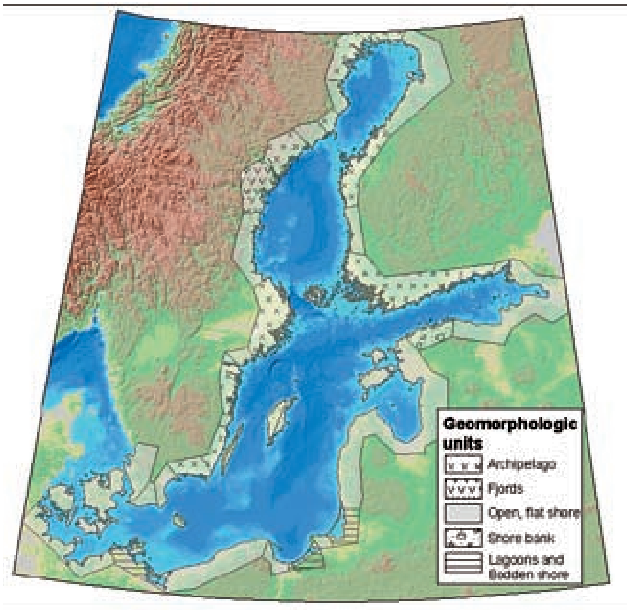

Fig. 2. Different geomorphological coastal zone types in the Baltic Sea Region. Sources: Baltic Sea University, Baltic Sea Research Institute Warnemünde.

ing landscapes between cliffs and low-lying areas with dunes on the top are typical for the coastal areas of the southern Baltic Sea. These features were built due to abrasion and accumulation of marine sand. Almost all of the southern regions are classified as areas of high exposure of erosion (Eurosion 2004).

In a short-term perspective, there are many ways to influence the sediment balance and protect the coastal areas. The big question is how much protection is actually practical. In a long-term perspective, coastal protection can only decelerate abrasion, while finally there is no way to prevent the erosion of the coast.

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PROJECTIONS OF FUTURE SURFACE WINDS, SEA LEVELS, AND WIND WAVES IN THE LATE 21ST CENTURY AND THEIR APPLICATION FOR IMPACT STUDIES OF FLOOD PRONE AREAS IN THE BALTIC SEA REGION

by

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Meier, H.E.M., Broman, B., Kallio, H. & Kjellström, E. 2006. Projections of future surface winds, sea levels, and wind waves in the late 21st century and their application for impact studies of flood prone areas in the Baltic Sea Region. Geological Survey of Finland, Special Paper 41, 23–43, 14 figures, 4 tables

The impact of anthropogenically induced climate change on surface winds, sea levels, wind waves, and flooding at the end of the 21st century is assessed using a dynamical downscaling technique. For this purpose, regional climate model simulations with two driving global models and two forcing scenarios were used. The results of calculated sea level changes in the Baltic Sea are combined with scenarios of global average sea level rise, land uplift, and digital elevation models to estimate flood prone areas. Regional and local maps of flood prone areas may serve as decision support for spatial planners. To estimate the impact on coastal erosion and navigation, the changing wave climate is assessed using a simple wave model. While the uncertainties of the projections, mainly caused by the global models, are considerable, the presented downscaling technique has shown that it may provide useful information for spatial planners.

Key words (GeoRef Thesaurus, AGI): climate change, winds, sea level changes, waves, transgression, floods, Baltic Sea

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1 INTRODUCTION

To perform scenarios of future climate, models are needed that comprise a huge range of spatial scales. As the global climate system is rather complex, including many non-linear feedback mechanisms, state-of-the-art global climate models are three-dimensional coupled atmosphere-ocean models that describe the circulation of both air and water particles based upon basic physical principles like the conservation of mass, energy, momentum, and matter. However, these global coupled Atmosphere-Ocean General Circulation Models (AOGCMs or short GCMs) are typically too coarse to resolve all scales of interest for climate change impact studies because present computers are not fast enough to calculate all relevant processes on these scales. Thus, the information provided by GCMs, which typically have a resolution of some 100 km, needs to be downscaled. Various methods of different complexity have been applied based upon either statistical or dynamical downscaling of GCM results. Statistical downscaling assumes that the statistical relationships between global predictors and regional or local predicted variables do not change in a future climate. As this assumption limits the applicability of statistical downscaling, we applied the concept of dynamical downscaling using a Regional Climate Model (RCM).

RCMs describe a specific part of the globe and presently have a typical resolution of about 20-80 km. At the lateral boundaries of the regional model domain, results of GCMs are used as forcing. In this study, the limited area model RCAO from the Rossby Centre at the Swedish Meteorological and Hydrological Institute (SMHI) was used to calculate regional climate change scenarios using data from two GCMs, one from the Hadley Centre (U.K.) and another one from the Max Planck Institute (Germany) (e.g. Räisänen et al. 2004). The RCM provides, inter alia, results of present and future surface wind and sea level (Fig.1). This information is combined with regional and local topographical maps and is used for climate change impact studies.

One of the aims of this study is to develop a method calculating flood prone areas at the end of the 21st century. The simulated future sea level is combined with a gridded topographical data set, the so-called Digital Elevation Model (DEM) (Fig.1). For this procedure, the same height system has to be used for the DEM and the simulated sea level of the RCM. The choice of a height system covering the whole Baltic Sea area is not trivial. Currently, several national height systems are in use. The increasing international co-operation causes pressure to create a common height system. Several gravimetric satellite missions are in progress. In the future, one consistent height system used by every country will give a much better starting point for international projects like SEAREG (Sea Level Change Affecting the Spatial Development in the Baltic Sea Region). This problem will be thoroughly discussed in the following section. In addition, for the calculation of flood prone areas land uplift and subsidence caused by the post-glacial rebound has to be considered.

The second aim of this study is to develop a simple wave model, which can easily be used to calculate the impact of global change on waves. The wave model is forced by surface winds from the RCM (Fig.1). An example for the application of this wave model is the impact of climate change on navigation. The wave climate is needed to classify routes for different kinds of ships. Shipping routes are divided into different classes according to the occurrence of waves with certain wave heights. Other examples are the impact of climate change on coastal erosion and erosion at the sea bottom. Finally, knowledge about changing wave climate is important when new harbours, coastal

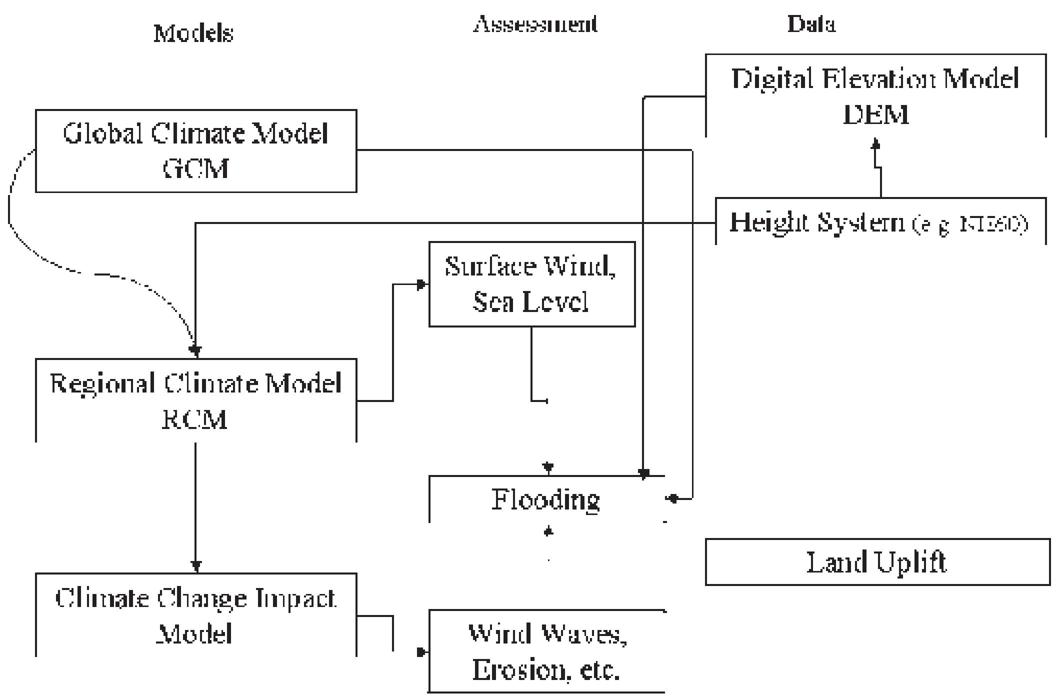

Fig. 1. Schematic illustration of the strategy of this study. Source: H.E.M Meier & B. Broman, SMHI.

protection measures or constructions in the sea (e.g. bridges across fjords or straits) are planned. Also, the combined effect of higher waves and increased sea level has to be considered. The impact of waves at higher water levels may be larger than at lower levels because wave breakers are built for a water height at present mean sea level.

Harbours and bridges especially have a long lifetime and with regards to their planning, climate projections in 100 years are relevant. Currently, in the Baltic Sea Region a changing climate is observed, which is very likely anthropogenically induced. Since 1860, the annual mean air temperature and the annual mean precipitation in Sweden have increased by 1.4 °C and 16 %, respectively (Alexandersson 2004). Thus for spatial planning in the Baltic Sea region, projections of changing surface winds, sea levels, and wind waves need to be considered.

2 METHODS

2.1 Regional climate modeling

The Rossby Centre regional climate model system RCAO (Döscher et al. 2002) was used to calculate climate change scenarios based on two different greenhouse gas emission scenarios, SRES A2 and B2 (Nakićenović et al. 2000). RCAO was driven by two different global models; the ECHAM4/OPYC3 model from the Max Planck Institute for Meteorology in Germany (Roeckner et al. 1999) and HadAM3H from the Hadley Centre in the UK (Pope et al. 2000, Gordon et al. 2000, Jones et al. 1999). Altogether six different simulations were undertaken, i.e., one control run (covering the time period 1961-1990) and two scenario runs (2071-2100) with each of the two driving global models. These will be referred to as RCAO-E and RCAO-H with the extension CTRL for the control runs and A2 or B2 for the scenario runs. For a detailed description of these simulations and their results, see Räisänen et al. (2003, 2004), Döscher & Meier (2004), Graham (2004), Kjellström (2004), and Meier et al. (2004a, 2004b). RCAO consists of an atmospheric part (RCA) (Jones et al. 2004) and a coupled sea-ice - ocean part (RCO) (Meier et al. 2003).

2.2 Eustatic and isostatic sea level changes

The two most important factors affecting sea level changes on time scales of more than 100 years are the land uplift (or the glacio-hydro-isostatic effect) and the global average sea level rise (or the eustatic rise). The balance between these two determines whether the sea level is generally rising or lowering in relation to the bedrock.

During the 20th century, a general rise in the global average sea level has been observed. So far this rise has been linear, in the limits of observational accuracy. The current estimate of the rise amounts to 1-2 mm yr^{-1} (Church et al. 2001). Within this study a eustatic sea level rise of 1.5 mm yr^{-1} is used. In the future, the linear trend of the global average sea level might change. According to the IPCC scenarios, sea level is projected to rise by 9 to 88 cm from 1990 to 2100 (Fig.2).

Since the Baltic Sea is located in an area of postglacial rebound, land uplift and subsidence have to be considered when calculating sea level changes. Land uplift varies from 0 and 9 mm yr^{-1} relative to the mean sea level, with the smallest values in the south and the largest values in the Bothnian Bay near the coast of northern Sweden (Fig.3). The calculation of land uplift can be categorized into four groups based on the source of the data used. Within this study, Ekman's consistent map of the recent postglacial rebound of Fennoscandia is used (Ekman 1996). The map is based upon 56 reliable tide gauge stations around the Baltic Sea with series spanning 60 years or more.

The calculation of land uplift can also be based on permanent GPS-reference stations, levelings and even observations of old historical seashores (Eriksson et al. 2002). In general, reported land uplift results do not differ much. The estimated bias amounts to about 5 cm per 100 year, which is smaller than the uncertainty of the global average sea level projections.

Different national height systems are discussed because they significantly affect GIS-applications of the SEAREG project. The concept of height is nor-

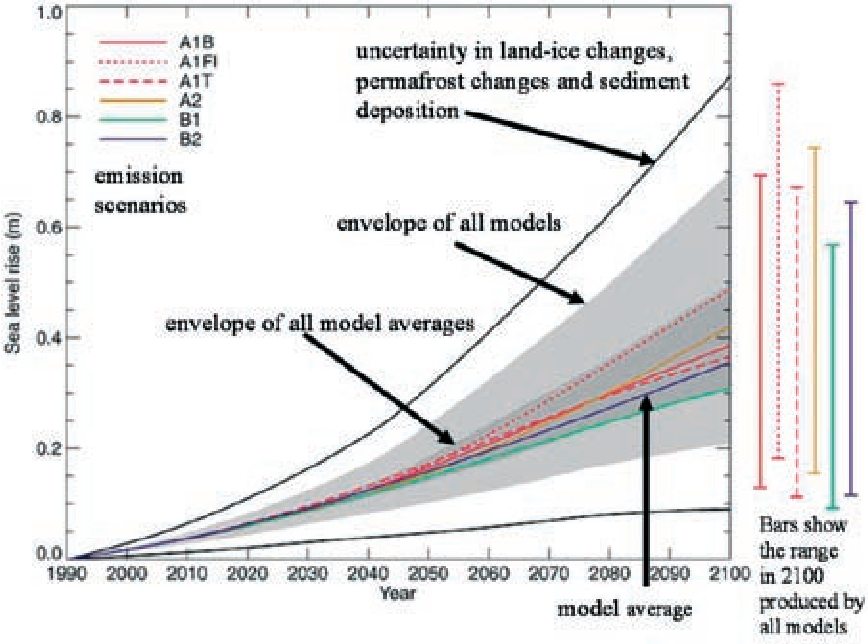

Fig. 2. Global average sea level rise from 1990 to 2100 for different IPCC scenarios (Church et al. 2001).

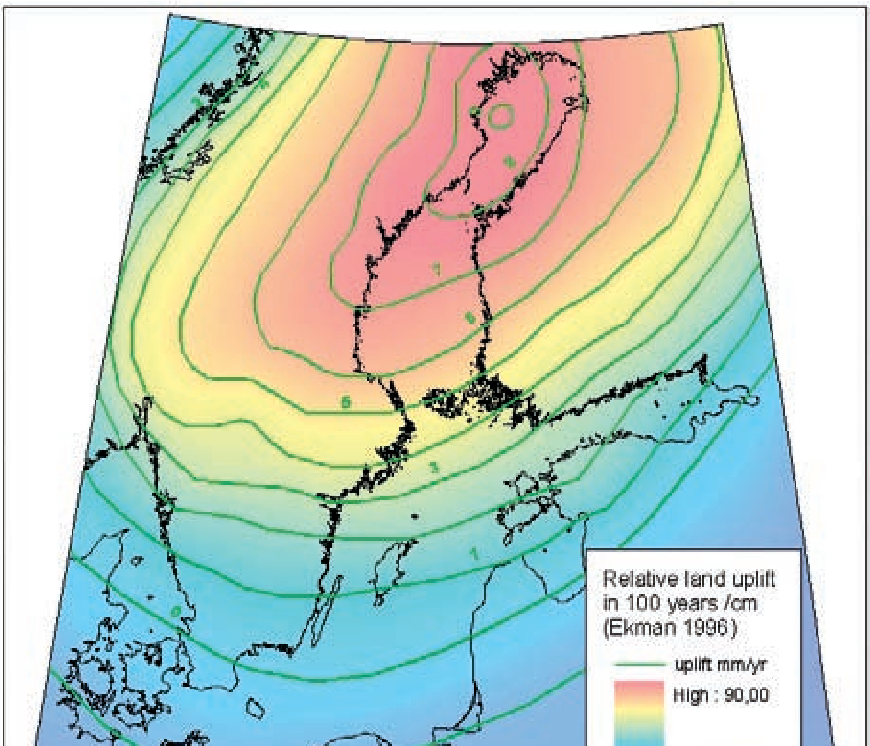

Fig. 3. Land uplift relative to the mean sea level following Ekman (1996).

mally understood as a coordinate. If x and y denote the horizontal location of a point, z is the altitude or distance from the ground. When the `ground´ happens to be the mean sea surface, this expression no longer works. In geophysics, *height* denotes the energy level of a certain place. The primary values of any height systems are actually geopotential values (GP-values). Although the GP-values are physically relevant, people normally want to have their height information in metric form calculated from some suitable reference surface. For this reason, the mean sea surface is used. More specifically, we should say equipotential surface of the Earth's gravity field that coincides with the mean sea surface. This surface is called a *geoid* (Fig.4). The same surface would arise if the sea water would freely intrude under the continents, for example, through a tunnel network (Vermeer 2002).

There are basically two different ways of handling the gravity field in height systems when turning geopotentials into heights. One is to use the actual gravity field to produce the *orthometric height H*:

$H = C/g$

where C is the geopotential and g is the mean gravity all the way along the plumb line to the surface of the geoid. To get the real orthometric height, one should know the exact density values of surrounding rock masses and the topography. In the Finnish N60 systems, the surrounding topography is ignored and the rock density values are estimated with the help of geological maps. In many other countries, a standard density of 2.67 g cm^{-3} is used. However, the differences between those two methods are not significant.

Another way to calculate metric heights is to use a simple normal gravity formula to produce *normal heights*. Normal heights differ from the orthometric heights and miss the intuitive physical interpretation. The Swedish RH70 system and the Estonian system are both based on normal heights (Vermeer 2002). The difference between normal and orthometric heights is approximately proportional to the square of the height of the topography; it vanishes at the sea level, amounts to about 10 cm for a height of 1000m and reaches 1 m for a 3000 m mountain (Ekman 1995). The difference between normal and orthometric heights is found to be less than 10 cm in most places in Fennoscandia and in the area of the Baltic States because the heights are so small (Poutanen 1999).

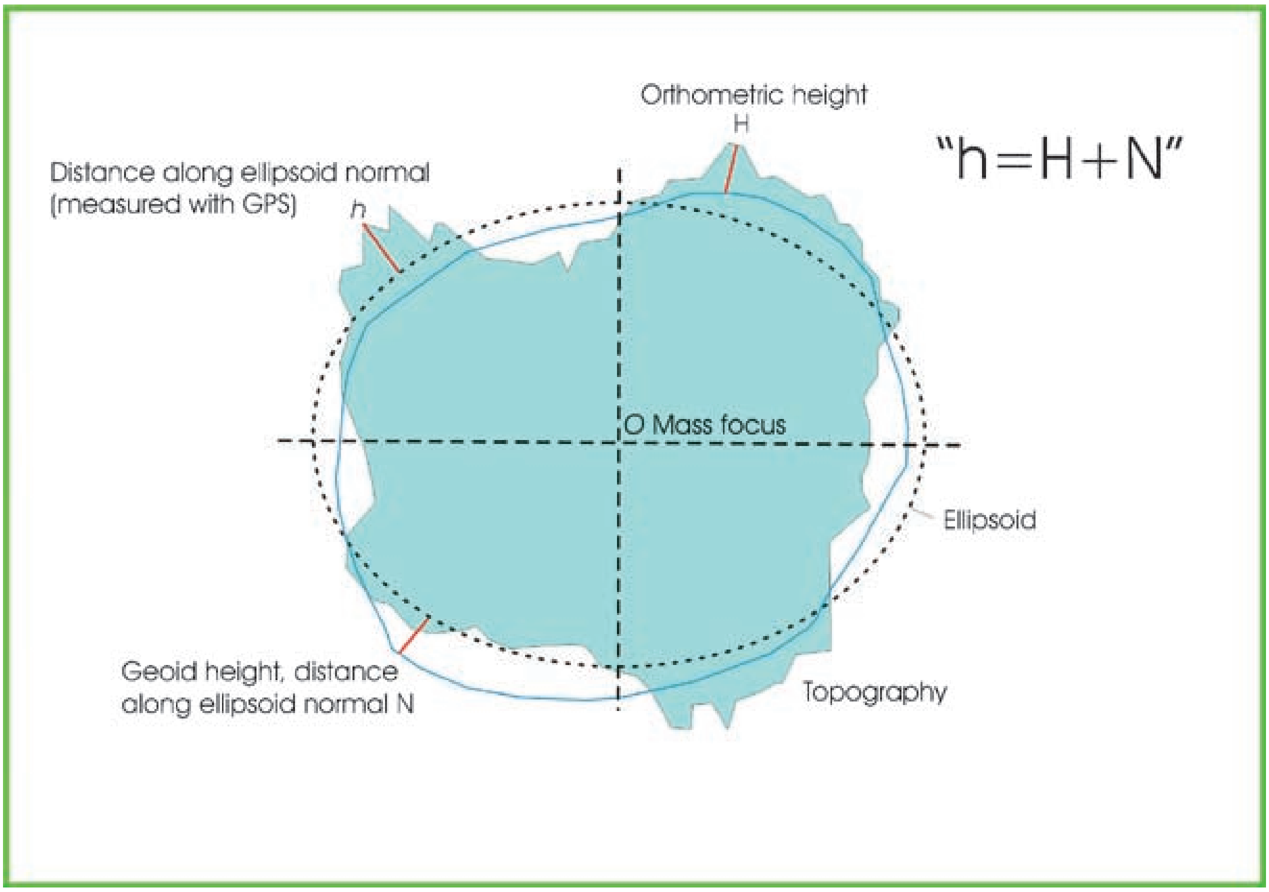

Fig. 4. Illustration of geoid, ellipsoid and the orthometric height. Source: Vermeer 2002.

Geoid is the physical form of earth with a complicated up-and-down shaped surface. It differs from the much simpler earth describing ellipsoid. The importance of the geoid has been emphasized since the GPS-location became more general. The GPS-heights are actually the heights from the reference ellipsoid surface whereas orthometric heights are heights from the geoid surface. In other words, a geoid map is needed to change the GPS-heights to orthometric heights (Vermeer 2002).

Given this short description of the height systems, it is clear that the connection of different systems is difficult. Small local leveling networks, like those of cities and municipalities can be connected to national leveling networks in a straightforward way. Connecting national networks this way is not correct (Table 1), and it is an oversimplification to compare height systems of two countries just by giving one number for the height difference (Poutanen 1999). A more reasonable way to do the connection is to establish a new, well defined height system for the area and compute transformation parameters from the old national systems to the new one (Poutanen 1999). This is one of the reasons why the Nordic Height System NH60 was created. This system covers the whole Baltic Sea area (Ekman & Mäkinen 1995). Ekman & Mäkinen (1995) used geopotentials instead of orthometric or normal heights. Their aim was mainly to study the sea surface topography and with the small heights, there is no need to distinguish between normal and orthometric heights. The consistent NH60 system is found to be well suited especially for oceanographic purposes (Carlsson 1997). However, from the GPS viewpoint it should be refined (Poutanen 1999). Table 2 shows the mean sea levels in Finland and Sweden in their national height systems and in NH60. The error caused by the incompatibility of the different height systems is estimated to be a maximum 12 cm.

Table 1. National height systems. In the Estonian system, the geoid type and epoch are not well defined (Ekman 1995).

Country height system	Geoid	Geoid type	Epoch
Finland N60, orthometric	Classical	Mean	1960
Sweden RH70, normal	Quasi	Non-tidal	1970
E. Europe Kronstadt	Quasi	Unknown	Unknown
W. Europe UELN73	Classical	Mixture	1960
NH60, geopotential numbers		Mean	1960

Table 2. Mean sea level in Finland (left) and Sweden (right). *H'* is the height in the national system and *H* is the height in the NH60 system (Ekman 1995).

Mareographs in Finland	H	H'	Mareographs in Sweden	H	H'
Hamina	14.2	2.9	Furuögrund	16.4	13.6
Helsinki	11.6	0.6	Ratan	16.7	13.9
Hanko	12.3	1.5	Draghällan	11.1	7.8
Turku	13.3	2.5	Gävle	16.5	13.5
Degerby	13.2	3.1	Björn	15.2	12.0
Lemström	13.4	3.3	Stockholm	13.7	10.8
Rauma	14.4	3.3	Södertälje	12.8	10.0
Mäntyluoto	14.9	3.2	Landsort	10.6	7.9
Kaskinen	15.3	2.7	Ölands norra udde	7.0	4.9
Vaasa	15.6	2.8	Kungsholmsfort	1.0	-0.5
Pietarsaari	15.4	2.4	Ystad	4.5	3.3
Raahe	16.6	3.7	Klagshamn	2.2	0.9
Oulu	19.0	5.9	Varberg	-1.4	-3.3
Kemi	20.5	6.6	Smögen	-5.6	-8.0

To calculate the mean sea level rise during the 21st century, both land uplift and sea level results of the RCM were calculated relative to the geoid. The sea surface height in the RCM is calculated in NH60 because sea levels at the open boundary in northern Kattegat are prescribed from observations given in NH60 (Meier et al. 2003). Thus, there is no need for conversion. The land uplift, however, has been given relative to the mean sea level, not relative to the geoid. To obtain the land uplift relative to the geoid, the following formula is used

$$u_a = u_r + u_{eust}$$

where u_a is the absolute land uplift rate, u_r is the land uplift rate relative to the mean sea level (Ekman 1996), and u_{eust} is the rate of the eustatic sea level rise of 1.5 mm yr^{-1}.

2.3 Wave modeling

Waves are recognized as rather rapid movements of the sea surface - typically a few seconds. The wave height is the vertical distance between the crest and the following trough. When waves are measured, the concept of significant wave height is used, which is approximately the height estimated by eye. In a series of observed waves, which are ordered in size, it is defined as the mean of the highest third.

Within this study a simple wave model, a so-called nomogram, is used to calculate the wave climate in present and future climates (Anonymous 1998). Therefore significant wave height is calculated from wind speed, fetch and duration on a regular grid with a spatial resolution of 20'×10' (longitude × latitude). The fetch is the distance between the grid point considered and the shoreline in upwind direction. Tests revealed that with a mean duration of 7 hours fairly good results are obtained. If sea-ice concentration is higher than 50%, it will be assumed that no waves occur. Although the nomogram only correctly describes waves in deep water with a depth greater than about 25 m, it is successfully used in this study to approximately calculate even the wave climate of the entire Baltic Sea.

2.4 Projections of flood prone areas

To calculate flood prone areas gridded topographical data H relative to the geoid, the DEM, are needed. Assuming that the DEM is given in the NH60 system, scenarios of flooded areas can be calculated from the difference between projected future land height H' and projected future sea level ζ relative to NH60 where

$$H' = H + u_a \times l$$

and

$$\zeta = \zeta_{scen} + \zeta_{global}.$$

ζ_{scen} is the simulated future sea level in the regional climate model, l = 110 yr is the time between future time slice and 1960, and ζ_{global} is the global average sea level rise during this period, which has an approximate range of 9 to 88 cm (Fig.2). The difference H'-ζ will be negative if the land is flooded. Heights above sea level will have positive values.

3 RESULTS

3.1 Surface wind

In both of the two control simulations (RCAO-E and RCAO-H), there are biases in the sea level pressure leading to errors in the wind speed (Räisänen et al. 2003). However, both the annual mean wind speed and the seasonal cycle are in relatively good agreement with the CRU data (New et al. 1999, 2000) in the Baltic Sea runoff area. Also, compared to the NCEP reanalysis data (Kalnay et al. 1996, Kistler et al. 2001) a high degree of correspondence in terms of the magnitude and spatial patterns of the flow characteristics was shown for the two control simulations by Pryor & Barthelmie (2004) and Pryor et al. (2005). In experiments with boundary fields taken from reanalysis data instead of GCMs, the biases in SLP are reduced leading to smaller errors in simulated wind speed in RCA (Jones et al. 2004).

We compared the simulated wind speed to the observed wind speed at Landsort (58.74˚N, 17.87˚E). Landsort is one of the few stations with wind speed observations representing conditions over open sea (Hans Alexandersson, SMHI, personal communication). We compared the simulated wind speed in the two control runs to the observed climatology for the same time period (1961-1990). In addition, we compared reanalysis-driven runs (boundaries from ERA-15, Gibson et al. 1997) with observations for a specific time period. The results are summarized in Table 3. Table 3 shows that the error in mean wind speed is substantially smaller in the reanalysis-driven simulations compared to the control simulations (67% of the error in RCAO-H and 53% of the error in RCAO-E). For the high wind speeds (99^{th} percentile), the error reduction is similar, about 50-55%. Regardless of this reduction, the remaining error of more than 2 m/s indicates that the problem with simulating high wind speeds does not lie solely in the boundary conditions. RCMs commonly underestimate high wind speeds unless a more explicit treatment of gustiness is included (Rockel 2004).

The bias in mean wind speed is rather uniform during the year (Fig. 5). At the same time, the bias in high wind speed is much larger during the winter half of the year than during summer. During the winter, the absolute wind speeds are highest. During the summer half of the year, the wind speeds are more moderate. For this particular location, the biases in the simulation with RCAO-E are larger than in RCAO-H. This is a broad-scale feature in large parts of the model domain as noted for sea level pressure in Räisänen et al. (2003), probably due to the fact that the HadAM3H-simulation was forced with observed sea surface temperatures while ECHAM4/OPYC3 is a fully coupled AOGCM. Therefore, it has more freedom to develop its own climate.

Table 4 shows area averaged seasonal changes in mean wind speed in the scenario runs compared

Table 3. Bias in wind speed at Landsort (58.74°N, 17.87°E). The bias is given for the mean wind speed and for the 99^{th} percentile. Both absolute (m/s) and relative (%) errors are given. For RCAO the comparison is made for the entire period 1961-1990. For RCA-ERA, the comparison is made with data from 1988-1994 from both models and observations. Source: E. Kjellström SMHI.

Experiment	Variable	(m/s)	(%)
RCAO-E	Mean	-1.94	-27.2
	99^{th} percentile	-4.94	-28.2
RCAO-H	Mean	-1.49	-20.5
	99^{th} percentile	-4.36	-24.2
RCA-ERA	Mean	-1.02	-14.3
	99^{th} percentile	-2.20	-16.0

Table 4. Area average seasonal changes (%) in mean wind speed over the Baltic Sea and Kattegat (DJF = December, January, February, etc.). Source: E. Kjellström SMHI.

	DJF	MAM	JJA	SON
RCAO-E A2-CTRL	18	15	-5.5	4.2
RCAO-E B2-CTRL	12	9.7	-4.7	3.8
RCAO-H A2-CTRL	4.8	1.3	3.0	-3.4
RCAO-H B2-CTRL	3.4	-0.6	5.2	1.4

with the control climate for the Baltic Sea and Kattegat. The RCAO-E runs showed increases in the wind speed during winter and spring in the range of 10-20%. In all other seasons and also in the RCAO-H scenario runs, the differences are about 5% or less.

Figure 6 shows the geographical distribution of these changes in the Baltic area. Here the differences between the driving models are emphasized. The RCAO-H runs show much smaller changes during winter and spring than the RCAO-E runs, both over the Baltic Sea and especially over the adjacent land areas. The large differences between the RCAO-E and RCAO-H runs during winter and spring can be attributed to the large differences in the driving global models; in ECHAM4/OPYC3 a stronger pressure gradient between northern and central Europe is simulated in the scenario runs compared to the HadAM3H, leading to stronger westerlies in northern Europe (Räisänen et al. 2003).

Regardless of the scenario and driving GCM, the strongest changes in the Nordic area appear over the Baltic Sea. Räisänen et al. (2003) suggested that changes in ice cover and sea surface temperature (SST) leads to decreased surface layer stability and increased wind speed over the Baltic Sea.

To investigate how the wind climate is simulated to change on a more detailed temporal scale than just seasonal averages, diurnal averages were studied. In Figure 7, probability distributions of diurnally averaged wind speeds at three locations around the Baltic Sea are presented. Shown are DJF conditions from the RCAO-E CTRL and A2 runs. The increase in wind speed in Figure 7 is more or less uniform, that is the entire probability distribution is shifted to the right in the lower panels describing the future climate. In the other seasons and other climate change simulations the pattern is the same, that is generally uniform changes in the probability distributions. This pattern is similar at most locations in the entire Baltic Sea Region (not shown).

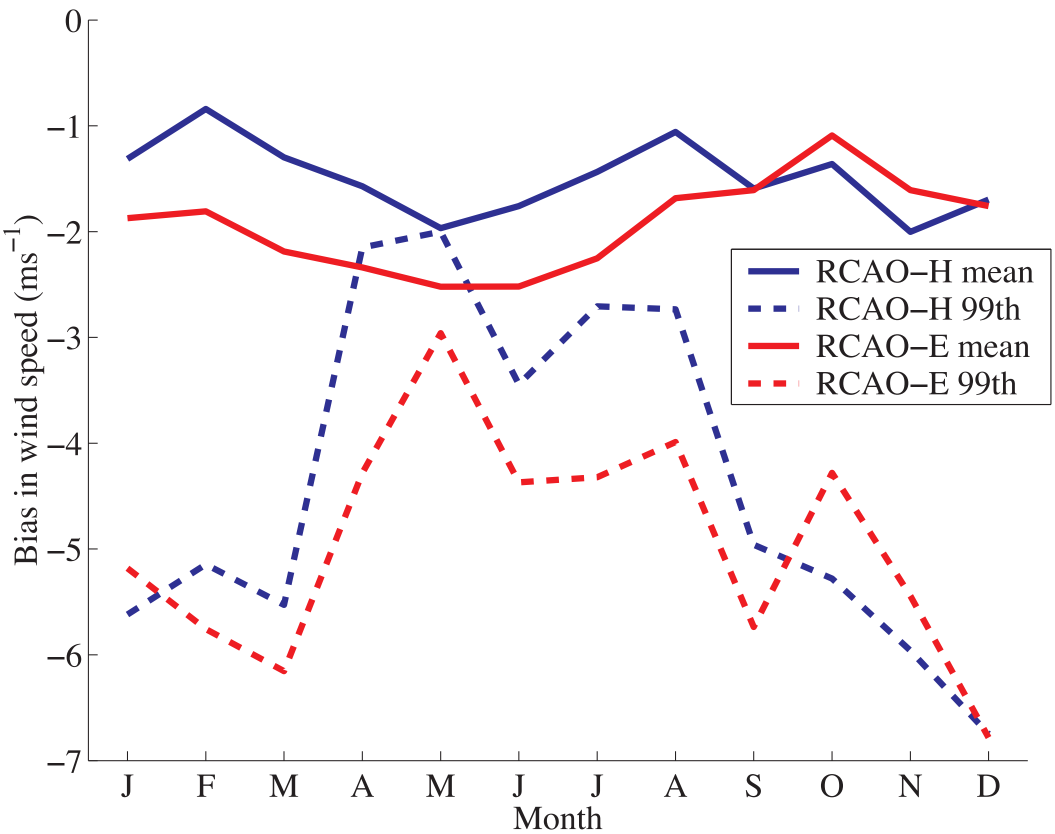

Figure 5. Seasonal cycle of the bias in wind speed at Landsort (58.74°N, 17.87°E). Source: E. Kjellström SMHI.

3.2 Sea level

Sea level data from several stations around the Baltic Sea were analysed to investigate present-day variability. Such an investigation is important to illustrate natural variability of sea levels in comparison with calculated sea level changes. For the period 1960-1990, these data have been prepared in

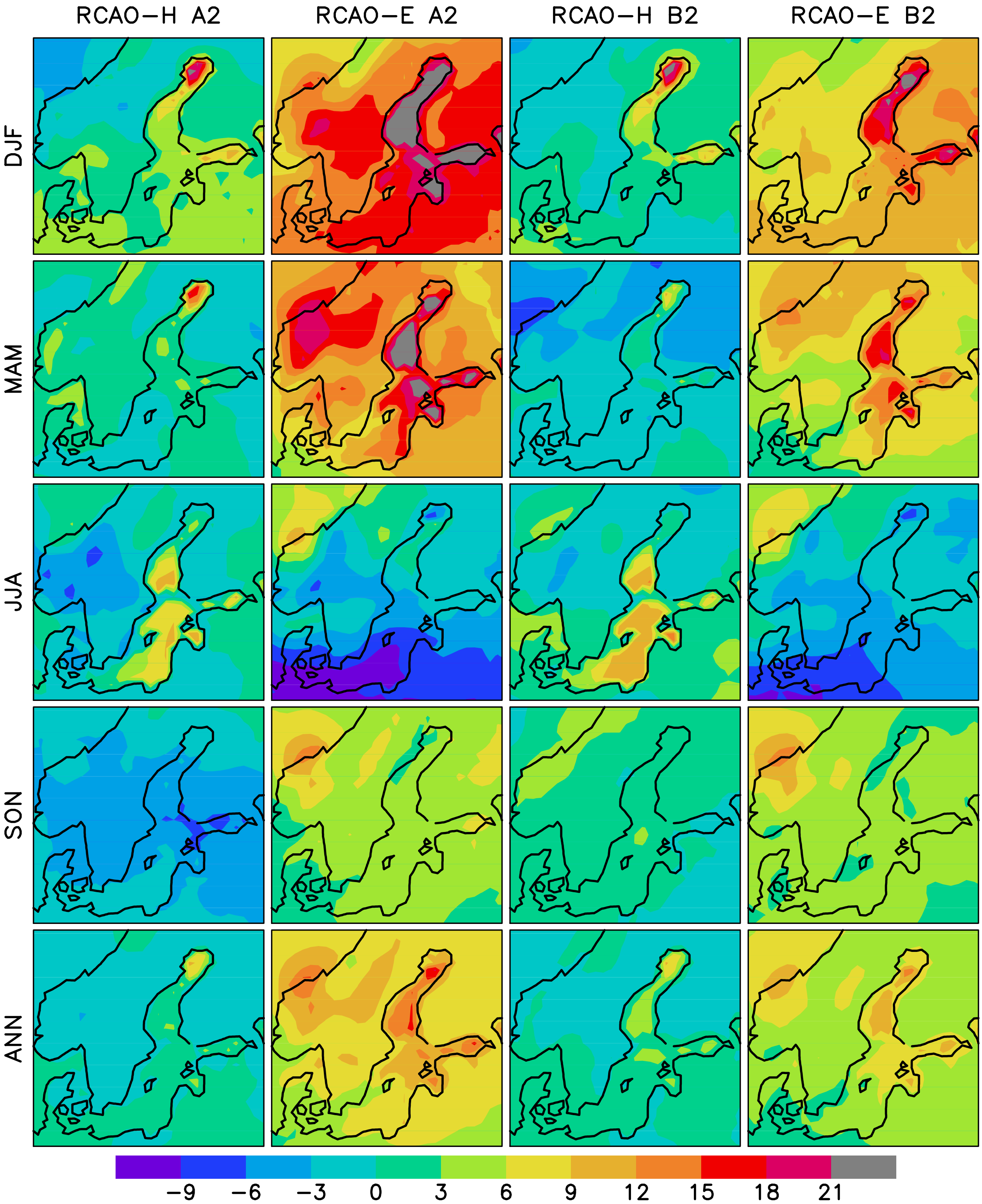

Fig. 6. Seasonal and annual changes in wind speed (percent differences from the corresponding control run) in the RCAO climate change simulations. Source: E. Kjellström SMHI.

10-day clusters. We calculated the mean seasonal cycle based upon the 10-day mean sea level and the 10-day standard deviations. The latter is a measure for the short-term meteorological caused variability. An example from the Swedish station Klagshamn is shown in Figure 8. A pronounced annual cycle is clearly seen. The sea level is high during winter and low during spring and summer. Also, the variability is much greater during fall and winter. The minimum variation normally occurs during summer. The inter-annual variability is large (Fig.8, left panels).

In Figure 9, the projected winter (December to February) mean sea level for 2071-2100 relative to the annual mean sea level of the reference period 1961-1990 as calculated in the control simulations is shown.

To estimate the impact of the uncertainties of the global and regional model results and the emission scenarios of anthropogenic greenhouse gases, we calculated three sea level scenarios. First, a `higher case´ scenario is estimated using the regional model results with the largest sea level increase (RCAO-E A2) together with the upper limit for the global average sea level rise of 88 cm (Fig.2). However, one should keep in mind that the projected sea level rise in the global IPCC scenarios on the regional scale differs significantly (Church et al. 2001, Fig.11.13). Therefore, our `higher case´ scenario might be lower than the worst case simulated within the IPCC ensemble of global models. Second, an `ensemble average´ is calculated from the four regional scenarios (including two forcing models and two emission scenarios, A2 and B2), assuming a global average sea level rise of 48 cm, which is the central value for all scenarios (not only A2 and B2) presented by Church et al. (2001). Third, a `lower case´ scenario is estimated using the regional model with the smallest (i.e. no) sea level increase (RCAO-H B2) together with the lower limit for the global average sea level rise of 9 cm. In our `lower

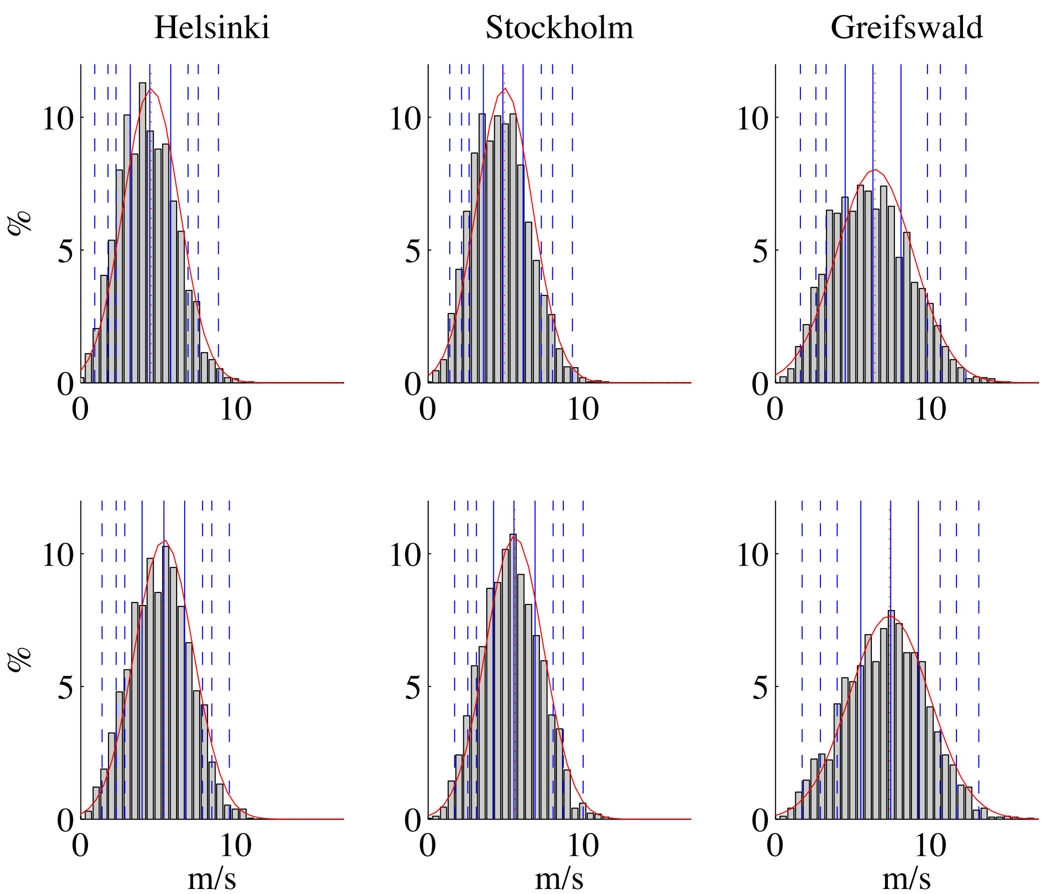

Fig. 7. Winter frequency (in %) histograms of wind speed in the RCAO-E CTRL run (upper panels) and RCAO-E A2 run (lower panels). The bars represent the actual distribution of the diurnally averaged data (N=2700 in each panel) with an interval of 0.5 m/s. The red dotted line is the mean and the red full line is a normal distribution with the mean and standard deviation taken from the actual distributions. The dashed and full blue lines are the percentiles (1st, 5th, 10th, 25th, median, 75th, 90th, 95th and 99th) of the distributions. Source: E. Kjellström SMHI.

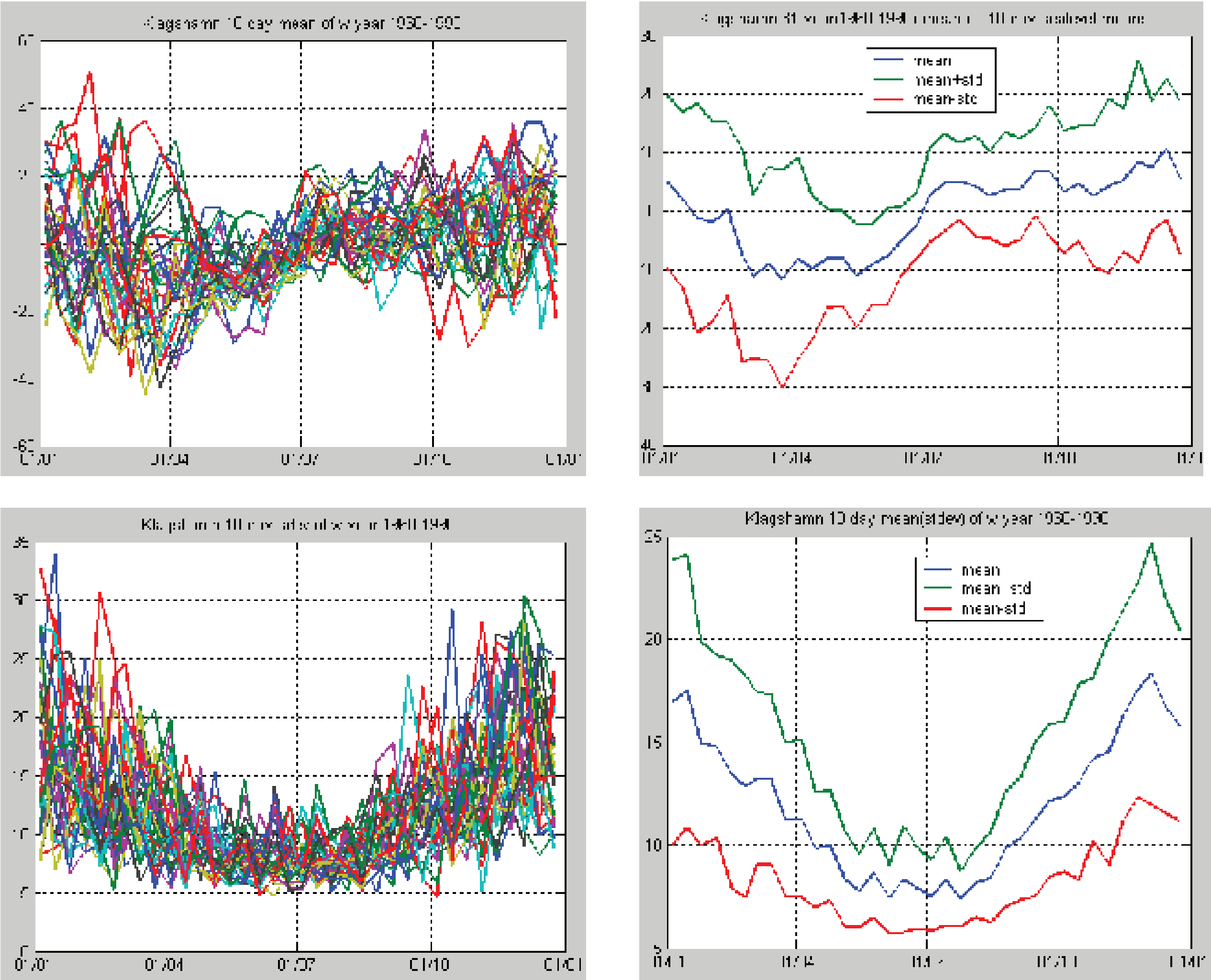

Fig 8. Changes of the mean and extreme sea levels 10-day means (upper panels) and standard deviations (lower panels) at Klagshamn (in cm) for 1960-1990. Results from every individual year (left panels) and the climatological mean with +/- 1 standard deviation (right panels) are shown. Source: B. Broman SMHI.

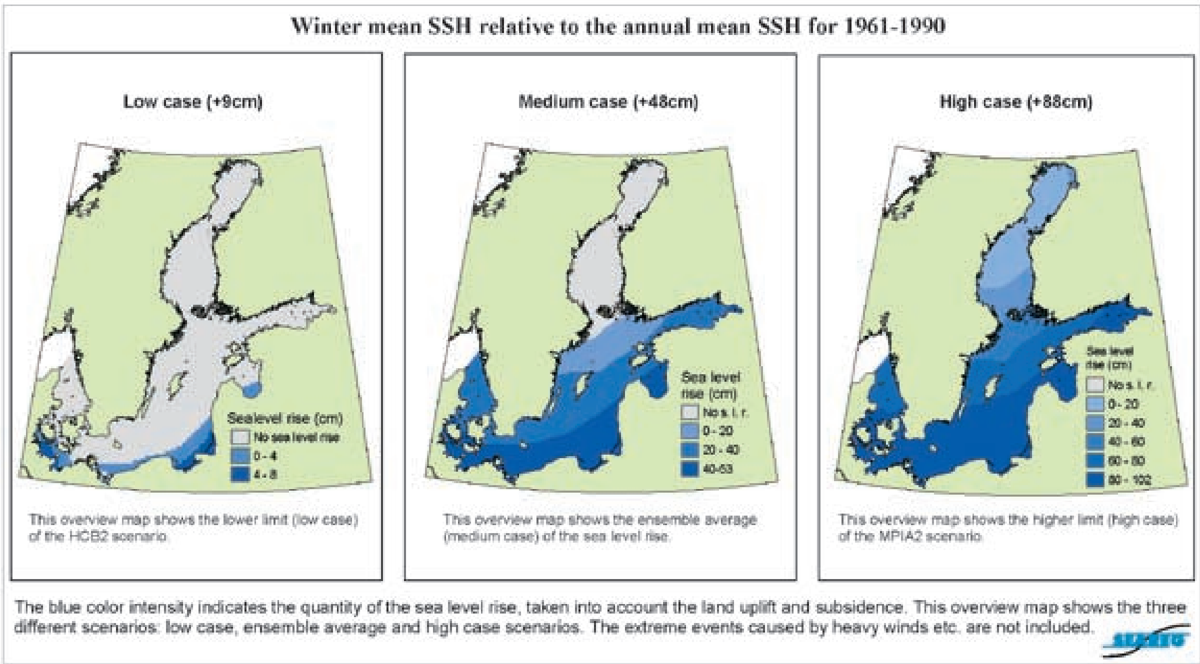

Fig 9. Winter mean sea level for 2071-2100 relative to the annual mean sea level for 1961-1990 (in cm). Results of three scenarios are shown (Meier et al. 2004). Source: H.E.M. Meier SMHI & H. Kallio GTK.

case' scenario, the future winter mean sea level in the Baltic Sea is lower compared to the control mean sea level except in the regions with subsidence close to the German and Polish coasts (Fig.9, left panel). This is explained by the overall land uplift, which is larger than the assumed global mean sea level rise of only 9 cm in this scenario. The calculated sea level increase in the southern Baltic is very small. In the `ensemble average´, the future mean sea level is higher in the southern Baltic, Baltic proper and Gulf of Finland and lower in the Gulf of Bothnia compared to the annual mean sea level for 1961-1990 (Fig.9, middle panel). The largest increase is found in the southern Baltic and in the eastern Gulf of Finland. In our `higher case' scenario, the future mean sea level increases in the whole Baltic Sea (Fig.9, right panel). A significantly higher sea level of about 1 m is projected for the eastern and southeastern coasts of the Baltic proper and Gulf of Finland.

The largest uncertainty of the calculated mean sea level changes in the Baltic Sea is related to the global average sea level rise. Although the differences of the three regional scenarios are substantial, it is possible to draw conclusions. If the global average sea level rise accelerates and if westerly wind speed increases significantly in a future climate (as suggested by two of our scenarios, i.e. RCAO-E A2 and RCAO-E B2), the largest changes will occur on the eastern and southeastern coasts of the Baltic proper and the Gulf of Finland. This result is explained mainly by land uplift in the Bothnian Bay and the Bothnian Sea (Fig.3).

In the previous section, the increase of the wind speed in the scenarios using either RCAO-E or RCAO-H was shown to be more or less uniform (Fig.7). In a future climate, the probability distribution functions are shifted to higher wind speeds, that is extremes will not change more than mean wind speed. In the same manner we have calculated probability distribution functions of the sea level at the three stations Helsinki, Stockholm, and Greifswald (Fig.10). In this calculation, the impacts of land uplift and global average sea level rise are not considered. In contrast to our results for wind speed, the sea level probability distribution functions change their shape,

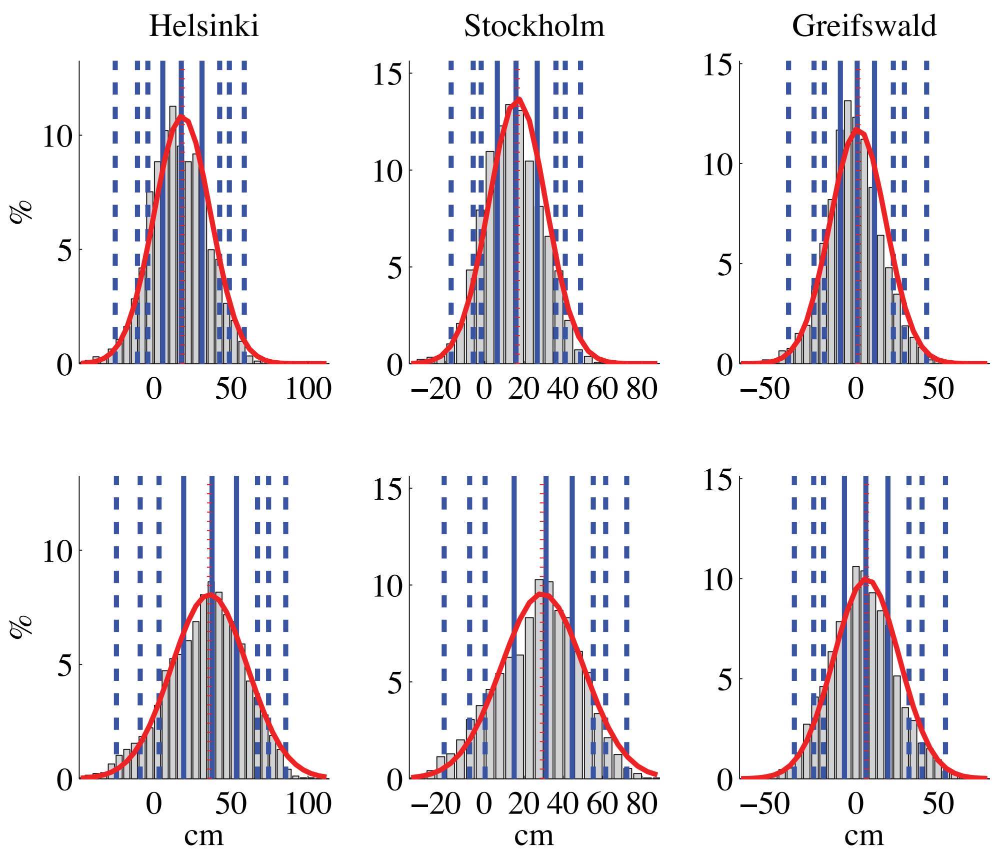

Fig. 10. Winter frequency (in %) sea level histograms in the RCAO-E CTRL run (upper panels) and RCAO-E A2 run (lower panels). The bars represent the actual distribution of the diurnally averaged data (N=2700 in each panel) with an interval of 5 cm. The red dotted line is the mean and the red full line is a normal distribution with the mean and standard deviation taken from the actual distributions. The dashed and full blue lines are the percentiles (1st, 5th, 10th, 25th, median, 75th, 90th, 95th and 99th) of the distributions. Source: H.E.M. Meier & E. Kjellström SMHI.

and in a future climate extreme sea levels increase more than the mean sea level. This non-linear behaviour is an important finding that supports our approach of using a regional climate model instead of applying a statistical downscaling method. An explanation might be that increased wind speeds during storm events locally stir anti-clockwise traveling Kelvin waves with maximum amplitudes at the extreme ends of bays or fjords, like in the Gulf of Finland. Further investigations are still necessary to illuminate the processes involved.

We have shown that depending on the scenario and location, the calculated changes for mean (Fig.9) and extreme (Fig.10) sea levels are significant compared to the internal variability of the system (Fig.8). For further details of the sea level scenarios see Meier et al. (2004b). Another study of sea levels in future climate was presented by Johansson et al. (2004).

3.3 Wind waves

The simplified wave model was validated against observations from two wave rider buoys. Significant wave heights were calculated using 3-hourly observed wind fields of the SMHI data base. In this data base, measurements of all available synoptic stations (about 700 to 800) covering the entire Baltic Sea drainage basin are interpolated on a 1°×1° regular horizontal grid. A two-dimensional univariate optimum interpolation scheme is used. As only geostrophic wind fields are available, a boundary layer parameterization is used to calculate wind speeds in 10 m height using a constant reduction coefficient of 0.6 and an ageostrophic angle of 17°. Using this wind, a 25-yr long hindcast simulation for the period 1980 to 2004 was performed. The results were compared to observations of the wave buoys at Almagrundet during 1984 and at Ölands södra grund during 2000. The agreement between model results and observations is satisfactory (Fig.11). Based upon 3-hourly data of the 1984 mean error *ME*, root mean square error *RMSE*, correlation coefficient *R*, and explained variance *VAR* result in *ME* = -0.19 m, *RMSE* = 0.47 m, *R* = 0.77, and *VAR* = 0.35, respectively. The annual mean significant wave heights in the model and in observations are 0.60 and 0.80 m, respectively. Finally, the maximum significant wave heights in the model and in observations are 6.39 and 6.69 m, respectively (Fig.11).

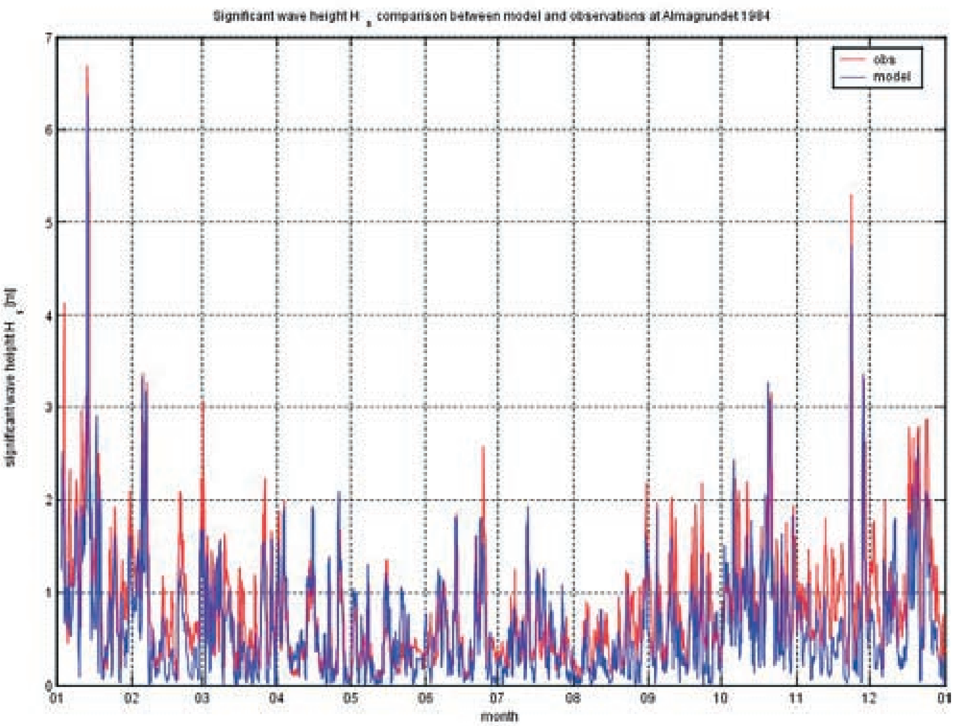

Fig 11. Modeled (blue line) and observed (red line) significant wave height at Almagrundet during 1984. Source: B. Broman SMHI.

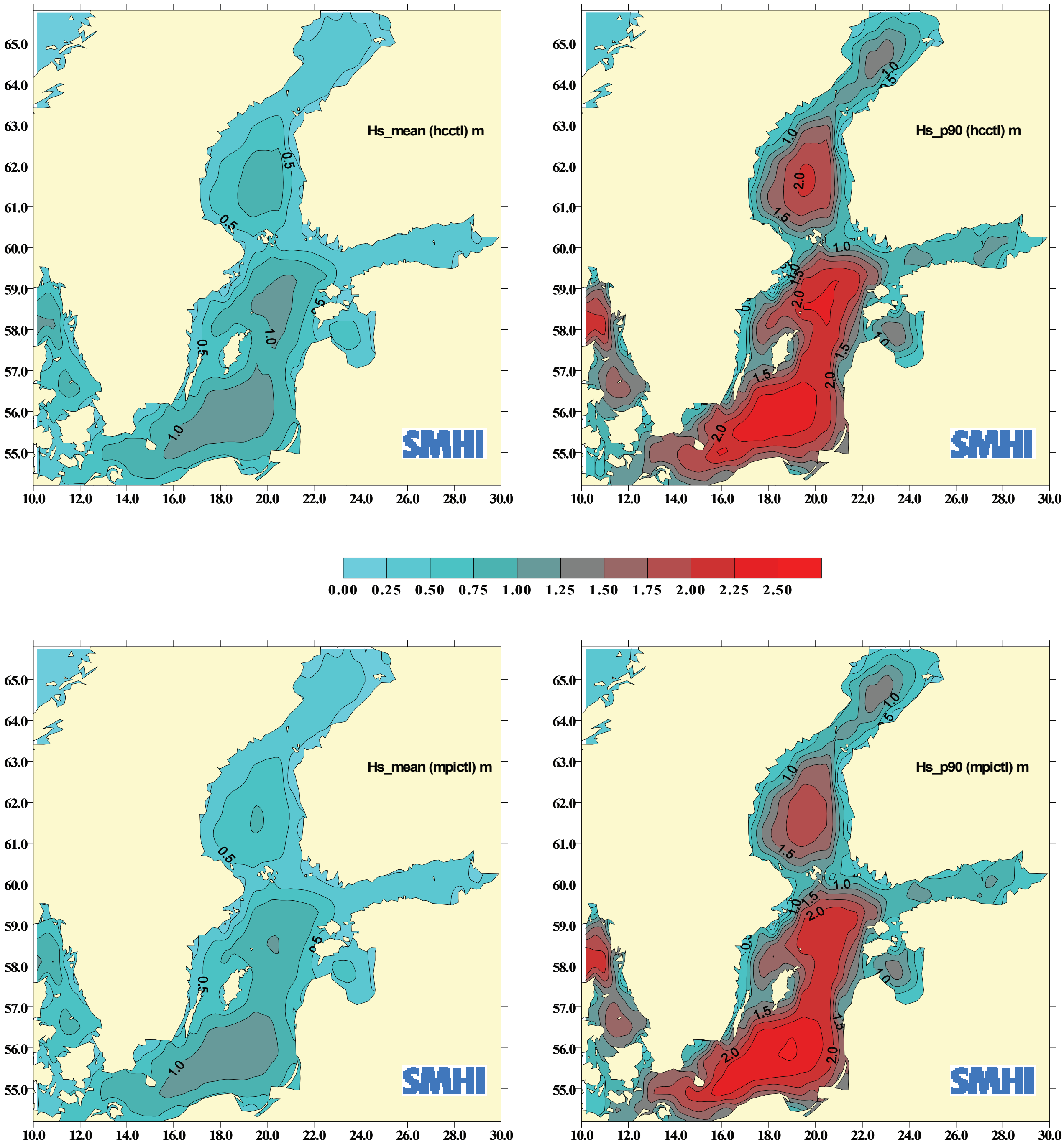

Fig. 12. Significant wave heights (in m) in the control climates: RCAO-H (upper panels), RCAO-E (lower panels), annual mean (left panels), and 90th percentile (right panels). Source: B. Broman SMHI.

Control and scenario simulations of the wave climate were performed using wind forcing of RCAO-H and RCAO-E. Therefore, wave maps for the whole Baltic Sea were calculated for every day during the 6 time slices. Results from the two control runs gave similar mean wave heights of 0-1.3 m (Fig.12). The corresponding 90th percentile shows waves on the order of 0-2.5 m with the highest waves in the southern and eastern Baltic proper (Fig.12). The differences of the mean significant wave height and the 90th percentile of the wave height between control simulations (1961-1990) and hindcast simulation (1980-2004) are in a range between -0.2 and 0.2 m approximately (not shown). In the basin centers, the waves of the control simulations are higher (mean and 90th percentile), whereas close to the coast the waves of the hindcast simulation are higher (mean significant wave height only).

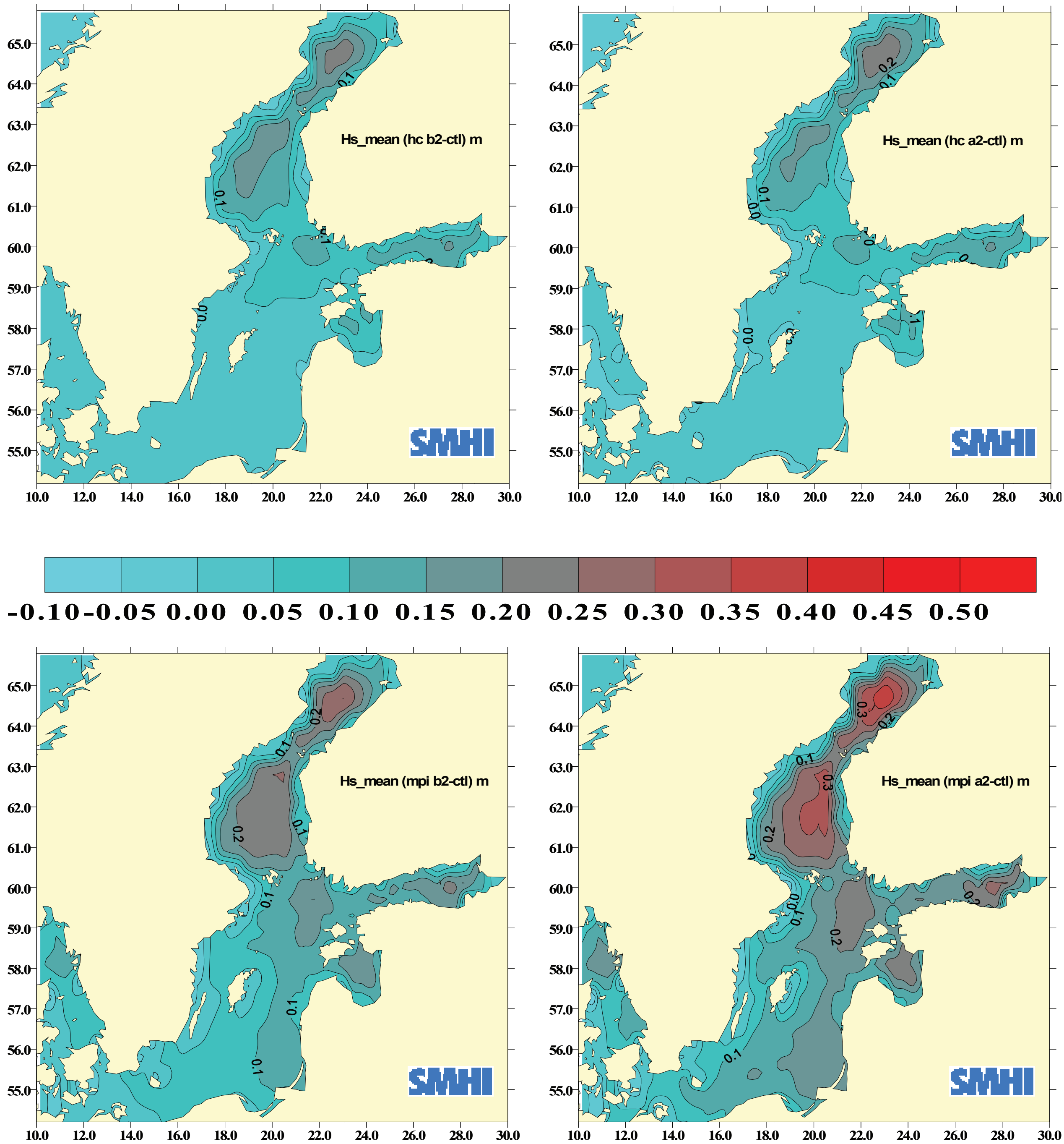

Fig. 13. Changes of annual mean significant wave heights (in m) in the scenarios compared to the control simulations: RCAO-H (upper panels), RCAO-E (lower panels), B2 (left panels), and A2 (right panels). Source: B. Broman SMHI.

Changes in the mean significant wave height are largest in the Bothnian Sea and the Bothnian Bay (Fig.13). Less sea ice in this area causes increased wind speed (section 3.1) and thus the waves are higher. The changes are on the order of 0-0.2 m in the B2 scenarios and 0-0.4 m in the A2 scenario. Larger values are found in RCAO-E compared to RCAO-H, which is consistent with the larger increases in wind speed in those simulations.

Changes in the 90th percentiles are also significantly larger in RCAO-E than in RCAO-H (Fig.14). Maximum changes of 0.5 m located in the eastern part of the Bothnian Sea, Bothnian Bay, and Gotland Sea are calculated.

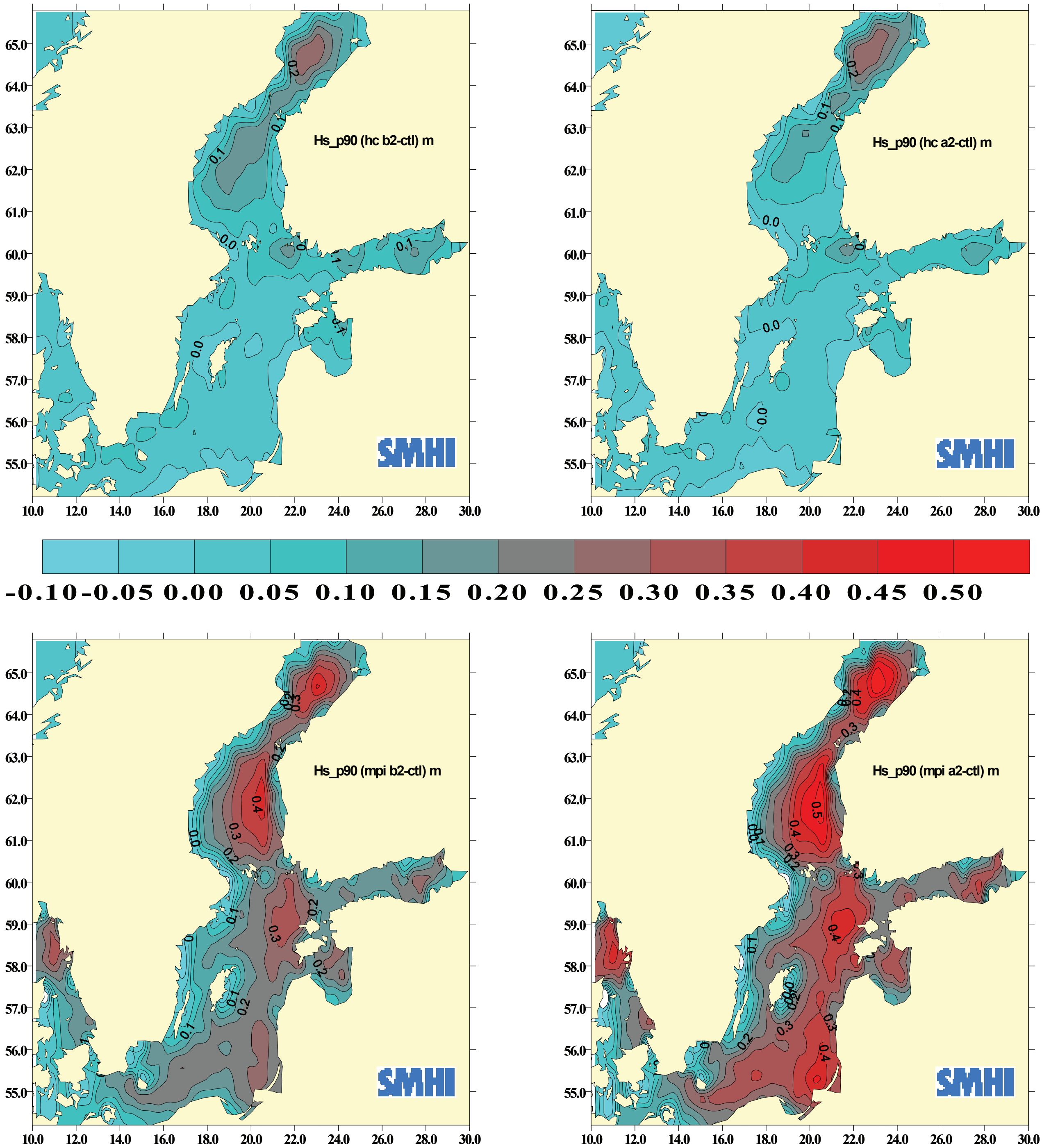

Fig.14. Changes in the 90th percentiles of the significant wave height (in m) in the scenarios compared to the control simulations: RCAO-H (upper panels), RCAO-E (lower panels), B2 (left panels), and A2 (right panels). Source: B. Broman SMHI.

3.4 Flood prone areas

Within the SEAREG project, selected regional study areas are Itä-Uusimaa/Finland, Lake Mälaren Region/Sweden, and Mecklenburg-Vorpommern/ Germany and the local study areas are Helsinki, Stockholm, Usedom, Gdansk, and Pärnu. In this volume, applications of the sea level scenarios in these selected areas are presented (Graham et al. 2006, Klein & Staudt 2006, Lehtonen & Luoma 2006, Röber et al. 2006, Staudt et al. 2006, Viehhauser et al. 2006, Virkki et al. 2006, *this volume*). Following our strategy (Fig.1), the sea level scenarios calculated with RCAO in the height system NH60 were compared with gridded topographical data of DEMs. Therefore, the global average sea level rise (Fig.2) and land uplift (Fig.3) were considered. The impacts of rising winter mean sea levels (Fig.9) and extremes adding the highest locally measured storm surge were studied. In the case studies, maps of flood prone areas in the various scenarios (`lower case´, `ensemble average´, and `higher case´ scenario) were compiled. For instance, the possible impact of future sea level rise was assessed for the city of Pärnu in the Gulf of Riga (Klein & Staudt 2006, *this volume*). Klein & Staudt (2006) combined a DEM, land-use data and sea level scenarios and found that in the `higher case´ scenario the impact of future sea level rise on the service sector, groundwater and water supply, and protected natural areas would be considerable (Klein & Staudt 2006, Figs.1-3, *this volume*). For the city of Gdansk and surrounding areas, a similar impact assessment was done (Staudt et al. 2006, *this volume*). Staudt et al. (2006) showed impact maps of selected hot spots (their Fig.3) and concluded that the vulnerability of the region is high because of the lack of awareness and resources to identify sea level rise as a threat in the future. Although the impact of sea level rise in the region of Itä-Uusimaa is smaller than in the most eastern and southeastern Baltic due to land uplift (Fig.9), the presented down-scaling technique was successfully applied to identify flood prone areas on a local scale (Virkki et al. 2006, Figs. 2 and 3, *this volume*). In this area, spatial planning plays an important role in mitigating the impacts of sea level rise. While in the impact studies performed by SEAREG RCM results of changing sea levels were mainly used, other variables like wind speed and wind waves were also used to calculate changing coastlines, erosion and sediment transports (Röber et al. 2006, *this volume*). In the case study of Usedom Island, future shoreline changes (abrasion and accumulation) were estimated. Sediment transports were calculated from wind and sea level scenarios, estimated from wave data, which in turn depends on wind distributions. Röber et al. (2006) found that the trend of the coastal evolution observed in historical records will continue over the next 100 years. In areas with current accumulation, changes in the wave energy due to climate change are more important than changes in the mean sea level. However, in areas with abrasion the sea level rise is more effective (Röber et al. 2006, Fig.6, *this volume*). According to results by Röber et al. (2006), changes in wave energy as in RCAO-E A2 have an impact on the average accumulation rate of about 14%. The impact on the average abrasion rate is about 5% smaller.

It is important to note that the downscaling approach presented here works for regional and local scales but not for the scale of the entire Baltic Sea Region. Topographical data available for the entire Baltic Sea Region are too coarse to resolve the scales of interest. The biases of these data are of the same magnitude as the projected sea level changes. This makes the calculation of flood prone areas impossible. For instance, Seifert & Kayser (1995) and Seifert et al. (2001) presented a digitised topography on a regular spherical grid based upon sea charts and soundings. The resolution is 2' and 1' in longitude and latitude, respectively. This bathymetric data set is used in the RCM to calculate water depths (Meier et al. 2003). Land heights were adapted from the GTOPO30 data set that has a resolution of 0.5' in longitude and latitude. The data specify a representative average of the water depth or the land height of each grid cell, counted by negative and positive values in meters. According to the resolution of the sea charts, the depth values were estimated in steps of 1 m, 5 m, and 10 m within the depth intervals 0-50 m, 50-150 m, and below 150 m, respectively. A typical range of differences between various bathymetric data sets is 0-2.5 m (Seifert et al. 2001). Since the change in the mean sea level in scenarios for the end of the 21st century is at maximum about 1 m, the accuracy of the topographical data is not sufficient to calculate flood prone areas. Another difficulty is that the height systems of the sea charts are unknown and very likely differ. Consequently, state-of-the-art topographical data sets do not allow an assessment of flood prone areas in the entire Baltic Sea region.

4 SUMMARY AND CONCLUSIONS

Projections of future surface winds, sea levels, and wind waves in the late 21st century were analyzed. The surface wind and sea level fields were an output of a RCM. The wave climates were calculated using a simple wave model based upon a nomogram forced with wind fields of the control and scenario simulations. Both sea level and wave results may be used to estimate the risk of flooding and damage to construction and buildings on the shoreline. In this volume, examples of combining DEMs on regional and local scales with changing sea levels and land uplift are presented. The results of two selected global models were scaled down to estimate the impact of global change on flooding and wind waves on a horizontal scale of about 1 m. In summary, the main findings of this study are:

1. In the control simulations (1961-1990), both mean wind speed and wind extremes are underestimated compared to observations at the Landsort station (21-28 %). The mean wind speed biases are caused partly by biases of the lateral boundary data of the GCMs whereas the underestimation of high wind speed is a general problem of state-of-the-art RCMs.

2. In the scenario simulations (2071-2100), area averaged mean wind speed increases in winter by 3-18 %. During the other seasons increases are either smaller or even negative, for example, in some scenarios a reduction of mean wind speed in summer by about 5 % is observed. The largest increases during winter and spring were found in the Gulf of Bothnia caused by changes to the sea-ice cover. In all scenarios, wind speed changes are approximately uniform, meaning wind speed extremes do not increase more than the mean wind speed.

3. Mainly due to the large uncertainty of a projected global average sea level rise of about 1 m, mean sea level scenarios in the Baltic Sea Region differ substantially (maximum change is about 1 m). Therefore, a quantitative risk assessment of flood prone areas is impossible. However, some conclusions may be drawn. The largest changes will occur on the eastern and southeastern coasts of the Baltic proper, Gulf of Riga, and Gulf of Finland. In contrast to changes of the wind speed, extreme sea levels will increase more significantly than the mean sea level.

4. In the hindcast simulation, the mean significant wave heights of the simple wave model presented are underestimated compared to observations from 1984 at the Almagrundet station (-24 %). In general, the differences in the mean significant wave height and the 90th percentile of the wave height between control simulations (1961-1990) and hindcast simulation (1980-2004) are in the range of -0.2 and 0.2 m. In the basin centers, the waves of the control simulations are higher.

5. In the scenario simulations (2071-2100), the annual mean significant wave heights and the 90th percentiles increase by about 0-0.4 m and 0-0.5 m, respectively. In all scenarios, the largest increases were found in the Gulf of Bothnia and in the eastern Gotland Sea when RCAO-E is applied.

6. The downscaling of global change results and the combination of RCM and DEM results have been shown to work satisfactorily to calculate flood prone areas on regional and local scales. However, state-of-the-art gridded topographical data sets of the entire Baltic Sea Region are still too coarse to allow an overall assessment. Consequently, within SEAREG limited study case areas were selected.

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IMPACTS AND COPING CAPACITY AS KEY ELEMENTS IN A VULNERABILITY ASSESSMENT ON SEA LEVEL CHANGE SCENARIOS

by
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Klein, J. & Schmidt-Thomé, P. 2006. Impacts and Coping Capacity as key elements in a Vulnerability assessment on Sea Level Change Scenarios. Geological Survey of Finland, Special Paper 41, 45–50, 4 tables.

The intensity and the type of the sea level rise impacts that might affect the coastal area of the Baltic Sea differ largely depending on the location of an area. The methodology for vulnerability assessment developed in the SEAREG project can be used for most areas along the Baltic coast. It enables a systematic examination of a local system to highlight the most critical issues concerning future sea level rise. As part of the Decision Support Frame the Vulnerability Assessment supports the work of spatial planners and decision makers and helps to take into account sea level rise for long-term spatial development.

Key words (GeoRef Thesaurus, AGI): climate change, sea level changes, transgression, floods, coastal environment, risk assessment, coping capacity, Baltic Sea.

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1 INTRODUCTION

Sea level rise is one of the expected effects of global climate change. Based on the scenarios of the Intergovernmental Panel on Climate Change (IPCC) a global sea level rise in the range of 9 and 88 cm is expected (Cubasch et al. 2001). The Baltic Sea can be affected by a changing sea level during the next century that diverges considerably from the projected values for global sea level change (Meier et al. 2004).

During the last decade, the focus of research was on mitigation strategies in terms of reducing greenhouse gas emission and slowing down the global climate change process. However, even successful mitigation strategies will not take effect immediately but rather in several decades (Lorenzoni et al. 2000). Global sea level is expected to rise for centuries owing to the long reaction time the deep ocean needs to adjust to the climate change (Houghton et al. 2001). Therefore mitigation strategies of the impacts of sea level rise are needed.

As most of the major urban areas of the Nordic and Baltic countries lie along the Baltic Sea coast, rising sea level may have serious impacts. For any mitigation of sea level rise impacts it is indispensable to raise awareness and enhance the communication between natural scientists, local and regional planners as well as decision makers. One component to support the interdisciplinary approach of the BSR Intereg III B project “Sea Level Change Affecting the Spatial Planning in the Baltic Sea Region” (SEAREG) is the development of a Vulnerability Assessment (VA).

Since the early 1990s, a number of methodologies for the assessment of vulnerability towards climate change have been developed. Nicholls (1998) differentiates between a methodological framework that offers several steps for the VA and VA-tools that are used to accomplish the individual steps. In the technical report for “Coastal Vulnerability Assessment for Sea-Level Rise: Evaluation and Selection of Methodologies for Implementation” Nicholls lists among other VAs, the IPCC Common Methodology (1992), the US Country Study Program (1995), the UNEP’s Handbook on Methods for Climate Change Impact Assessment and Adaption Strategies (1998) and the South Pacific Island Methodology (1995). The VAs comprise qualitative screening as well as detailed quantitative assessment dependent on the methodology and the way of implementation.

The VA for the BSR has to meet several demands. The intensity and the type of the impacts that will affect the coastal area of the Baltic Sea will differ largely depending on the location of the assessed area. Whereas northern Scandinavia still rises up to 9 mm/year (relative to the sea level from 1892 to 1991), there is a subsidence of about 1 mm/year in Vorpommern in northern Germany (Ekman 1996). Impacts, which are comparable in total numbers (e.g. square kilometers of inundated area or number of flooded houses), can lead to different results in terms of vulnerability depending on local conditions. Land loss caused by inundation can be negligible in sparsely populated areas, meanwhile in an area with high population density and development areas for housing close to the shore, a similar land loss will be much more serious.

The availability of data for the assessed areas may differ largely. The German ATKIS database (Amtliches Topographisch-Kartographisches Informationssystem) provides detailed and well-structured information ready for use by GIS-systems. In comparison, in Estonia the development from a part of the Soviet Union to a member of the European Union (since 2004) comes along with breaks and changes in data maintenance. Different GIS-systems for space-orientated data and changing reference systems are a challenge to handling the data.

The framework developed in the SEAREG project has a structure that can be applied in all case study areas of the project. At the same time, it is open to take into account local differences. The Vulnerability Assessment (VA) enables a systematic examination of a local system to highlight the most critical issues concerning future sea level rise (SLR). As part of the Decision Support Frame (Schmidt-Thomé P. & Peltonen 2006, *this volume*), the Vulnerability Assessment supports the work of spatial planners and decision makers and helps to take SLR into account for long-term development.

2 METHODOLOGY

The VA is built on the assessment of the ‘hard and soft characteristics’ of an area concerning SLR. The hard characteristics are evaluated in the impact assessment describing how SLR would affect today’s natural and built-up environment. The soft characteristics comprise the capacity of stakeholders and institutions to cope with the impacts of SLR. How and in what order impact assessment and assessment of the coping capacity are done depends strongly on the local conditions. There is no recommended chronology of steps. Several iterative steps in this approach are possible, for example, a rough screening followed by a detailed assessment or use as a static-comparative model by assessing two different scenarios.

The impact assessment (IA) develops from an impact matrix derived from an approach for vulnerability assessment introduced by Nicholls (1998). Nicholls’ matrix shows so-called “biophysical” impacts of SLR versus socio-economic impacts. Nicholls’ matrix was modified (Table 1), as the effects of SLR were separated from the impacts on specified sectors because the same effect of SLR can cause different impacts depending on the affected sector. The direct effects of SLR are flooding and inundation (Table 2). These effects depend only directly on the height of SLR and the topography of the affected area. At the same time, the categories shown in this matrix decompose the assessed area in a way that all entities affected by SLR could be attached to one of the categories.

Table 3 shows the definitions for each of the eight categories.

Thus, the IA is open to take into account the local situation. The very basic form of the matrix and the abstract formulation of categories allows for the use of the IA in different areas without changing the structure. The results for the impact matrix can be shown in an ordinal scale ranging from "no impact" to "extreme impact". The advantage of the matrix structure is that the results for the categories can be seen in relation to each other. This provides a kind of inherent weighting of the impacts, if the matrix is filled consistently, that is there are no contradictions comparing single cell values in pairs. Dependent on the available data and the effort with which the IA is done, the impact levels in the matrix can be based on a very rough estimation or an elaborate system with several subcategories. The significance and accuracy of the results may vary depending on the way the IA is done.

While the matrix gives an overview on the impact, the descriptive part ensures that the system used in the detailed assessment is transparent. This part comprises a description of the way the assessment is done and of the data used for the IA. The descriptive part gives reasons for the results of each of the impact matrix categories and explains them in detail.

Table 1. Screening Assessment Matrix for impacts of sea level rise taken from Nicholls (1998).

Biophysical Impact of Sea Level Rise	Socio - Economic impacts							
	Tourism	Human Settlements	Agriculture	Water Supply	Fisheries	Financial Services	Human Health	Others?
Inundation								
Erosion								
Flooding								
Salinization								
Others?								

Table 2. Structure of the impact matrix developed in the SEAREG project.

Sea Level Rise Effects	Agriculture, Forestry, Fishery	Industry	Services	Infrastructure	Housing	Open urban area	Ground water	Protected nature areas
Inundation								
Flooding								

Table 3. Definitions for the categories of the impact matrix.

Category	Exemplary Description
1st Sector	Agriculture, Fishery, Forestry
2nd Sector	Industry Industrial dumpsites
3rd Sector	Administration Trade Retail Tourism Other services
Infrastructure	Publicly used facilities characterized by indivisibility, manifold use, long lifetime and difficulty to exclude specific users
Housing	Residential areas that are not covered by any field above.
Open Urban Area	Parks Greenfield Wasteland Brownfield All areas not in use for buildings, any infrastructure or one of the three economic sectors
Groundwater and Water Supply	Aquifers Recharge areas Wells
National Parks / Protected Areas	National parks Nature reserves Other protected areas Any other area of high ecological value

Independent of the assessment system, the choice of an assessment scale remains challenging because the process is partly subjective and depends on the background, experiences and opinions of the person doing the assessment. With respect to the aim that the assessment should enhance the work of local and regional planners, it is important to integrate the experience of local experts and authorities.

The IA benefits from the input of modeling and GIS applications. This input comprises a set of SLR maps showing three scenarios “Low Case”, “Ensemble Average” and “High Case” for the case study area. These three scenarios are based on the results of the RCAO model system (Meier et al. 2006, *this volume*). The SLR maps can also include information about storm surges and floods, provided that the available data are comprehensive enough.

Coping capacity refers to the ability of an entity (single stakeholder, an organization or a region) to withstand and cope with SLR impacts, which are assessed and identified as described above. The aim of the coping capacity assessment is to estimate the current possibilities of planners, local decision makers and other stakeholders to define appropriate mitigation strategies towards future SLR. The assessment helps to identify the strengths and weaknesses of the assessed area.

Retreat, accommodation and protection are the three main options to mitigate the effects of SLR. Retreat means to abandon an area that will be affected by SLR. Accommodation is a way to cope with SLR by changing land use and construction standards for buildings. Protection means dealing with future SLR by building sea walls or other protective physical constructions. These three actions are not exclusive and can be applied at the same time in an area. A combination of retreat, adaptation and protection forms a mitigation strategy for an area. (IPCC 1990)

Since the impacts of SLR vary over different sites and structures, the requirements for coping capacity differ. While non-existent impacts of SLR do not require coping, strong impacts call for stakeholders, organizations and institutions with a strong coping capacity.

The first step is to choose the categories most affected by future SLR. Each of these categories contains entities that contribute significantly to the category’s impact level. These are the so-called “hotspots”. For each of these hotspots, the related stakeholders are identified. This bundle of hotspots and stakeholders can be displayed in a table as shown the example in Table 4.

In the second step, the following four questions help to assess the coping capacity of each stakeholder:

- What is the knowledge of the stakeholder?
- What are the resources of the stakeholder?
- What is the stakeholder awareness of the climate change impact?
- What is the motivation of the stakeholder (depending also on if the stakeholder represents private or public interests)?

The knowledge encompasses how familiar the stakeholders are with legislation and regulations, with techniques and measurements to deal with SLR. The resources comprise funds available for mitigation measurements, flood insurances or any other financial aid for the stakeholders to cope with the expected impacts. The awareness describes how far the stakeholders have recognized possible impacts of future SLR in their sphere of action. The question of motivation assesses the priority of mitigation strategies as part of the present actions and the effort made to cope with SLR so far. The same questions are answered not only by the stakeholders but also by the local and regional planners and decision makers who have to deal with the entire assessed system rather than with individual hotspots.

The coping capacity of a region or area depends not only on individual persons, but also on the interaction of persons and the respective institutional background. Therefore, in the third step the institu-

Table 4. Hotspots and stakeholders.

	Hotspots	Stakeholder 1	Stakeholder 2	Stakeholder x
I	E.g. beach			
II	E.g. houses			
III	E.g. road			
x				

tional coping capacity is assessed. Again, five questions are used for guidance to a final evaluation. The first aspect asks for the cooperation among regional stakeholders. It assesses existing cooperation (e.g. flood groups) or conflicts of interests. The second point assesses the strength of institutions, that is, how the division of labor is structured among the institutions and how the implementation of regulations works. Thirdly, the credibility of politicians and decision makers is estimated. The fourth question evaluates the importance of planning in guiding regional or local development. Finally, public awareness concerning climate change and future SLR are assessed, analyzing the discussion in local media and using indicators such as the existence of active citizens or lobby groups.

To state a level of vulnerability for the assessed area, a clear definition of the meaning of vulnerability is needed. Vulnerability can be defined as "a set of conditions and processes resulting from physical, social, economical and environmental factors, which increase the susceptibility of a community to the impact of hazards." (Schmidt-Thomé 2005). In that sense, vulnerability depends on the possible impact determined by the effects of SLR and the susceptibility of the system towards SLR, as well as the capacity of the stakeholder and the entire system to withstand and cope with it. The vulnerability is the synopsis of a category's impact level and the coping capacity of the related stakeholders or the coping capacity of a stakeholder and the impact level of the categories in his/her sphere of action.

3 RESULTS

The VA was implemented in four case study areas of the SEAREG project (please see relevant articles in this publication): in Gdansk (Poland) and Pärnu (Estonia) on a local level; and in Itä-Uusimaa and Vorpommern on a regional level. The focus of the VA was different in each of the case study areas. In Gdansk, the results arose in equal shares from available spatial data and expert interviews and opinions. An initial screening of the impacts led to a major discussion involving scientists and local planners. The following assessment was amended by the judgment of local experts. The VA in Pärnu is mainly based on land use data and spatial information supported by only few interviews done after a detailed assessment. The case studies in Itä-Uusimaa and Vorpommern gained results from a large number of interviews of regional and local planners, decision makers and stakeholders. The VA was introduced by the questions of coping capacity. These initial questions raised awareness and initiated a lively discussion based on the information given by the SLR maps. The VA proved to be widely applicable and independent of the local conditions and constraints.

4 DISCUSSION

When merging several assessed data into one category, one cannot avoid the fact that important aspects are neglected or ignored. One faces the same kind of dilemma inherent in all attempts of aggregation: the simplification, which helps to make the impacts understandable, adds and omits information and hence strongly influences the final impression of the impact.

The large time frame of 100 years causes another assessment problem. Many local authorities and decision makers desire a monetary assessment following the principle of "from map to money". Future SLR will not cause a sudden impact of a certain amount in a well-defined time, as storm surges do for example, but SLR is rather a continuous process that affects the existing system as well as its future development. Local and regional planning and private decisions will react to occurring events, even though SLR might be not recognized as an ongoing process triggering these events. Klein & Nicholls (1998) call this interaction of the development of an area and SLR "autonomous response". The impossibility of separating the development into two clearly distinguishable parts, "development without SLR" and "autonomous response" (in case of no explicit action is taken) leads to questionable cost-estimations of future SLR. Therefore, a monetary assessment like a cost-benefit analysis of mitigation actions involves difficulties.

So far, the assessment is applied to the impacts of SLR in the present state of the socio-economic system. This bypasses two assessment problems. Since the future development of the socio-economic system is not taken into account, the problem discussed in the paragraph above does not affect the assessment. The second bypassed problem is to find an appropriate discount rate for assessing impacts occurring at different points in time. Depending on for whom the assessment should be valid, the discount rates might differ largely. However, this challenge rises as soon as mitigation and adaption strategies are discussed not only concerning what action should be taken and to which extent but also when they should be taken.

5 CONCLUSIONS

The VA helped to identify potential impacts of sea level rise on the ecological and socio-economic systems in the case study areas as well as to initiate discussions about the topic among the involved stakeholders. The impact assessment and assessment of coping capacity together with the SLR maps provided by GIS applications enhanced the understanding of interactions between SLR and local systems.

SLR is only one of a set of climate change effects. In many areas, the impact of sea level change might be negligibly small compared to other climate change impacts or the consequences of economic and political changes. The broadening of the VA to take into account other climate change effects can be a first step to considering other aspects of an area's future development and the interdependencies and relationships between them.

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ACTORS, NETWORKS AND ACTOR-NETWORKS IN COPING WITH SEA LEVEL RISE

by

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Coping with sea level rise calls for new constellations of actors. The notion of networks and the so-called actor-network theory (ANT) are discussed in relation to SEAREG results, with reference to stakeholders and the challenges of knowledge transfer between them. This perspective highlights how existing networks help to tackle sea-level rise and, how climate change adaptation and sea level rise "recruit" new sets of actors into response networks. The ANT perspective also points to non-human entities (e.g. sewage systems or power plants), thus providing an innovative element to mapping vulnerable networks facing climate impacts. Overall, the network perspective reveals missing links in organisational and institutional structures that are relevant for planning and decision-making.

Key words (GeoRef Thesaurus, AGI): climate change, sea-level changes, floods, preventive measures, planning, cooperation, networks.

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1 INTRODUCTION

How concerned should the people around the Baltic Sea be about climate change? Is the possible sea level change going to affect spatial development of the region? Are spatial planners prepared to discuss mitigation strategies? Such questions have been dealt with in the SEAREG project. The acronym stands for Sea Level Change Affecting the Spatial Development of the Baltic Sea Region. The project was carried out from 2002 to 2005 as part of the Baltic Sea Region (BSR) INTERREG IIIB programme. The starting point of the SEAREG project was to seek an interdisciplinary understanding of the challenge of climate change induced sea level change. The experts in climate change research and geology were to meet spatial planners and, with the help of social scientists, to learn from each other. They were to build a common base (which later got its form in the Decision Support Frame), to find concepts and categories that make an exchange of ideas possible.

Studies of the effects of sea level change fall into a fuzzy in-between zone of physical and social sciences. Understanding both the causes and effects or the stress/pressure effects and vulnerabilities of sea level change requires the joint efforts of experts in many disciplines. A key conceptual challenge that emerged in SEAREG was the discrepancy between the complexity of the issues at hand and the dichotomous categorizations that seemed to surface inevitably: How to link global climate change with local development? How to link climate modelling to planning practice? The phenomenon of sea level change reveals itself as a complex 'bundle' or hybrid between physical and social sciences. This hybrid constellation, combining climate science and regional planning practices can only be understood through interdisciplinary co-operation. Linkages are also needed between theory and practice. An important challenge in this respect is to address the two different modes of scientific inquiry, namely the quest for certainty propagated by natural and physical sciences and the mode of praxis, the quest for pragmatic solutions for planning problems. Any expertise has to be "embedded" and relevant for local realities to have effects on adaptation measures.

The hybrid constellations that the phenomenon of sea level rise implicates (e.g. Global climate - Baltic Sea - Climate science - local organisational patterns - socio-economic realities - regional planning practice) can be understood only if we see beyond binary divisions of scales and disciplines. In the following, we will try to make sense of these constellations, focussing on actors and networks. First, we will discuss the concept of networks, including the description of the so-called actor-network theory (ANT), to find entries to understanding the multi-faceted, hybrid phenomena connected to sea level change. Second, the network notions will be examined in relation to stakeholders and sea level rise, referring to SEAREG results. Third, the role of networks will be discussed from the point of view of knowledge transfer. Finally, some conclusions will be drawn regarding the uses of network notions and the actor-network theory in addressing climate change adaptation in general and sea level rise in particular.

2 THEORIES OF NETWORKS AND ACTOR-NETWORK THEORY (ANT)

Many environmental issues are an exemplary case of *wicked problems*, which have far-reaching implications for many actors, even future generations. Networks can be seen as an answer in such cases, where no actor can address the problems alone (Bueren et al. 2003). Notions such as co-operative governance or network management have been used in this context as new approaches to planning and decision-making (e.g. Glasbergen 1995 and 1998, Hajer & Wagenaar 2003).

From a planning perspective, power to coordinate actions and collaborate emerges from network connections. Booher & Innes (2002) have used the notion of network power to describe the "shared ability of linked agents to alter their environment". According to these authors, network power is closely linked with flows of communication:

Network power emerges from communication and collaboration among individuals, public and private agencies, and businesses in society. Network power emerges as diverse participants in a network focus on a common task and develop shared meanings and common heuristics that guide their action. The power grows as these players identify and build on their interdependencies to create new potential. In the process, innovations and novel responses to environmental stresses can emerge. These innovations in turn make possible adaptive change and constructive joint action. (Booher & Innes 2002 p. 225)

Network power emerges in conditions where there is a diversity of actors that are interdependent and able to enter into authentic dialogue to explore options for joint action. Interestingly, Booher and Innes relate their notion of network power to adaptive change. This relates easily to environmental issues and wicked problems such as climate change adaptation.

Another implication of the notion of networks is that they are more flexible than hierarchies. Networks do not have a pre-given sense of direction such as "top vs. bottom". Beech and Cairns (2001) have argued that post-dichotomous ontologies are useful for dealing with complex organisational change. They argue that rigid and dichotomous ontologies (e.g. organisation vs. environment) may prohibit innovative solutions to pressing problems. The challenge of hybrid network relations between an organisation and its environment undermines the meaning of 'managing' change. According to Beech and Cairns, the notion of 'coping' is more suitable. This lesson is just as pertinent in the case of adaptation to climate change in general, and more specifically the challenges climate change poses to planning organisations and their practices. In this light, understanding network connections becomes a factor in an organisation's coping capacity, which further affects its vulnerability to extrinsic events such as environmental change and unforeseen events.

Thus, the notion of network carries the implications of 1) social relations and collective action, 2) flexible organisation and 3) innovative linkages between entities that have not been understood as linked earlier. A special strand of network theorizing, namely the so-called actor-network theory, adds another (quasi-ontological!) aspect here: 4) shared agency in hybrid linkages between human and non-human actors or *actants*.

Proponents of the Actor-Network Theory have enlarged the idea of networks over the dichotomies such as nature-society or social-material. The theory has its roots in science studies, where Bruno Latour first traced the birth of scientific facts through a hybrid network constellation of disparate elements such as laboratory work, material elements and non-human elements such as microbes (Latour 1987).

Actor-network theory (ANT) has received considerable attention among researchers dealing with human-nature relationship. ANT takes distance from the ontological separation of nature and society. Latour (1993) has strongly opposed the way these two poles have been taken for granted in various practises, including critical research, for so long. The ”middle” has been conceived as a mixture of two pure forms: nature and culture. He claims that by forgetting the two poles one can get a better grasp of the hybrids, of the various phenomena that do not lend themselves to an in-depth study with conventional categories. He offers an alternative way with the help of actor-networks.

ANT sees social agency as a hybrid and collective performance that can include both human and non-human actors. Agency is a quality of the network, an achievement that is spun between various parts of a system/network. The ability to act is not an existing attribute but it is born and achieved by building different kinds of networks. The different elements of the actor-network take part in the action through their ability to affect the other elements and thus the whole network.

Both the ’purified’ categories and the de-centred agency were useful concepts when the SEAREG project was developing the tool called Vulnerability Assessment (Klein & Schmidt-Thomé 2006, *this volume*). To discuss the hotspots in relation to future sea level rise (both permanent inundation and flood events), some kind of matrix was needed in the first place for mapping possible damages. A division into socio-economic and ecological effects was discussed but later abolished. The matrix that was tested in case study areas also raised a considerable number of questions related to locating the identified problems in the matrix. Under which category should one mention the ashes of a wood/ coal burning power plant in Porvoo that one expert claimed risky since they contain cadmium and other heavy metals? Would it be under the secondary sector (as side-products of industrial production) or under infrastructure (as waste deposits) or under ground water resources (as potential contaminants) (Virkki et al. 2006, *this volume*)?

The same ashes can also be used to demonstrate how actor-networks can be perceived. The ashes were actually considered irrelevant for the theme at hand until one expert mentioned them as a potential hot spot and thus brought the enterprise and the environmental control authorities into the round of potentially concerned. On the other hand, one can say that they all were brought into the discussion through the researchers who had produced maps based on the climate change scenarios. A climate model or a resulting map can also be seen as an actor here, as one part of the collective agency.

If one does not like to call climate models or ashes actors, the term ’actant’ can be used instead. It was introduced as a response to the criticism ANT has faced as a theory or methodology. The division between actors and actants underlines the ability to be aware of one’s own actions and the consciousness of the actors. A climate model would thus be an actant as it lacks the awareness, but so might the owner of the enterprise that produced the ashes, at least as long as the potential harmfulness of the ashes has entered his consciousness. This could happen due to contaminated waters after a flood event or to a researcher that came to do an interview.

ANT has also faced criticism as it encourages the exploration of the unique rather than the general in the networks under scrutiny. Some claim that ANT undermines the explanatory power of theoretical frameworks and ignores the societal power relations. In recent applications of ANT, criticism has been addressed by reflecting more upon the positionality of actors and differentiating more carefully between interactive and indifferent kinds of actors (Latour 1999, Law 1999).

In the following, we will not enter into a discussion on the development of ANT. Instead, we present ANT as a heuristic framework that can be used to bring forward new perspectives to climate change adaptation.

3 ACTORS AND STAKEHOLDERS IN CLIMATE CHANGE ISSUES

To understand the relationship of actors to sea level change, researchers need to be rather comprehensive but also creative. Mapping issues and related actors are useful for this purpose. Networks are built around different "hotspots" that arise with climate change and sea level rise. Taking the network concept further, the actor-network theory can be a helpful reference in identifying hybrid actor-networks. It also brings up the concept of actants, highlighting the fact that all actors are not aware of their links to the question of sea level change. Furthermore, in ANT, all actors/actants need not be human. The case studies of the SEAREG project have shown the significance or the role played by single storm events and their linkages to various regulations (e.g. the Water Court Decrees on the level of Lake Mälaren in Sweden) (Graham et al. 2006 and Viehhauser et al. 2006, *this volume*).

The various identified actor-networks of the case study areas offer a chance for other localities to learn which issues can be significant when discussing the effects of sea level change. If the discussion took place before some major damage by sea level rise has occurred, the task would be much easier than afterwards when people look for the "guilty" or try to find somebody to take responsibility for the losses.

An example of actors and stakeholders can be seen in Helsinki, where the sea level rose to a new record height during a winter storm in January 2005. The threat of a flood activated a network, a series of actors that do not have contacts with each other on a daily basis. The higher the water got, the more stakeholders got connected to the network.

As the actor-network theory would conceptualize it, the winter storm *recruited* many actors and structures into a network. In the case of the winter storm, individual households and their properties were affected in low-lying residential areas, underground structures in the city centre needed pumping for drainage, and the rain water sewage system had to be sealed so that the sea water would not intrude into the system and cause flooding in the streets. In addition, roads and harbour facilities were cut off by flooding causing disruptions in both land-based and marine transportation. Simultaneously, the management of the Loviisa nuclear power plant (situated some 90 km east of Helsinki) was forced to consider a shut-down of the reactor as the storm surge came close to the safety margins of the discharge outlet of the plant's cooling system.

The multiple effects of a single winter storm forced response measures to be taken. Such an event also has political implications: even events that are considered "natural" become political as they disrupt, challenge and "question" existing social practices (Haila & Lähde 2003). For instance, the Mälaren flood group was not started because of a new policy or regulation: it was instigated by exceptional flooding in the year 2000 (Viehhauser et al. 2006, *this volume*). The flood pointed to the need for a collective effort to mitigate future damages and gave the impetus for establishing a response network. Thus, the extreme event had definite political power. The history of the flood group is, in a sense, "disaster driven", since the disaster has momentum in instigating institutional change and learning. The approach to climate change after the flood group has been started, however, does not need to remain focused on the disaster (flood) itself, since the interaction within the group supports a more holistic and precautionary approach to floods and climate change.

Extreme events challenge existing organisational barriers. For instance, in the context of integrated coastal zone management (ICZM), the administrative-regulatory division between land and sea has proved problematic, since it hinders management efforts (Anker et al. 2004). Young (2002 and 2003) has applied an institutional perspective on such issues, referring to them as problems of (institutional) fit, interplay and scale. Sectoral responsibilities, legal arrangements and other institutional factors may lead to undesirable outcomes if they are not properly coordinated, fitting with the problem at hand and adjusted at the right scale. These problems can be seen as consequences of institutional inertia, which hinders adequate and effective responses to pressing societal or environmental challenges (Becker 1995). If the institutional inertia can be loosened and network relations seen from a problem-based perspective, not from an administrative one, better grounds exist for developing novel management strategies. Such strategies are founded on networks.

Organisational barriers also concern interdisciplinary co-operation and communication. In the SEAREG project, round table discussions were organised with both scientists and planners to better understand the patterns of existing linkages between the two groups. The round table discussions serve as a model for tackling emergent problems related to climate change. The discussions, especially if continued on a regular basis, allow for development of direct face-to-face communication and trust. The SEAREG round tables demonstrate that network power also implies shared cognitive functions. Actors with different knowledge bases, disciplinary backgrounds, and practical experiences complement one anothers capacities. Evidently, the shared history and experience of a network are important in determining how a network can become operational and reflexive. Thus, it is not only the network form that counts, but also the network properties such as resources and interaction. Thus, it is the qualities of the network that count, not the qualities of a single individual in the network. Also, the totality of the networks is more than the sum of its individual components and their individual capacities. In addition to the communication issues, networking needs to deal with hindrances resulting from institutional and organisational barriers mentioned above.

Another important characteristic of network communications is that communication may flow more freely in different directions, not only top-down. Thus, the notion of participation and participatory planning are important. This is especially important in the case of climate change and its regional and local impacts, where measures cannot be taken based on any global or universal considerations. For instance, assessment exercises of climate change effects benefit greatly from such an open flow of information. To quote an example, researchers from Penn State University asked a large number of stakeholders for input on a regional climate assessment and found the suggestions valuable in determining what was important in global climate discussions (O'Connor 2000). Determining what is relevant for the *praxis* of different actors requires network-like, non-hierarchical communication structures that inform researchers about the local circumstances.

4 KNOWLEDGE TRANSFER AND NETWORKS: SEAREG LESSONS

Networks enable collective action because they embody forms of "distributed cognition", that is, the network as a whole knows more than any of its constituent parts. Its knowledge is also more diversified. Two examples from the SEAREG project are provided here to discuss the importance of networks in dealing with sea level change:

Example 1: Lake Mälaren Flood Group

The Lake Mälaren Flood Group, hosted by the Stockholm County Administrative Board, is an example of an active network that can take climate change issues into account as one dimension of its work with flood prevention and mitigation. The flood group was established after the exceptionally high flood of Lake Mälaren in autumn 2000. Its work is based on the voluntary cooperation between a wide range of actors that are concerned with flood risks. The group consists of approximately 50 member organisations, including county administrative boards, municipalities, water enterprises, transport and shipping authorities and rescue services, as well as the Swedish Meteorological and Hydrological Institute (SMHI). Improved information exchange and collaboration between the stakeholders helps in achieving its aims, preventing future flood events and mitigating their impacts. (Stockholm County Administrative Board 2005, Viehhauser et al. 2006 and Graham et al. 2006, *this volume*).

Although the Flood Group deals with sea level change only indirectly, the wide array of authorities that it has brought together is clearly an asset. The group contributes positively to the coping capacity of the region. Besides initiating strategic discussions, it has organised "flood exercises" to test the how well the response networks functions in case of rising water levels. Such simulations have provided essential information about acting and co-operation in real-life emergency situations. As demonstrated by other European examples on river flooding (Bronstert 2003, Mitchell 2003), societal changes and institutional constraints that affect land use patterns and water management systems have a greater influence on flood risks than climate change. Also, such changes may affect the ability of different stakeholders in dealing with climate change impacts (Tol et al. 2003). Therefore, the integrated assessment and multi-stakeholder co-operation exemplified by the Lake Mälaren Flood Group, are of essential importance in mitigating flood risks.

The Lake Mälaren Flood Group is a good example of a regional stakeholder network that has been brought together to carry out collective action and coordination tasks which cannot be managed by any authority alone. As such, it exemplifies the idea of modern environmental governance where organisations often act in new 'spaces' that do not follow conventional boundaries. Such networks are a means to stretch institutional capacities to engage with environmental issues that escape normal jurisdictions (Meadowcroft 2002 p. 171). As with other such networks, the Mälaren Flood Group is voluntary and, thus a horizontal organisation. With such new forms of organisation, it is possible to cover and remedy what Hajer (2003) has called institutional voids (areas of fuzzy jurisdictions and responsibilities) and create deliberative arenas where new policy approaches can be crafted (Hajer & Wagenaar 2003). Since the network has members from different levels of government, it embodies a form of multi-level governance, enabling non-hierarchical exchanges between institutions at national, regional and local levels (Peters & Pierre 2001).

From the perspective of ANT, it is interesting to look at Lake Mälaren as an actor/actant. First, the flooding of the lake actively contributed to the establishment of the flood group. Second, an earlier institutional element in the regulation is an important "triggering" actor in the network. The Swedish Water Courts have set guidelines for the acceptable water levels in regulated water systems (Graham et al. 2006, *this volume*; on the legal base see Swedish Water Law 1983). Thus, the water level guidelines are based on the possibilities for regulation (i.e. the lakes can hardly be punished for exceeding the set limits, but the regulating agencies such as hydropower companies have to adhere to them). This implies that the lake is not a natural entity, but a part of a human and organisational actor-network. When the water level approaches the limits set in the guidelines, a whole range of actors is activated to cope with the flood threat. Although the water system is an "indifferent" actor, it recruits other actors some of which had been involved in creating the regulation in the first place. Third, the technical infrastructure used to regulate the level of the Mälaren is also part of the network. The locks at Slussen in Stockholm, regulating the water flow between the Mälaren and the Baltic Sea, for instance, act as a material extension of the institutional and cognitive capacities present in the flood group network. The ANT is made of more or less visible actors and actants, which jointly affect the coping capacity of the region towards climate change and flooding events.

As time passes, both the organisational setting and the role of the flood group are probably going to change. Depending on future climatic events and institutional dynamics, an increasingly formal configuration might be preferred to the current informal status. Also, the changes in the participating organisations, and in the activities of their individual representatives affect the positioning of the group.The advantage of building a stronger organisation resides in its permanence and continuity. Here it becomes evident that networks, to be legitimate and efficient in the face of environmental change, need to be functional and reliable over time. However, becoming more established might also turn the multi-agency and multi-disciplinary network into just-another-sectoral-organisation that would eventually be subject to the problem of inertia and, consequently, the problems of institutional fit, interplay and scale.

Here we can see how the agency is an achievement that is spun between various parts of a system, as the ANT suggests. The different elements take part in the action through their ability to affect the other elements and thus the whole network.

Example 2: Case Itä-Uusimaa: Networking around hazards

The town of Loviisa in Itä-Uusimaa was one of the SEAREG case study areas (Virkki et al. 2006, *this volume*). It was chosen because the old town has low-lying areas that could be threatened by sea level rise. However, during the project another feature was found to be of major importance, namely the nuclear power plant. The winter storm between the 8th and 9th of January 2005 led to a storm surge that broke records for highest water levels all over the Finnish coast, especially in the Gulf of Finland. In Loviisa, the water level reached 170 cm above the normal. The water came close to the safety limit for the functioning of the nuclear power plant, threatening a shutdown. The safety of the nuclear power plant thus emerged as a crucial topic that captured the attention of many stakeholders and the Finnish media. The linkage between the natural hazard (storm surge) and the technological hazard presented by the nuclear power plant (possible shutdown and cuts in electricity) gave the storm extra importance and visibility.

A comparison between Loviisa and the neighbouring town, Porvoo, is also interesting. Both Porvoo and Loviisa have old town centres at river mouths facing the sea. Both towns have experienced floods during heavy storm surges and have even got used to them. However, when the vulnerability of both towns to sea level rise was assessed, it was noted that the strengths and weaknesses in coping capacity of the two towns seemed to differ from each other. In Porvoo, the authorities stressed that the town planning has paid a lot of attention to minimum construction levels in relation to sea levels, having learned from the long history of building by the sea, Loviisa seemed to stress the role of cooperation between various authorities in case of high waters. The focus on existing networks in Loviisa seems to be due to the presence of the nuclear power plant, which has required the establishment of a network of organisations to cope with possible emergency situations. The pre-existing network can thus be considered a major strength, even if the network was put up to cope with something rather different than sea level change.

From an ANT perspective, the nuclear power plant can surprisingly be seen as an important actor in the preparedness for sea-level rise. It has brought human actors together in communication networks that can be mobilised for multiple purposes. Also, the recent storm "recruited" the nuclear power plant to act as a powerful ally in the construction of the hazard and raise public awareness. Evidently, the learning challenge here is to transform the networks "recruited" by immediate disasters and extreme events into long-term mitigation arrangements through regulatory systems such as land use planning.

5 CONCLUSIONS

The lessons of the SEAREG project suggest that the importance of networks is threefold. First, existing networks of human actors (such as the Mälaren Flood Group) can be mobilised to deal with emerging problems such as sea level rise. The benefit of existing networks lies in their experience in working together and sharing information. Similarly, regional networking and preparedness even in a field other than flood protection can be very useful as a communication structure and a source of trust when dealing with new emerging problems such as climate change adaptation.

Second, the challenges of climate change adaptation and, more specifically sea level rise, activate or recruit new sets of actors into (often involuntary, e.g. as reactions to disasters) networks which, at first, may have little capacity to act as an organised entity, but provide valuable lessons for building new networks for short term response and long-term adaptation. Thus, sea level rise reveals gaps and missing links in organisational and institutional structures that are responsible for functions such as spatial planning. An important issue here is that networks are embedded and located. Since the impacts of sea level rise vary in different places, the constellations of the local networks also vary accordingly. For instance, in Gdansk, the risk of drinking water salinization recruits specific actors into the network (Staudt et al. 2006, *this volume*), while the same problem is not as pertinent in Helsinki, where drinking water is pumped from an inland lake, Päijänne. Understanding the role of *located networks,* however, does not mean that we can only look at *local networks*. From the policy perspective, networks related to climate change and sea level rise provide a case for multi-level governance where different institutions at different scales co-operate to achieve common goals.

Third, our discussion on actor-network theory highlights the hybrid character of networks implicated in climate change adaptation and sea level rise. Since non-human entities such as concrete networks (sewage systems, electricity networks or transportation networks) have the ability to link or disconnect and disrupt social functions, they can be seen as elements of the same networks as human actors. The ANT gives a fresh and innovative perspective into mapping possible networks that are subject to climate impacts.

In the SEAREG project, such mapping exercises were used to construct the vulnerability assessment package in the decision support frame (DSF) (Klein & Schmidt-Thomé 2006 and Schmidt-Thomé & Peltonen 2006, *this volume)*. Further, such network maps can be used to locate fuzzy areas where, for instance, organisational responsibilities are not assigned. These areas are a challenge for governance structures and underline the importance of reinventing management and policy practices. It is important that network style governance does not lead to an erosion of responsibility. It can be argued that assigning responsibility in hierarchical organisations is easier than in horizontal networks.

In sum, the network perspective may be seen as a cognitive (heuristic) and organisational response to situations where existing institutional arrangements cannot cope with new forms of environmental change. The actor-network theory can be useful in understanding the hybrid constellations related to sea level change. To find the links between huge numbers of interconnected factors is a task that requires creative thinking. ANT can help in identifying the way agency is spread among various actors and actants within the network. It may also be used as an inspiring frame for inter-disciplinary projects. Every region and city has its own actor-networks related to sea level change, but the tools developed by the SEAREG project can be used as a start if there is a will to begin discussing adaptation strategies. Both the round table discussions and case studies carried out in SEAREG point to possible stakeholder networks. By studying these relations, the project also has– and hopefully – contributed to linkages between actors that have not co-operated earlier in issues concerning sea level rise and flooding. It should be noted, however, that network qualities such as their resources, competences and reliability remain key factors in addressing the impacts of climate change.

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RISK COMMUNICATION AND SEA LEVEL RISE: BRIDGING THE GAP BETWEEN CLIMATE SCIENCE AND PLANNING PRACTICE

by

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Due to the multiplicity of issues, uncertainties and interests involved, risk communication is an important element in dealing with climate change and sea level rise. The challenges of risk communication are first discussed and, second, lessons are drawn from the SEAREG project on the communication between scientists and planners. Research should not be seen only as the *project* and its *results*, but as a learning process in a practical context. Communication between science and planning should take the form of a dialogue, instead of a scientific monologue. Sufficient early-on communication between scientists and planners or decision-makers is needed to identify the right issues and stakeholders and to gain a shared understanding of the uncertainties related to climate change and sea level rise.

Key words (GeoRef Thesaurus, AGI): climate change, sea level changes, risk assessment, research, planning, cooperation.

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INTRODUCTION: CONTEXTUALISING CLIMATE SCIENCE

The role of science is central in our understanding of phenomena such as climate change and sea-level rise. Science also has a key role in proposing and justifying relevant actions and regulatory measures. Other actors, however, determine the fate of such proposals. In the field of spatial planning, the role of political decision-makers, planners and planning organisations is central in the design and implementation of adaptive measures. Consequently, the communication between science and planning is an important determinant for the success of adaptation to climate change effects, such as sea level rise. The communication between science and planning emerged as a key point of interest in the INTERREG IIIB project "Sea Level Change Affecting the Spatial Development in the Baltic Sea Region" (SEAREG), which was co-financed by the European Regional Development Fund (ERDF). The project set out to improve the interaction between the scientific community and the regional planners. The project aimed to provide a bridge between the two, and to activate the exchange of information and analysis of the communication processes.

In the following, the communication between science and planning is studied from the perspective of *risk communication*, which can be defined as the process of communicating responsibly and effectively about the risk factors associated with industrial technologies, natural hazards, or human activities (Leiss 2004). Risk communication is needed in the assessment and management of risks and it needs to take into consideration the nature of the risks and their context (OECD 2002). The importance of communication in public policy, planning and decision-making also arises from the number of stakeholders involved. Transparency and sufficient communication are thus prerequisites for the successful coordination of different social actors. An important aspect of this capacity is the way communication fosters trust between the different actors, thus making any joint action and implementation of policies much easier.

The problems of climate change and sea level rise, together with the interface between science and planning, provide a challenging context for risk communication. First, events related to climate change are highly uncertain, and the outcomes poorly defined. Both climate change and the societies with which it interacts are highly complex and dynamic entities. The kinds of uncertainties related to climate change include epistemic uncertainty (related to imcomplete knowledge), natural stochastic uncertainty (relating to the chaotic nature of the climate system) and human reflexive uncertainty (relating to human agency in terms of greenhouse gas emissions, mitigation and adaptation measures) (Patt & Dessai 2005).

Second, the communication between the fields of science, planning and decision-making is far from straightforward. The two groups have their personal interests and codes of professional conduct, which affect their actions. Referring to the relation between scientists and so-called "end-users", Nowotny (2000) asks: *"What are the conceptions that engineers, climate modellers, molecular biologists and others have about people – as individuals and collectives – who will utilise or be affected by the knowledge they produce?"* Nowotny argues that such conceptions are usually not very well articulated. She also argues that science is increasingly being critically reviewed and the end-users of scientific knowledge are more and more educated and reflexive towards the "products" of science. This means that "society talks back to science" (Nowotny et al. 2001).

Larger organisational and structural issues are also at stake. As Luhmann (1989) pointed out from his particular systems perspective, communication processes between social subsystems are often problematic since these subsystems have different deciphering codes. While science, for instance, is interested in whether something is true or false, legal systems are more concerned about the legality or illegality of actions. In the practice of planning and decision-making, science becomes intertwined with other considerations. The authority of science is relative and often contested, and the use of power interferes with any ideal form of rationality (Flyvbjerg 2001, Edmondson & Nullmeier 1997).

Renn (2004) describes the interacting systems of society with their own operating logics. The economic system, the expert system, the social system and the political system operate with their own respective goals: efficiency, competence in knowledge, fairness and legitimacy. This division of labour is depicted in Figure 1, which also includes elements of interaction between the four subsystems. In this context, science is filtered through an expert system that contributes to the function of knowledge production through testing truth claims. As to risk management decisions – such as planning in the face of climate change – all four systemic requirements need to be covered; decisions need to be based not only on solid research, but also economically efficient, effective, politically legitimate (hence the importance of participation and democratic procedures), and socially acceptable.

In sum, the context of scientific knowledge influences how its reliability and objectivity are assessed. Nowotny (2000) argues that contextualisation can make knowledge robust and operational. Climate scenarios, for instance, are not universally reliable and useful in planning for adaptation measures. Dessai et al. (2005) have pointed out that the role played by climate scenarios depends on many contextual factors such as the chosen adaptation assessment approach and the availability of technical and financial capacity to handle scenario information. An interest towards the context of knowledge is also visible in recent paradigms of risk assessment, which call for a participatory procedure, involving different stakeholders early in the risk analysis process to characterize risks even before they are given a formal assessment. This does not diminish the role of modelling and quantification, but is aimed at eliciting the values and the perspectives of the community involved so that the multiple dimensions of risk can be taken into account early in the assessment (Amendola 2002).

In the scope of the SEAREG project, the "universals" of climate change were contextualised through 1) downscaling the climate models for the regional scale and 2) the use of case-specific research in determining the important regional issues in different

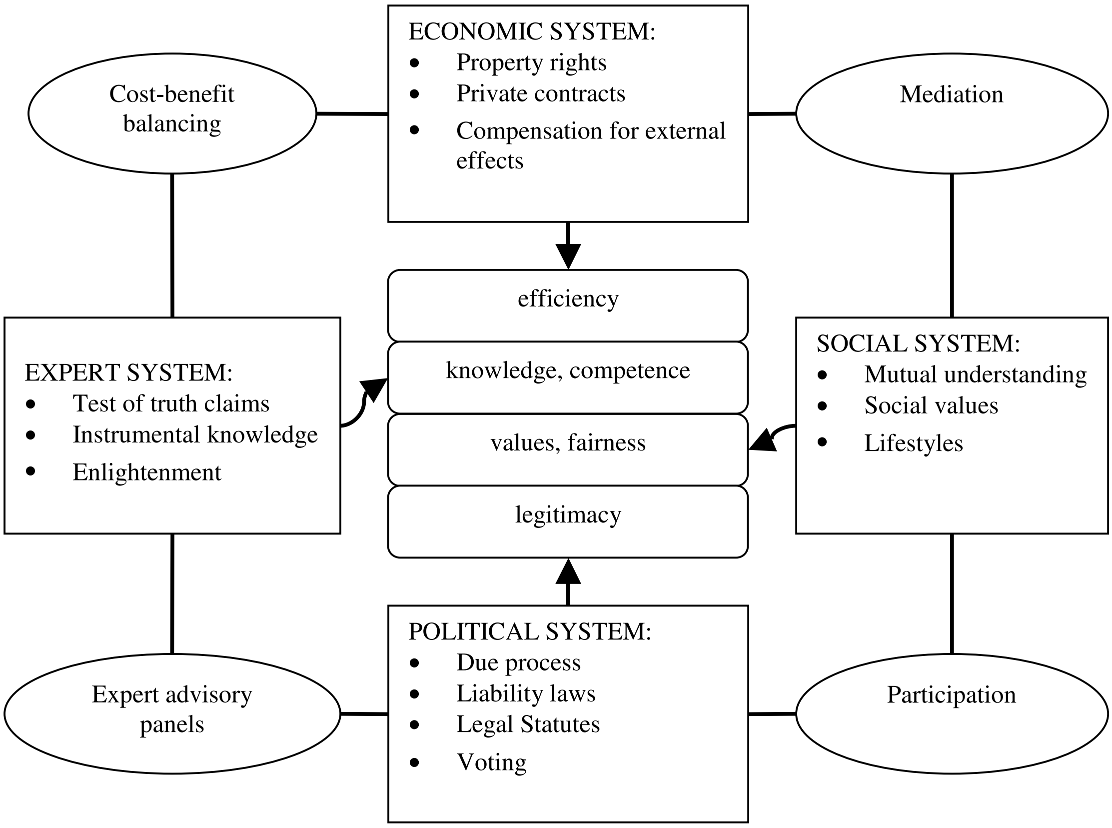

Fig. 1. Societal subsystems and their logics in decision-making (Renn 2004 p. 295)

settings around the Baltic Sea. Such contextualisation provides lessons on how scientists, planners and other stakeholders communicate most effectively. The idea of contextualisation is important since modelling and quantification may produce data on sea level rise, also in relation to coastal topography, but they cannot be definitive about the needs and values of local communities. Such considerations, however, are important in determining local priorities for planning.

2 RESEARCH QUESTIONS AND METHODOLOGY

One of the key goals of the SEAREG project was to improve the interaction between the scientific community and the planners. The project aimed at understanding the relations between the two and providing a bridge between them, trying to activate the exchange of information and analysing the communication processes. In the scope of the SEAREG project, a study was carried out for this purpose with two functions: 1) to gather base knowledge for the Finnish case studies (Itä-Uusimaa and Helsinki) and 2) to examine the current communication settings and to develop guidelines for better practices.

Qualitatively oriented action research provided the methodological base for the study. Action research is conducted together with practitioners (e.g. planners), which creates the possibility to influence problematic issues and especially, to improve practices. The role of a researcher is to help actors to become aware of and find solutions to existing problems and learn to cope with them (e.g. Kuula 2001 and Eskola & Suoranta 1998). In accordance with the action research agenda, questions were asked on both descriptive and normative grounds, addressing the current communication practices and improvement of those practices. The key research questions were the following:

How is the context of risk communication perceived by scientists and planners?

Who are the relevant actors in knowledge production, risk communication and decision-making?

How should functional and feasible knowledge transfer and risk communication be organized?

The research data were collected in three phases: 1) e-mail questionnaires, 2) round table discussions and 3) single person interviews. These were conducted among planners, scientists and politicians.

As part of the project's initial phase, which studied the relationship between the scientists and potential users of their results, questionnaires were sent out to a set of selected Finnish researchers and planners via e-mail. The results of the questionnaires sent to scientists and planners were used to gather background material for the round table discussions. Approximately half of the scientists who responded had some kind of a connection to climate research. Research on water ecosystems was also well represented. None of the planners had previously been directly involved in discussions related to climate change adaptation.

Round table discussions were conducted as three events: one with scientific experts (Figure 2., round table 1.), one with planners (round table 2.) and one with scientists, planners and politicians together (joint round table 3). A planning researcher acted as chairman on all events. Discussions were recorded for further analysis. Between 6 and 9 participants took part in every discussion.

The purpose of the round table discussions was to create a situation where the researchers found out how planners and scientists understand certain issues and what kind of experiences they have in solving different matters. Group interviews made it possible for both the participants and the researchers to find out how people build their ways of thinking and what the arguments are behind their points of view. A fourth round table was also organised during a SEAREG project meeting in Greifswald. The Greifswald round table gathered project partners to discuss communication issues.

In addition to the group interviews, single person interviews were conducted to gather knowledge from actors that were not taking part in the round table discussions. The single person interviews served especially in the Finnish case studies and provided additional information on actor relations and communicative settings in each location.

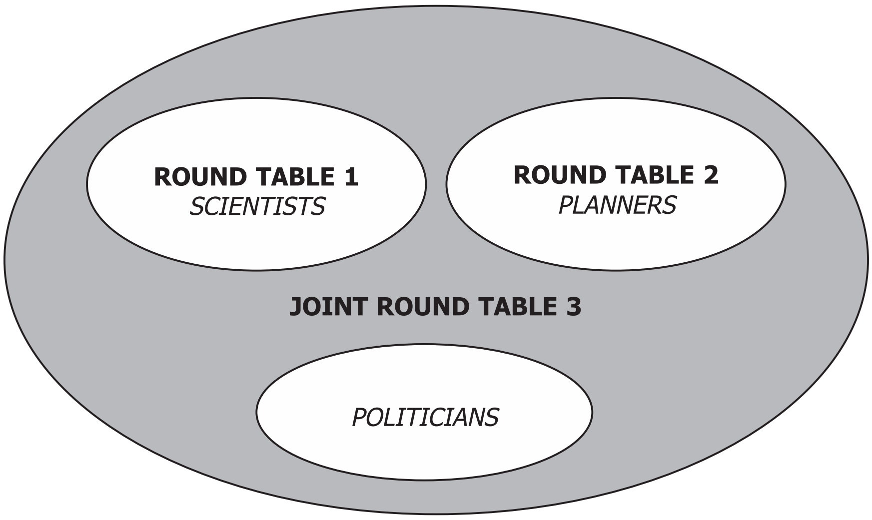

Fig. 2. Structure of the round table discussions.

3 RESULTS AND DISCUSSION

3.1. The context of risk communication

Overall, the operating context of planning was seen as a crucial determinant of what actually gets planned and implemented. Planners saw themselves as standing between science and politics. On the one hand, the planner is expected to be aware of a great variety of things related to planning (including issues related to climate change), but on the other hand, does not possess expertise comparable to that of the scientists (climate researchers). While planners may struggle to incorporate climate change issues into the plans, it is still the decision-makers (politicians) who have the power to discard or approve a plan, following their own considerations and judgment.

Many planners felt the need for solid scientific evidence that they could use in convincing their superiors and decision-makers of certain lines of action. However, the role of planning in general and scientific planning in particular, was seen as increasingly marginal. Relying on scientific research as background material for planning was, according to a participant in the round table for planners, more popular in the 1960's and -70's when planners and decision-makers were more confident of the power of planning. The planner said provocatively that nowadays planning is more directed to administrative functions and serving the market economy. Thus, the faith in the influence of planning and especially scientific planning seems to have been eroded. Some scientists also presented similar views:

Scientist: "We have quite the same joys and sorrows with the cities' environment offices (…) The planners get results of our work to be used in EIA-procedures [Environmental Impact Assessment], but so far they have not had much effect. Planning proceeds first and foremost on the basis of economic matters. "

In terms of Luhmann's subsystems (fig. 1), the concern for economic efficiency in development was thus experienced as an important source of pressure towards the other functions that planning could serve, such as expert competence, legitimacy and social fairness.

Overall, the questionnaire and the round table discussions emphasized the need for risk communication in the context of climate change and sea level rise. First, the issue of multiple uncertainties was addressed. Even state-of-the art climate science cannot provide accurate predictions about the future climate. Both climate change and societal change were discussed as sources of uncertainty. Planners saw the rapid changes in their operating environments as an important source of uncertainty.

Dealing with the uncertainties of climate change and sea level rise was a crucial issue for both researchers and practitioners throughout the SEAREG project. Differing ways of conveying the sea level information may have direct impacts on decision-making related to local development. For instance, if the results of sea level change scenarios are communicated in the way of a "worst case scenario" only, investors might withdraw from development projects. On the other hand, the "worst case scenarios" should always be taken into account as a precaution. Not to discuss the worst case scenario could also be seen as withholding information that is crucial for public safety. The usefulness of scenarios also depends on the affected area. Older structures such as historical city centres and even recently constructed urban areas do not benefit as much from state-of-the-art information on sea level changes as cities and regions that are currently starting to develop new coastal development areas. In the latter case, adaptation is much cheaper. The political sensitivity of climate change and sea level information can be easily understood when thinking of areas that have recently invested in coastal development but neglected climate change as an issue. In such situations, new information on sea level rise may even be seen as a threat that could jeopardize ongoing development. Hence, the way research is communicated becomes more crucial.

Second, risk-relevant decisions in planning and politics were seen as not only as matters of scientific knowledge, but also as value-driven. This means that there is a need to communicate both the "facts" and the valuation of what is at risk. Especially in discussions on decision-making, it was evident that different individuals and communities have different attitudes towards risk in general and climate change in particular. Such views refer to differing "risk cultures" (Douglas & Wildavsky 1982), implying that the perception of risk is not uniform and does not depend only on the factual scientific estimates of the extent or probability of the risks.

3.2 Organisational issues in risk communication

In the context of SEAREG, and specifically taking the case of Helsinki as an example, it was not straightforward to identify relevant planners and other stakeholders who should take part in a communication process over the issue of sea level rise. The Helsinki case study revealed that the technical division of the city planning department is the key actor functioning as an intermediary between science and urban planning, and, for example, managemnet of water and energy infrastructure. The sectoral structure of city administration where departments have different status and power-relations complicates stakeholder identification. On issues concerning sea level rise in Helsinki, the Geodetic Division of the Real Estate Department and the Environment Centre also have important roles in the science-planning dialogue. Hence, the dialogue should not be fostered only between a researcher and a planner but within a wider range of the planning organisation, including different planning related departments in the city administration. Science-planning communication, in a setting similar to SEAREG, should take into account and identify existing knowledge inside administration and between departments, and finally, to bring the knowledge together.

Organisational issues also included the topics of raising awareness and learning, which typically remains implicit (as "good principles") and becomes explicit only in conflict situations. Different city departments might have different definitions of robust and useful knowledge. For a city planning department that needs to pursue strategic development objectives, a flood map presenting hazards in newly built areas is politically risky. However, the same map might prove valuable for other departments responsible for hazard management or risk analysis. The steering of research by planners and local officials can also be politically driven.

A central theme that emerged in discussing different stakeholders in risk communication was the importance of authorization of knowledge claims. This is clearly a reaction to the dilemma of multiple perspectives and conflicting information. The weight of authority was considered important both in knowledge production and bureaucratic legitimacy. Thus, for research to become relevant for planning it should come from an authoritative source and it should be backed by administrative authorities (e.g. legal base or guidelines adopted by ministries).

In the e-mail questionnaire, planners were asked what issues affect their use of research results. The answers indicated that easy access ("material is easily available") and trustworthiness ("research is conducted by a reliable source") were key factors. For sea level rise scenarios and research in Finland, the Finnish Institute of Marine Research (FIMR) holds a high level of authority. During the January 2005 winter storm, FIMR issued a warning on rising sea levels in the Gulf of Finland. The warning was followed by precautionary actions from responsible actors such as rescue departments. Another source of authoritative knowledge related to sea level rise that was often mentioned by respondents were the guidelines on coastal development produced by the Finnish Environment Institute (SYKE). The regional environment centers and municipal authorities have very efficiently adopted these guidelines (Ollila 1999). In Finland, digested guidelines from an authoritative and legitimate source are more easily adopted by practitioners than individual research reports or more informal guidebooks.

3.3 Lessons for risk communication between science and planning

The round table discussions provided insight into the way the knowledge transfer between science and planning is perceived by the different actors. They also provided information on how planners and scientists could cooperate in a fruitful way. The following lessons seem pertinent. After each lesson, examples or problematic aspects of cooperation and communication are reflected upon using topical issues that were brought up in the interviews and questionnaires.

1. Communicating climate change needs to be made concrete.

Planners may know about climate change, but it remains a distant and abstract topic. It is perceived as a global phenomenon whose local impacts are not that drastic. Climate change needs to be addressed in concrete terms, building linkages to real-life events such as the recent storm surge in the Baltic Sea in January 2005. Previous extreme events are important in this sense, because they serve as reminders and examples of what the future climate might look like. Even if it is unrealistic to provide "*exact predictions*" of future impacts of climate change (e.g. definitive changes in flood zones etc.), the concrete nature of the imaginable impacts can help the inclusion of climate change and sea level rise in planning.

A division between awareness rising and guidelines or "prediction development" can be made when discussing the topic. To raise awareness by linking events such as the January 2005 winter storm to climate change could be valuable in helping people to understand the possible effects of climate change. As well, research influenced planning can help planners to regulate development of vulnerable areas and to define flood prone zones for planning documents. In addition, the latter issue emphasizes the importance of clarity in planning regulation.

2. There is a need for "digested" scientific information in planning. Even the best research results will not influence planning practices unless they are in a suitable "digested" format. This may take place through, for example, expert consultation or applied research. Planners usually do not have the inclination or time to follow in-depth academic debates in their field. The need for digested information is also related to the issue of authorization as mentioned above.

In the discussions, the combination of already excessive workloads and "information overload" (in the form of the vast amount of relevant research reports) was considered quite heavy and seen as a definite limitation as to how much climate research planners can handle. Also, many comments on language issues were brought up:

Planner: "Researchers should avoid their own professional jargon, simplify and popularise their message and they should be able to make value judgments."

Planner: "Researchers' theoretical emphasis, insecurity and inexperience of real-life issues are the most disturbing factors."

Scientist: "The PR-officers require clarity and simplicity. I don't find that unreasonable."

Most scientists who responded to the questionnaire or took part in the round tables, considered *"the scientific community"* as their main target group. Several were unsure how their own research findings were used. This indicates a low level of "digesting" and communication between the fields.

3. There is a need for intermediaries and arenas to facilitate interaction between science and planning. Well-functioning communication between scientists and planners requires active individual intermediaries and suitable arenas (project meetings or more permanent bodies such as regional "flood groups") to foster co-operation. This co-operation should begin in the early stages of any development project.

The Lake Mälaren Flood Group as a unit consisting of topical actors in the Stockholm region is an example of a functioning and institutionalized forum for cooperation (Viehhauser et al. 2006, *this volume*). Local flood groups are also found elsewhere. For example during spring 2005, a flood group was established in Espoo, Finland. The January 2005 winter storm gave an impetus for the founding. The group consists of rescue department, city planning department, environmental department and water and energy related departments.

Fothergill (2000) has stressed the importance of social and personal communication between scientists and planners and emphasized the role of different intermediaries between the parties. In the context of the SEAREG project, it seemed especially important to engage in such communication over specific planning challenges, not only as a matter of communication at an abstract level. Researchers and practitioners who are able to step out of their paradigms and effectively communicate with each other are especially valuable.

4. The linkages between the time scales of climate change and planning need to be understood. The time scales of climate change, planning and decision-making were discussed during the round table sessions. Time scale emerged both as a normative issue (e.g. sustainable development) and a more concrete issue, referring to for instance, long-term infrastructure investments.

Although plans are generally prepared for the next 10-20 years, the completed structures, especially infrastructure, have a much longer life span. In this sense, the respondents agreed that the 100-year time scale of the SEAREG project was relevant and feasible for planning. However, the short-term tempo of development in the market economy in general and the changes in land and real estate markets in particular were seen as pressures that clearly challenged decision-making and the goals of long-term planning. In this sense, considerations relating to the time-scale were intertwined with the understanding of uncertainties involved.

5. Importance of clarity in planning regulation. Since climate change is not incorporated in the legislative and institutional setting of planning, the regulation of the matter was seen as difficult and fuzzy. A tool such as a clear planning symbol for potentially inundated and flood prone areas would help planners in communication with decision-makers and legitimise actions, such as the creation of buffer zones in flood prone areas. This could also clarify liability issues that were perceived as somewhat vague nowadays. The definition of, for example, buffer zones should be based on scenarios but complemented with other planning related information.

The findings of the SEAREG project on risk communication support the conclusions of Fothergill (2000) and Jürgens (2004), who emphasized the importance of early inclusion of stakeholders (e.g. planners) in research projects. According to Fothergill, the communication between science and planning should take the form of a dialogue, instead of a scientific monologue. Participation and evaluation by planners makes it easier to provide robust and useful knowledge. She also argues that research results should be interpreted and opened up to planners. Jürgens (2004) argues that collaboration between policy-makers and the scientific community should be ensured by preparing participatory projects where practitioners take part in a research project from the beginning. Putting the participatory approach into practice is especially valuable for communicating and dealing with the prevailing uncertainties in the climate change research.

In the SEAREG project, interpretation and opening up of research results was a central concern from the beginning of the project. Within the project, a "zooming in" of more general global or Baltic Sea level research findings to a local level has been made. Opening up and interpretation has mainly meant summarizing and localizing the research. "Digesting" available findings to a usable format has been crucial. However, some issues, such as the uncertainties involved in climate change and the long time frame, became topics of continuous discussion throughout the project.

4. CONCLUSIONS

Researchers often encounter social and political logics through the demands of applicability and *policy relevance*. Many policy-driven research programmes demand policy relevant research and policy recommendations from researchers. It can be argued that autonomous academic research would be the most relevant policy in the end; without non-academic (political) pressure or even demand of predefined policy recommendations, research would have the most valuable impact on policy choices (Bengs 2004). This view is debatable, however, as it takes the side of pure knowledge, or even the "ivory tower" model of academia. It would not provide the best answer to the challenges of contextualizing knowledge.

We have suggested the model of action research as a pragmatic approach to policy relevance. In the framework of a participatory research project, research cannot be seen only as the *project* and its *results*. Disseminating the results is evidently important but emphasis should be on the *learning process* enabled by collaboration between the practitioners (e.g. urban planners in the context of the SEAREG project) and the researchers. Eventually, the practitioners will further disseminate the valuable information in their working places. Taking an action research approach in the case studies of the project proved valuable (Lehtonen & Luoma 2006, *this volume*). For the researchers, it is valuable to be aware of the *real* needs and problems of the policy-makers and practitioners.

This communicative process should ideally begin with stakeholder identification, keeping in mind the difficulties of identifying and bringing the relevant actors together. In addition to specific individual actors, the identification of different networks (practitioner networks, networks inside the scientific community and collaborative networks) is valuable for linking the research to practice. It also helps researchers gain new insights and pose new research questions. Network identification, finding the needed intermediaries and arenas is also central for risk communication. The earlier this takes place in a development oriented research project, the better the chances are for practicable results. Sufficient early-on communication between scientists and planners or decision-makers is also needed to gain a shared and clear understanding of the existing uncertainties related to climate change and sea level rise.

Communication between science and planning has to be understood in its proper context and the knowledge relating to climate change and sea level rise should be made to fit this context. Through the experiences of SEAREG, it also became clear that there are specific challenges in conducting INTERREG IIIB projects (and other EU-funded research projects), which should address and integrate not only science and planning but many different planning systems across the Baltic Sea Region. Integrating research results into different national planning processes and practices has to overcome organizational and language barriers, which could otherwise distort or block communication processes.

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EVALUATION OF FUTURE SEA LEVEL RISE IMPACTS IN PÄRNU / ESTONIA

by
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Klein, J. & Staudt, M. 2006. Evaluation of future sea level rise impacts in Pärnu / Estonia. Geological Survey of Finland, Special Paper 41, 71–81, 3 figures and 3 tables.

The vulnerability assessment for the city of Pärnu (Estonia) applies three regional scenarios projecting a sea level rise (SLR) of 5, 52 and 104 cm. A local digital elevation model is the basis for SLR maps and the assessment. An estimation of storm surge frequency and local land use data provided additional information. The assessment identified the strongest impacts on the service sector, the water supply and protected areas along the shore of Pärnu. These impacts meet a Coping Capacity that is limited by low awareness of the possibility of SLR, low interest and participation in planning processes and a planning system in a young stage of development.

Key words (GeoRef Thesaurus, AGI): climate change, sea level changes, transgression, floods coastal environment, risk assessment, coping capacity, Pärnu, Estonia.

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1 INTRODUCTION

This article describes the assessment of vulnerability towards sea level rise for the City of Pärnu (Estonia). The assessment applies three regional sea level rise (SLR) scenarios generated with the Rossby Centre Atmosphere Ocean (RCAO) model (Meier et al. 2004) and a system for Vulnerability Assessment developed by the SEAREG project (Klein & Schmidt-Thomé 2006, *this volume*).

The assumption of future sea level rise is the basis for the Vulnerability Assessment. Maps showing the areas possibly affected by SLR and storm surges help to identify impacts and support the assessment. The local system is divided into eight categories to ensure a comprehensive evaluation of possible impacts (see Table 1).

The Coping Capacity assesses the ability of local stakeholders, planners and decision makers to withstand and cope with the impacts of future sea level rise. The Vulnerability of the local system is described by the synopsis of the level of impact and the Coping Capacity of the related stakeholders (Klein & Schmidt-Thomé 2006, *this volume*).

Table 1. The impact matrix.

Sea Level Rise Effects	Agriculture, Forestry, Fishery	Industry	Services	Infrastructure	Housing	Open Urban Area	Groundwater and Water Supply	Protected Nature Areas
Permanently Inundated	no impact	low impact	strong impact	low impact	no impact	no impact	strong impact	extreme impact
Risk of Flooding	low impact	low impact	strong impact	low impact	strong impact	no impact	strong impact	low impact

2 METHODOLOGY

The implementation of the Vulnerability Assessment in Pärnu required the processing and adjustment of the available data. It was necessary to calculate a digital elevation model (DEM) for Pärnu, to adjust the results of the SLR scenarios to local land uplift rates, which were not yet taken into account, and estimate the height of a 100-year storm surge by tide gauge records.

2.1 Local Digital Elevation Model

A local digital elevation model (DEM) was the basis for creating local SLR maps. The availability of data in Pärnu was remarkably good. 30285 height points surveyed in 2001 and 2002 were the basis for the calculation of a DEM. As well, the zero level contour line was available. A DEM with a resolution of 10 to 10 m in the Baltic Height System (BHS) is the result of processing done with ArcInfo.

2.2 Sea Level Rise

According to Ekman (1996), the land uplift is about 1mm/year in Pärnu but there might be a remarkable interpolation error because of a huge gap between the tide gauges of Kronstadt and Liepaja along the southeastern shore of the Baltic Sea used by Ekman. According to Jevrejava et al. (2002), the results for the individual sea level stations in Estonia are scattered, but in general smaller than Ekman's uplift values. Northern Estonia experiences uplift while in southern Estonia subsidence occurs. In the case of Pärnu, the uplift is -1 to 0 mm/year rather than +1 mm/year. Based on Jevrejeva's results, 11 cm were added to the results of the SLR scenarios, which were calculated with a land uplift of ca. 1mm/year in Pärnu. The "Low Case" for Pärnu then shows a SLR of 5 cm, the "Ensemble Average" scenario 52 cm and the "High Case" 104 cm.

The modeled SLR is given relative to the mean sea surface height (SSH) for the period of 1961 to 1990. The SSH for this time at the Pärnu sea level station is 3.6 cm over Kronstadt, which is significantly higher than the zero level (5% level of significance). Therefore, an additional 3.6 cm had to be added to the values of future SLR.

2.3 Storm Surge Frequency

A projected higher wind speed during winter and spring in conjunction with a shorter period of ice coverage (Meier et al. 2006, *this volume*) can lead to the expectation that storm surges will be more probable in the future. Since calculated extreme sea level changes are very likely underestimated (Meier et al. 2004), the estimation of storm surges were based on sea level values from the Pärnu gauge for the years 1923 to 2003, that is today's frequency and height of storm surges were assumed, but in relation to the projected sea level for 2071 to 2100.

For the assessment, the height of a 100-year flood was chosen. It is defined as the maximum storm surge height of a year that will be exceeded with 1/100 probability, that is the value of the upper 0.99 percentile of the distribution.

According to this definition of the 100-year flood, the level in Pärnu will be 196 cm over the mean sea level. This value is used for the calculations concerning storm surges in the Pärnu case study.

2.4 Land-use Data and other Information

The General Planning of Pärnu City provided the basic information about land-use (Pärnu City Council 2001). Maps for the use of territory, for environmental protection, water supply, sewage and rainwater drainage and traffic are part of the General Planning. The reference land-use data set for the year 2000 of the MOLAND (Monitoring Land Use/Cover Dynamics) project was a second source of land-use data (Demicheli et al. 2003). This data gave detailed information about land cover in non built-up areas.

To highlight the economic aspects of the impact, the locations number of employees of the 50 biggest companies in Pärnu County were taken into account (Pärnu County Government 2003, Pärnu City Council 2004). The Statistical Office of Estonia (2004) and Nordregio (2000) provided additional economic statistics.

3 RESULTS

Table 2 summarizes the SLR values of the three scenarios and the inundated and flooded areas in absolute numbers and in relation to the total area of Pärnu. A detailed assessment was done for the "High Case" scenario to take into consideration the strongest impact according to the scenarios.

The delineation of the Pärnu case study area is determined by the city. Since the idea of the SEAREG project is to support regional and local planning and decision-making, it seems reasonable to choose administrative borders to delineate the case study area.

3.1 Fishery, Agriculture and Forestry

Among the 50 biggest companies in Pärnu are two fish processing companies with a total of 300 employees (Pärnu County Government 2003, Pärnu City Council 2004). 22 of Estonia's 97 fish processing industries are in Pärnu County (Ministry of Agriculture 2003). Four fishing harbors along the Pärnu and Sauga River indicate that fishery plays an important role in this area. While agricultural production was declining, the fish catch in the Baltic Sea has been on a relatively constant level from 1998 to 2003. (Statistical Office of Estonia 2004).

SLR in the "High Case" scenario does not affect the location of the companies mentioned above. In case of a 100-year flood, one of the fish processing companies would be affected as well as the fishing harbors.

Table 2. Projected water levels relative to mean sea surface height 1961 to 1990.

Scenario	**Low Case**			**Ensemble Average**			**High Case**		
	Δh [cm]	area [km^2]	area [%]	Δh [cm]	area [km^2]	area [%]	Δh [cm]	area [km^2]	area [%]
SLR	5	0.29	1	52	1.69	5	104	3.03	10
SLR + 100-year flood	201	5.26	17	248	6.48	21	300	7.87	25

An area of 3.8 km^2 is forest dominated by a mix of coniferous and deciduous trees and only 0.3 km^2 in Pärnu are possibly used for agriculture (E.O. Map 1997, Demicheli et al. 2003). A higher sea level will not affect areas possibly used for agriculture or forestry.

3.2 Industry

In Pärnu, 387 ha are signed as areas for production or shared area for trade and production, 39 ha of this area belongs to ports (Pärnu City Council 2001). 21 % of employees work in the industry sector (Pärnu County Government 2003, Pärnu City Council 2004).

In case of the 104 cm SLR ("High Case"), 7 ha of the harbor area can be lost, but only 1 ha of other industrial areas. A dredging company, a shipyard and one of the smaller fish processing companies are all located in the harbor area and would be directly affected by SLR.

The impact of a 100-year flood is stronger; 25 ha of the harbor area and 12 ha of current industrial areas are flood prone in addition to the inundated area. A large number of companies located in the industrial area along the Pärnu and Sauga Rivers could be impacted.

3.3 Services

Pärnu has a long history as a health resort and tourist town. During the recent years, the tourism sector has grown rapidly. The number of beds for tourist accommodation increased from 1319 in January 2002 to 3379 in April 2004. The number of overnight stays more than doubled from 240 000 in 2002 to 500 000 in 2003 (Statistical Office of Estonia 2004). Among the 50 biggest companies are five centers for health and rehabilitation with about 1100 employees (Pärnu County Government 2003, Pärnu City Council 2004).

The impact of future SLR on the service sector seems to be enormous. While in the "High Case" scenario no building will be directly affected, nearly the entire coastal area and the beach along the Pärnu peninsula can be lost (see Fig 1). One of the main attractions for Pärnu as a tourist town and "Summer Capital of Estonia" might change significantly. The migration of the beach landwards is difficult because the new coastline would be very close to a built-up area and no uncultivated or semi-natural zone would be left in between.

The impact of a 100-year flood could cause huge damage to the service sector. One big hotel and all five centers for health and rehabilitation mentioned above would be flooded. A small sea wall 70 cm height in front of the Tervis Spa does not offer sufficient protection.

3.4 Infrastructure

In Pärnu, the following land-use categories can be counted among infrastructure: health care, culture and sports, social and communal buildings, pre-school education, education and graveyards. The land-use map (Pärnu City Council 2001) marks an area of about 120 ha for these categories. As well, there are transport facilities with 213 km of streets and 14 km of railway (Demicheli et al. 2003), the communal wastewater treatment plant and all line facilities, such as electricity, water supply, heat supply, systems for sewage and rainwater, gas supply and communication lines.

The impact of future SLR on the infrastructure in the "High Case" scenario is very low. Most of the areas in the infrastructural land-use categories are not affected or just to a very small extent. Attention should be paid to that part of the graveyard area, which is lower than the projected sea level. The affected area belongs to the Vana Pärnu Kalmistu (Old Pärnu Graveyard), which is located directly along the Sauga River. Currently, the graveyard needs protection because of erosion (Kupper, chief specialist of green zones at the environmental service, Pärnu town

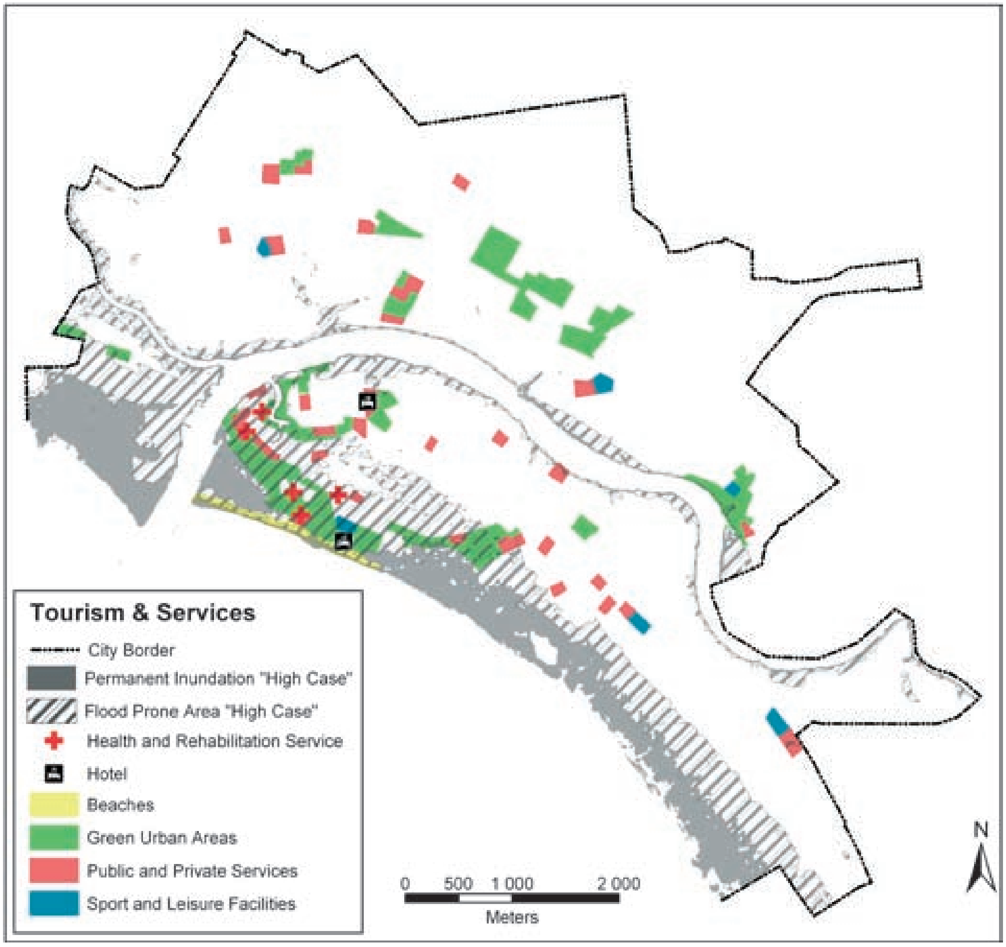

Fig. 1. The third sector in the "High Case" scenario and 100-year storm surge. Source: J. Klein.

government, see list of interviews). The danger of further erosion may grow with a rising sea level.

A rising sea level and a missing sewage system in Vana Pärnu may threaten the use of private wells for water supply. The general planning of Pärnu indicates that the gaps in water supply and sewage system will be closed within the next years (Pärnu City Council 2001), but detailed plans were made only for the area of Raeküla (the southeastern most part of Pärnu) so far. Most roads and railways are safe in the "High Case" scenario. Only about 2 km of small streets leading to the beach area will be affected.

The possible impact of the 100-year flood in the "High Case" scenario is more serious. Almost 39 km of Pärnu's streets will be flood prone. Depending on the design of the streets, flooding can cause damage to the construction. Large parts of the area reserved for social and communal buildings will be at risk as well. Flooding of the graveyard and the wastewater treatment plant could cause further problems.

3.5 Housing

The impact of a "High Case" SLR is very low. Less than 1% of the area for one-family houses will be affected. The loss of the apartment houses' area is according to calculations about 0.08%.

The impact of the projected 100-year flood can be considerable (see Fig. 2). 21 % of the area for one-family houses and 9% of the apartment house area are in the flood prone area. 25 % of the garage area can be flooded, but this area in total numbers is small compared to the 140 ha of housing area affected by a 100-year flood. The impact to the "valued residential areas" is remarkably low. SLR does not affect these areas at all and a storm surge just touches the edges of some areas.

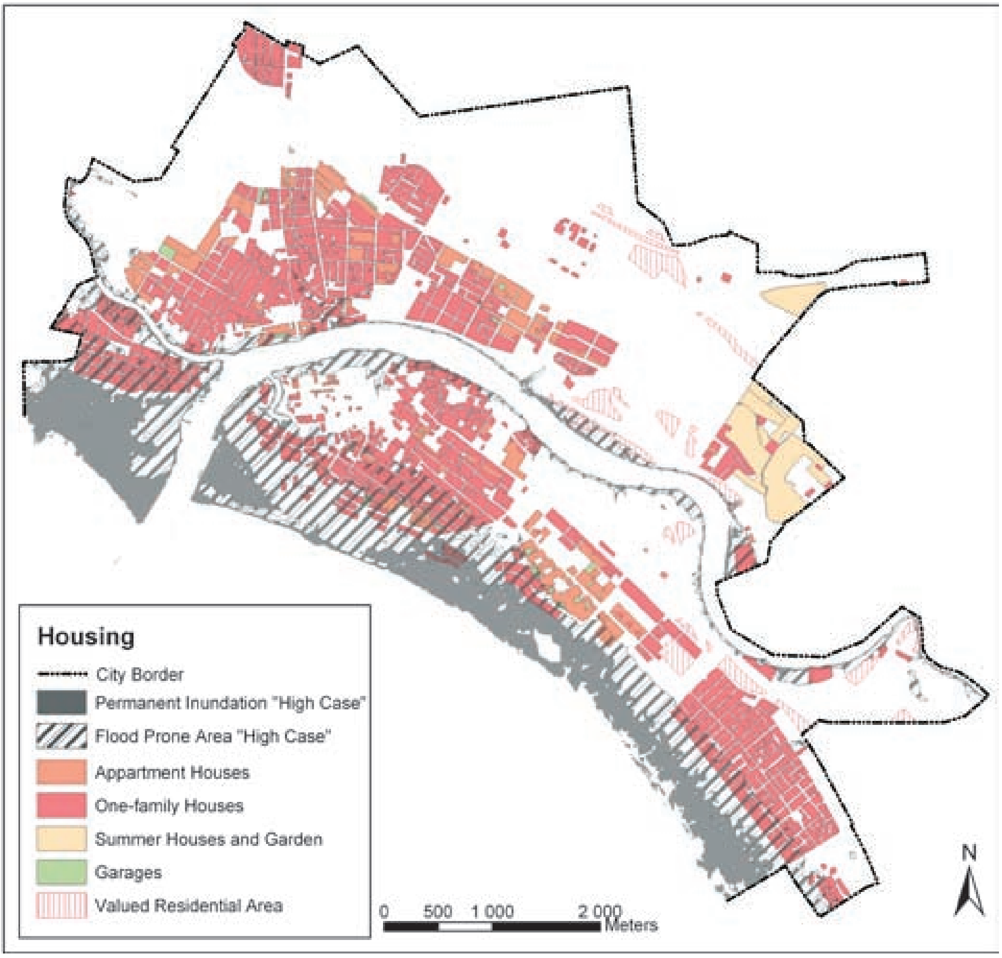

Fig. 2. Housing in the "High Case" scenario and 100-year storm surge. Source: J. Klein.

Although the original purpose of the Shores and Banks Protection Act is to protect marine and freshwater coast, it also helps to lower the impact of SLR. The act prohibits construction closer than 100 m to the coastline in an open area and closer than 50 m in cities, villages and towns (HELCOM 1996).

3.6 Open Urban Area

An area of about 2.7 km^2 does not belong to any of the above mentioned categories. This area consists of green urban area without special protection, bogs in the northern part of Pärnu, abandoned land and a dumpsite (Demicheli et al. 2003). The dumpsite and abandoned land may be especially suspicious for soil contamination that could be mobilized during a storm surge or inundation. However, the raised sea level in the "High Case" scenario only affects an area of grassland at the Pärnu River close to the eastern border of Pärnu. The abandoned areas and the dumpsite are at least 600 m away from the Pärnu River and Sauga River and over 1.5 km away from the coast in the "High Case" scenario.

In case of a 100-year storm surge, some green areas and grassland will be flooded. The possibly critical areas will not be impacted.

3.7 Groundwater and Water Supply

The water supply system in Pärnu had a length of 187 km in 2001. According to the General Planning of Pärnu City, additional 72 km are planned to be built by 2010 (Pärnu City Council 2001). It is remarkable that 38% of the built up area is without public water supply. In part Vana Pärnu (south of the Sauga River) and Raeküla (the southeastern most part of Pärnu) especially have neither public water supply nor a sewage system. This could cause contamination of the private drinking water wells.

In the "High Case" scenario, about 1 km of the existing system and 1 km of the planned system will be affected. The planned water supply helps to reduce the impact of a possible SLR, because private wells that have to deal with the intrusion of brackish water and sewage contamination will be replaced by public water supply.

In case of a 100-year flood and "High Case" Scenario, 28 km of the existing system and 15 km of the planned system could be affected. This is 15% of the existing system but 21% of the planned water supply.

Since an over-extraction of groundwater leads to land subsidence and intrusion of brackish water into the groundwater, many wells in Pärnu were closed and replaced by a well field in the hinterland of Pärnu. Only two wells in Pärnu contribute to the public water supply, but they are to be closed soon. Therefore, there is no danger of salinization of drinking water.

3.8 Protected Areas

The basic distinctions of classifications of nature protection are Limited Management Zones, Special Management Zones and Strict Nature Reserves (Estonian Law on Protected Natural Objects, in force since 2004). Strict Nature Reserves delineate areas in their natural state and free of direct impact by human

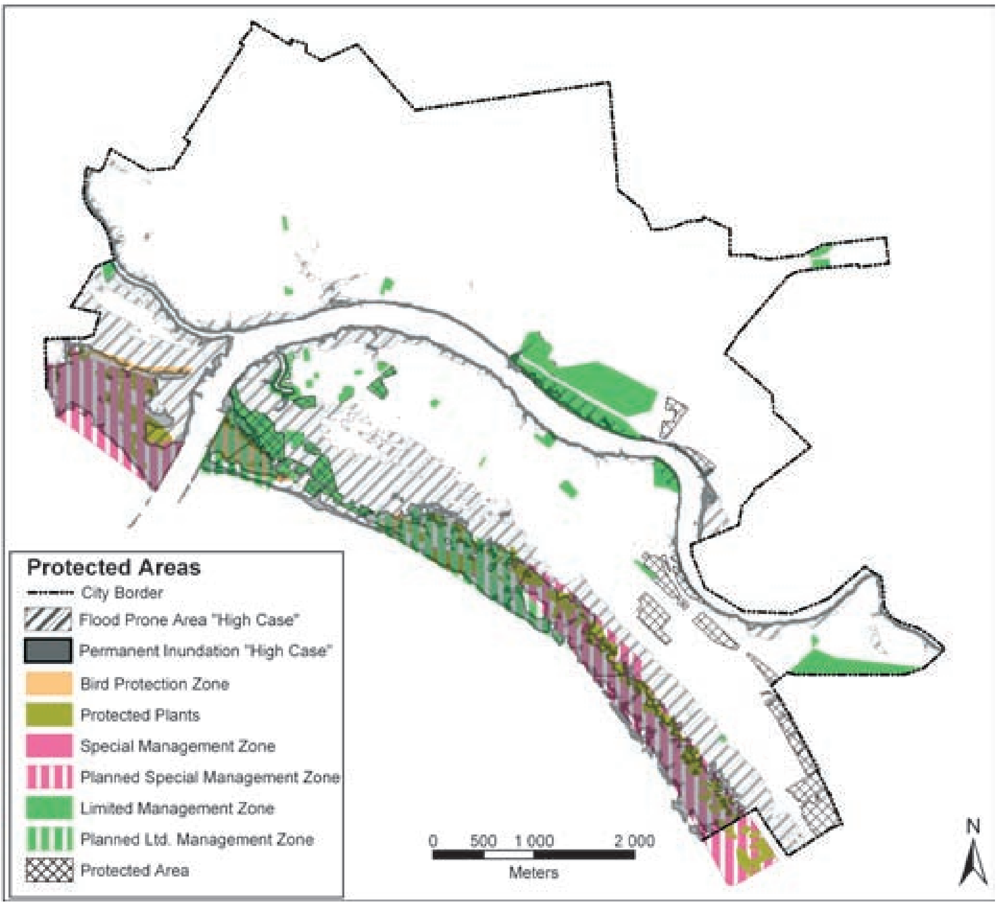

Fig. 3. Protected areas in the "High Case" scenario and 100-year storm surge. Source: J. Klein.

activities, whereas Limited Management Zones and Special Management Zones allow restricted human activities.

Several zones of protected plants and bird protection zones are located in the dunes and salt marshes along the shore. The map of environmental protection shows the whole coastal area as Planned Special or Limited Management Zone (Pärnu City Council 2001). The coastal area is to be included in the Natura 2000 zone according to the European Flora, Fauna and Habitats Directive and the Bird Protection Directive in conjunction with Estonia's membership into the European Union (Kupper, chief specialist of green zones at the environmental service, Pärnu town government, see list of interviews).

In addition to the damage due to tourism, the inundation of the beach area caused by SLR comes along with the loss of protected salt marshes and dunes, which are habitat for rare plants and birds (see Fig. 3). The impact of storm surges to the protected areas left after inundation will not differ remarkably from the impact of today. Changing gauges and recurrent flooding characterize the coastal habitat.

3.8 Coping Capacity

3.8.1 The Estonian Planning System and institutional Coping Capacity

The Estonian planning system is very young. During the time of the Soviet Union, planning was centralized in Tallinn. There was no planning authority on county or local level. The duties of local governments were mainly limited to executive work. Therefore, Estonia had neither an existing planning system nor enough planning experts when it gained independence. (Lass 2000)

In 1995, the Planning and Building Act (PBA) came into force. It organized spatial planning, building design and construction. Since the possibility for everyone to do detailed planning (i.e. determine plots, planting of vegetation, architectural requirements, environmental protection measures and other regulations on a very local level) caused problems, a new Building Act and a new Planning Act came into force in 2003. However, the new Planning Act still allows interested people to do detailed planning with only a few restrictions. (Lass 2000)

The PBA requires interrelating sustainable development and physical and economical development, taking into account protected areas and making proposals for the establishment of new protected areas and for the conservation of ecosystems and landscapes. Besides the requirements of the PBA, other laws such as the Law on Protected Natural Objects, the Shores and Banks Protection Act and the Water Act influence spatial planning on all levels.

The common interest and participation in planning processes is limited. In Pärnu, new plans are publicly displayed and can be criticized by everyone before they come into force. Remarks and proposals are discussed and can be taken into account. Nevertheless, most people do not use the possibility to participate actively in the planning process. (Kupper, chief specialist of green zones at the environmental service, Pärnu town government, see list of interviews)

The effects of a possible future SLR are not taken into account in Estonian planning laws, but the organization of planning in Estonia offers good possibilities to integrate the topic of SLR into the planning process. The responsible planning authority on a national level is the Ministry of Internal Affairs (Estonian Planning Act §4(1)), but for the coordination of plans certain tasks are in the competence of the Ministry of Environment, which might be able to effectively consider SLR as a topic in spatial planning (Estonian Planning Act §8(5) and §16(1^1)). The Planning Act focuses on the conformity of the plans. That might result in changing a more general plan, if the more detailed plan requires its modification (Estonian Planning Act §24(4) and (5)).

At least two studies have researched the effects of SLR in Estonia. Tarand & Kallaste (1998) edited the "Country Case Study on Climate Change Impact and Adaption Assessments in the Republic of Estonia". Their study examines the possible impact of climate change on agriculture, forestry and water resources on a national level and discusses possible adaptation strategies. Kont et al. (2003) assessed the effect of SLR for Estonia. Assuming a SLR of 1 m, they investigated the impact on seven case study areas in Estonia, among them Pärnu-Ikla.

On a local level, future SLR does not seem to be a topic of daily life and the public awareness is limited. Suursaar et al. (2001) completed a hydrodynamic modeling of Pärnu Bay based on the data of sea level stations in Pärnu, Rohuküla and Heltermaa, but they did not take into account possible future SLR. The flood height assumed for the planning of Pärnu City is 2 m, which matches well with the result for a 100-year flood calculated in this work (Kupper, chief specialist of green zones at the environmental service, Pärnu town government, personal communication). Possible effects of climate change are not taken into account for the development of tourism. In the southeast, just beyond the border of Pärnu City, a beach and golf resort is planned on a 1.5 km wide zone between the shore and Riia Maantee (Riia road).

In Pärnu, there exists no institution with a special task concerning storm surges and floods. In case of a bigger emergency like a storm surge, the mayor cooperates with the rescue services and the chief of the economic department (Kupper, chief specialist of green zones at the environmental service, Pärnu town government, personal communication). During the winter storm on the 8th and 9th January 2005, which was one of the most severe in the last 100 years, the cooperation seemed to work well, for example, the evacuation of citizens and tourists was organized and news, instructions and contact addresses were available and regularly updated on the Pärnu City web-page.

3.8.2 Hotspots and Stakeholders' Coping Capacity

In general, the Coping Capacity of most stakeholders is determined by the limited awareness of the possibility of a future SLR. Currently, no actions or plans take SLR into account. The people are aware of the impacts of storm surges. People are used to flooding of infrastructure and cellars and new plans and actions include protection measurements.

The most eye-catching hotspot is the coastal zone on Pärnu's peninsula (Hotspot I in Table 3). This area will be most affected in case of future SLR. At the same time, it has a high economic value as a tourist attraction and ecological value with areas for bird and plant protection. The municipality is responsible for the coastal area. So far the knowledge of the persons in charge is limited to a very general knowledge about climate change and to the information provided as part of the SEAREG project. Consequently, there has been neither special resources nor motivation to deal with possible future SLR until now. There will be a new area for buildings close to the beach probably intersecting with the future Natura 2000 area along the coast. The only possible protection for these buildings could be a compulsory construction height of at least 2 m above the current sea level (Kupper, chief specialist of green zones at the environmental service, Pärnu town government, see list of interviews).

The locations of several health and rehabilitation centers (Hotspot II Table 3) are prone to flooding today and in the future. There is a certain level of awareness concerning floods. The Tervis Spa is protected by a small sea wall. Indirectly, the situation of the health and rehabilitation centers depends also on the condition of the coastal area and the beach. As a recreational area and major tourist attraction, the beach is of vital importance for Pärnu as a health resort and tourist town.

The Old Pärnu Graveyard (Hotspot III in Table 3) is affected by erosion on the riverside. In case of a higher sea level, this situation might get worse. This problem is recognized, but no sustainable solution has been found so far.

Hotspots IV and V should be jointly considered. Large parts of Vana Pärnu and Raeküla are neither connected to the water supply system nor to the sewage system. In these areas, drinking water is often taken from private wells. According to the Estonian Public Water Supply and Sewerage Act, there is no obligate control of these wells. This was confirmed by Pärnu Vesi (Vohla, Pärnu Vesi, see list of interviews), which has no information about the drinking water quality of private wells. Infiltration of sewage into

Table 3. Hotspots and stakeholders in Pärnu.

	Hotspots	**Stakeholder 1**	**Stakeholder 2**	**Stakeholder 3**
I	coastal zone	municipality		
II	health and rehabilitation centers	owner and operator	municipality	
III	graveyard	municipality		
IV	sewage system	Pärnu Vesi	municipality	
V	water supply	Pärnu Vesi	owner of private wells	municipality

drinking water wells cannot be excluded. A higher sea level and flooding caused by storm surges could cause higher salinity and enhance sewage infiltration. Raeküla is to be connected to the public water supply by 2008, but there is no detailed planning for Vana Pärnu yet.

3.9 Vulnerability

The impacts of SLR meet a generally low Coping Capacity of the stakeholders. While nature protection helps to keep infrastructure construction and buildings away from the endangered areas, there is so far no awareness of the possible loss of the protected natural areas. There are no mitigation strategies developed to cope with the impact on the coastal area. Currently, SLR could considerably affect the water supply of some parts of Pärnu. Short- and middle-termed planning does not take SLR into consideration. However, to ensure good water quality and to match international standards for drinking water and environmental protection, there is motivation to complete public water supplies and sewage systems regardless of the impact of future SLR.

In case of a 100-year storm surge, nearly all parts of daily life are affected. Although the impact can be considerable, the vulnerability is low. Flooding is a recurrent event that people are aware of. Flooding events are taken into account when constructing new buildings and protecting existing ones. Nevertheless, the vulnerability would rise in the "High Case" scenario compared to today, because the site density close to the coast is growing while a higher sea level at the same time causes a higher flood frequency.

4 DISCUSSION

The reliability of the results depends to a large part on the quality and resolution of the DEM. To assess the reliability of the DEM, the root mean square (RMS) error (eq. 1) of the DEM was calculated in comparison to the given zero contour line.

$$RMS = \sqrt{\frac{\sum_{i=1}^{n} \Delta z_i^{\,2}}{n}} \qquad \text{[Equation 1]}$$

RMS: root mean square error
Δz_i: height difference between the zero contour line and the DEM at the benchmark i

When benchmarks are placed every 100 m along the given zero contour line, the overall RMS Error is 0.35 m. This is a comparably good value, taking into account the resolution of the DEM and the steep slope along the sides of the Pärnu River and Sauga River, where a small shift in x and y direction causes a strong height deviation.

On the sandy shore of Pärnu, the coastline is changed continuously by sediment transport. During the last decades, the coastal zone east of the Pärnu River estuary was growing, but an accelerated SLR might slow down or reverse this process. The coastal evolution caused by effects of sediment accumulation and erosion along the shore of Pärnu might lower the impacts of SLR. The coast change is not taken into account in the assessment, although Klein (2004) attempts to estimate a development on the basis of the SLR scenarios.

A higher sea level might cause a backwater effect on the Pärnu River and contribute to a higher risk of river floods. A higher sea level will affect the water level over a much longer distance than the upstream simple bathtub model used for the impact assessment indicates.

5 CONCLUSION

The impact of future SLR on Pärnu is limited to a few hot spots. In case of the "High Case" scenario, there would be considerable impacts on the service sector, groundwater and water supply and protected nature areas. The impact on the service sector and the protected areas can be ascribed to the loss of large parts of the coastal area. The impact on the water supply is limited to the areas with no public water supply and no sewage system. A low Coping Capacity makes Pärnu vulnerable to impacts at the hot spots. However, a higher awareness might help to cope with the impact of future SLR.

To offer ample information for planning and decision making, further research is needed. An assessment of the impacts of SLR on the Pärnu River, like backwater and intrusion of brackish water could enhance the significance of the results. Studies dealing with coastal evolution and sediment transport should include perspectives for future coastal development in case of SLR to enable stakeholders to find appropriate mitigation strategies.

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INCORPORATING SEA LEVEL RISE SCENARIOS IN HELSINKI CITY PLANNING

by
Samuli Lehtonen[1] & Samrit Luoma[2]

Lehtonen, S. & Luoma, S. 2006. Incorporating sea level rise scenarios in Helsinki City planning. Geological Survey of Finland, Special Paper 41, 83–94, 3 figures and 1 table.

The phenomenon of climate change induced sea level rise has been on the City of Helsinki planning agenda since the late 1980's. For example, identification of low-lying areas was made during that time. Following these discussions current developments are regulated. However, the resolution to cope with the impacts of possible future sea level rise is more difficult in the old built up low-lying areas such as the Market Square. Storm surges in 1990 and 2005 have shown that sea level rise poses a threat not only to the old built up areas, in the inner city and suburbs, but also to the old combined sewer system in the central business district for example. As many coastal areas in the City of Helsinki are opening for development during the next 5-10 years, planning decisions made today regarding climate change related sea level rise and its impacts on urban structures are greatly important.

Key words (GeoRef Thesaurus, AGI): climate change, sea-level changes, transgression, floods, coastal environment, urban environment, urban planning, Helsinki, Finland.

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1 INTRODUCTION

Situated in the northeastern part of the Baltic Sea, Helsinki, in southern Finland, is the capital and largest city of Finland. The municipal territory covers 186 km^2 of land area and 500 km^2 of sea, with a population of approximately 559 000 inhabitants. Although Helsinki was founded in 1550, most of the present infrastructure was built during the 19th and 20th century. As the capital city of Finland, Helsinki is a centre of administration, economic and commercial activities, educational institutions and transport. Since the 1990's, the population of Helsinki has increased rapidly, creating a high demand for suitable land for construction of housing, services and workplaces.

1.1. Urban planning in Helsinki in the SEAREG context

The urban planning in Helsinki is administratively centered in the Helsinki City Planning Department where both the master plans and local detailed plans of Helsinki are prepared. Its responsibilities also include traffic planning and regulation. The Development Unit of the Helsinki City Office and the City Planning Department jointly manage the larger site development projects, such as the Jätkäsaari project. The Helsinki City Planning Department functions in accordance with the decisions made by the City Planning Committee, which is a political organ. The Real Estate Department and the Environment Centre also have an important role in the urban planning of Helsinki. The Real Estate Department is mainly responsible for managing land and real estate owned by the City of Helsinki. It also offers geotechnical services and its geodetic division has been active in sea level rise related issues. For sea level rise and the urban environment, water and energy infrastructure is very important in vulnerability management. In emergency situations, the Rescue Department has a vital function in organizing other actors.

The technical division of the Helsinki City Planning Department has taken an active role in sea level rise related issues, providing guidance for water and energy management, for example. Hence, a major part of this article focuses on technical issues in comparison to urban planning seen as zoning of specific functions. For general urban planning, coastal areas are considered to be the most attractive and sought-after living environments in Helsinki, thus there is a high demand for coastal housing (see Figure 1). Large areas close

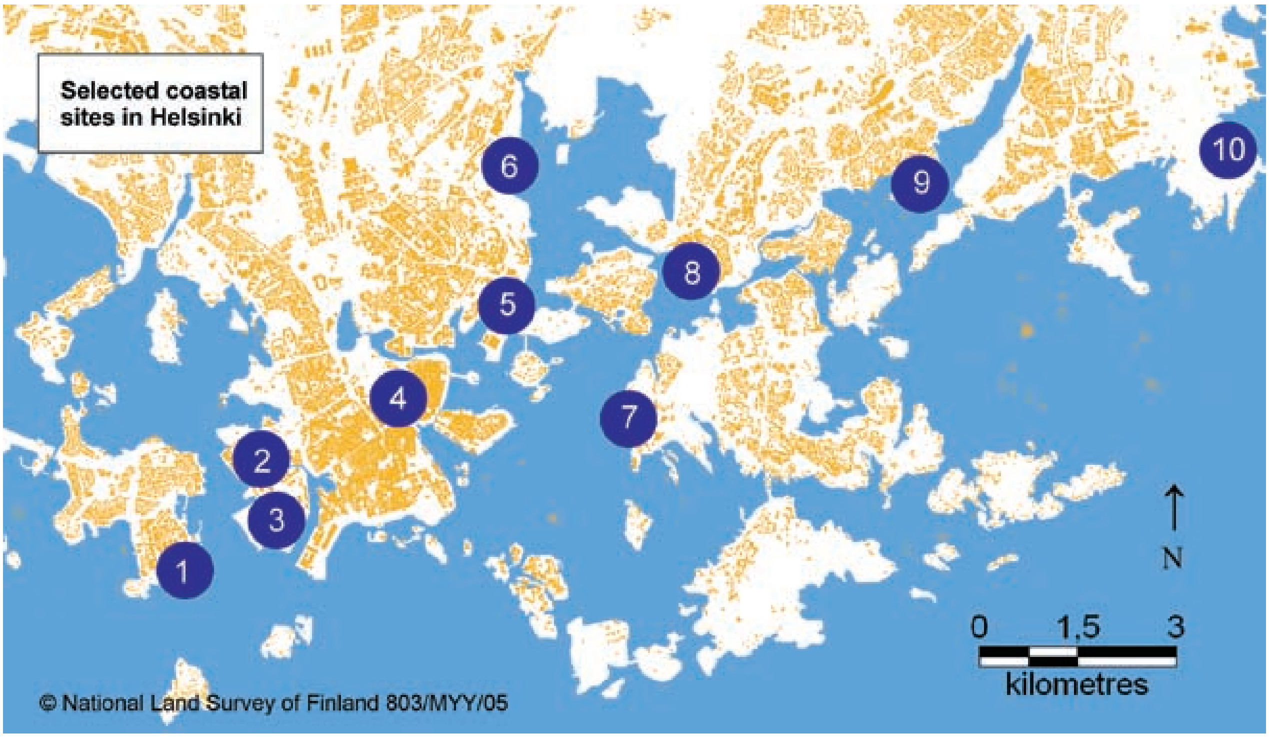

Fig. 1. Coastal development and selected low-lying areas in Helsinki. 1. Lauttasaari (new coastal housing, built during late 1990's). 2. Ruoholahti (new coastal housing, early 1990's, lowest construction level lifted to 3 meters after the 1989 climate change seminar at City Planning Department). 3. Jätkäsaari (planned coastal housing, current harbour functions will be moved to Vuosaari harbour, approximately 2010). 4. Market Square and Kluuvi areas (low lying central areas, flood prone). 5. Sompasaari - Kalasatama (planned housing, current harbour functions will be moved to Vuosaari harbour, approximately 2010). 6. Arabianranta (new coastal housing, built during early 2000 and partly under construction, flood prone recreational areas). 7. Laajasalo - Kruunuvuorenranta (planned coastal housing, development will begin after 2010). 8. Herttoniemenranta (new coastal housing, late 1990s). 9. Marjaniemi (older low-lying coastal small scale housing, flood prone). 10. Vuosaari harbour. Map: S. Lehtonen.

to the central business district and on the shoreline are becoming available for housing in 2010, when the harbour functions will be moved from Jätkäsaari and Sörnäinen (Kalasatama) to their new location in Vuosaari. In the new master plan of Helsinki, 6,6 million floor square meters are planned to be built for housing. Approximately half of the planned housing will be located on coastal areas (Kare 2005). The technical aspects of, for example the lowest floor-levels (above mean sea level) and the capacity of the sewage system to cope with flood waters are key to how successful the future coastal housing projects will be in relation to climate change and possible sea level rise.

1.2. Characteristics of the natural environment in Helsinki

Helsinki is dominated by the exposed acid plutonic bedrocks of the synorogenic and late orogenic phases of the Svecokarelidic orogeny (Simonen 1980) and forested hills alternating with low-lying clay areas that once constituted the seabed. The city centre is situated on a rocky peninsula near the sea with 98 km of shoreline and 315 islands in the Helsinki archipelago. The inland landscape is dominated by granite hills (up to 30–60 m above sea level), mixed with gneiss, amphibolites, quartz-diorite and granodiorite, cliffs and tiny canyons (Vähä-Piikkiö & Maijala 2003, Hytönen 1980). In several low-lying clay areas the elevation is close to the sea level, which causes problems during floods. According to Cubasch et al. (2001), by the year 2100 the mean surface temperatures will raise between 1,4 and 5,8 °C compared to the 1990 mean level. According to recent studies on the Arctic environment, projected global sea level rise in this century would range between 10 cm and 90 cm, depending on the IPCC scenario used. In the Arctic region, the increase is projected to be greater than the global average (Hassol 2004). In the Baltic Sea Region however, land uplift will partly compensate for the impact of sea level rise.

This study was made in the context of the INTERREG IIIB project "Sea Level Change Affecting the Spatial Development in the Baltic Sea Region" (SEAREG), which was co-financed by the European Regional Development Fund (ERDF). A fundamental idea of the SEAREG project was to increase awareness and to identify possible impacts and hotspots in different case study areas around the Baltic Sea. The project results can help the local and regional stakeholders to identify appropriate regional and local adaptation measures. Contradictory information and the long time scale makes climate change related sea level rise an abstract and distant hazard in the eyes of many decision makers and stakeholders alike.

2 METHODOLOGY

Action research forms the methodological basis for this study. In action research, the role of the researcher is almost parallel to the role of a consultant: both help actors to become aware of and find solutions to existing problems and learn to cope with them (e.g. Kuula 2001, Eskola & Suoranta 1998). According to Heikkinen et al. (1999), a historical aspect of resolving how something has evolved to its current state is characteristic to action research. Also, action research focuses on finding better practices. Action research is a useful setting for the SEAREG project since the project deals with both the existing and the always-improvable relation between planners and scientists and also with finding new ways to deal with new issues such as climate change. The network that becomes activated during the project can be seen as one result developed by the project.

The methodology of the action research within the SEAREG project was as follows:

1. Study of the existing situation and outlining of the "problems" using E-mail questionnaires
2. Analysis of E-mail questionnaires and composition of interviews and an action program.
3. Single person interviews and round table discussions.
4. Evaluation and recommendations for the action subjects.

By analysing the e-mail questionnaires sent to planners and scientists, an outline for this study was formed. The questionnaire focused on climate change, awareness on climate change and risk related issues and risk-based decision-making. This first phase of the study was used to outline the problems for three round table talks (round table 1. involving scientists, round table 2. planners, round table 3. scientists, planners and politicians together). The questionnaires and round tables were thoroughly analysed during the SEAREG project (e.g. Lehtonen and Peltonen 2006, *this volume*). As well, single person interviews were conducted to gather more detailed information on problem related facts. The persons interviewed were the key actors on sea level rise related issues and hence provided important information on actor relations, roles and responsibilities. The so-called snowball-method was used to identify relevant actors for interviews. Interviewees were asked to identify important actors working in a field relevant to the sea level change and spatial planning. In this way it was possible to discover networks (active, passive and potential) relevant to the topic.

In addition to the interviews, round tables and questionnaires, different administrative documents and publications were studied. The interviews centred on the issues of urban planning, energy and water management. The discussion focused on the impact of future sea level rise in the Helsinki area in the next 100 years. No explicit impact or vulnerability assessment was made for the city of Helsinki, but in analysing the interviews and other material a general overview of major impacts and vulnerabilities was made.

3 RESULTS

3.1. Sea level rise scenarios for Helsinki

In the SEAREG project, the Swedish Meteorological and Hydrological Institute (SMHI) calculated 3 scenarios for winter mean sea surface height for 2071-2100. The “low case” scenario indicates -26 cm decline from 1990, the “high case” scenario 72 cm and the ensemble average scenario of 21 cm sea level rise for Helsinki (Meier et al. 2004). An earlier study by the Finnish Institute of Marine Research projects approximately 10-20 cm mean sea level rise in the Gulf of Finland until the 2090’s (Johansson et al. 2004).

Although mean annual sea surface height is an important figure, storm surges pose a greater acute risk for Helsinki. For example during a longer period of westerly winds the sea level has risen to 136 cm (January 1990) and to 151 cm (9.1.2005) above the theoretical mean water in Helsinki (Kahma et al. 2005). Extreme weather events, such as storm surges that push the water masses towards the coast of Helsinki, are assumed to be more common in late 21st century (Maa- ja metsätalousministeriö 2005) and it is realistic to think of sudden events of sea level rise between 125 cm to 223 cm happening during the next 100 year period (low case and high case scenario plus current highest sea surface height in Helsinki, 151 cm, combined).

3.2. A brief historical review on climate change and sea level rise in the context of Helsinki city planning

The concept of sustainable development was brought to the public debate by the Brundtland report in 1987 (WCED 1987). The topic of climate change entered the discussions alongside the sustainability discourse. In Finland, comments from municipalities on the Brundtland document were collected by the Ministry of the Environment. During this process, individual employees of the Helsinki City Planning Department and the Geotechnical Division of the Helsinki Real Estate Department tried to find aspects of sustainability and greenhouse effects relevant for Helsinki.

At that time, major planning decisions affecting areas near or on the shoreline were taking place. The current plans did not take climate change related sea level rise into account and hence a discussion among planners was rising. In 1989, a seminar focusing mainly on sea level rise was held in the Helsinki City Planning Department, organised by Kari Silfverberg (currently working in the Helsinki Environment Centre). Experts from different fields (e.g. meteorology, oceanography) attended the seminar together with people from the city administration, planning, environment, water and energy related departments. The discussed sea level rise scenarios suggested mean sea level changes between –50 cm to +150 cm or an even higher rise in a 100-year period (Silfverberg, interview 20.2.2003). These discussions affected the planning process of Ruoholahti (an area 1 km from the inner city), where the lowest elevation level for housing was raised from 1 meter to approximately 3 meters above mean sea level.

Usko Anttikoski, the head of Geotechnical Division of the Real Estate Department at that time, conducted a study on prerequisites for a flood dam in Helsinki (Ravea & Korhonen 1992). In the report, it was noted that sea level rise could have extensive effects on the Helsinki city centre and other areas close to the seashore. Two options for dams were identified. Although the plan was rejected, responses to the SEAREG questionnaire sent to Helsinki city planners still indicated some existing interest in dam building.

In 1999, the Finnish Environment Institute (SYKE) published a guidebook on the lowest recommended minimum elevation above mean sea level for construction (Ollila 1999). Guidelines related to flooding of seawater were based mainly on research work at the Finnish Institute of Marine Research (Kahma et al. 1998). The booklet has played a major role in setting the minimum elevation level above mean sea for construction near the shoreline in Finland generally. In Helsinki, the measures of the SYKE-guidebook were adopted into the Helsinki building code in 2000 (Helsingin kaupunki 2000). Also in 2000, a new national Land Use and Building Act was enforced. The law has a clearer emphasis on flood-prone areas than the preceding law (MRL 2000).

According to some interviewees, interest in climate change related issues and sea level rise has not been very high in the City Planning Department. The Geotechnical Division of the Real Estate Department and nowadays the Environmental Centre have been most active in raising the discussion. However, among all of the SEAREG project's case study areas, Helsinki has reacted to the phenomenon most decisively. The

Fig. 2. Market Square protected by wastepaper cubes during the January 2005 winter storm. In addition, pumping of excess seawater from the combined drainage and sewage system was organised. (Photo: S. Lehtonen)

1989 seminar on sea level rise, the sudden sea level rise in 1990 to a new highpoint, the study on the dam and the rising of the lowest construction level in Ruoholahti may not have a direct relationship, but a certain interconnection between the events is visible. Also, new information on sea level changes affected the planning of the Arabianranta housing area, where the elevation levels of local detailed plans were changed after pressure from the Helsinki City Office (Silfverberg, interview 20.2.2003).

Storm surges or other extreme events are important for awareness, raising especially in the short term. In winter 1990, the water level rose to a then historical highpoint of 136 cm above mean sea level. The occasion had wide coverage in the media, which showed pictures of firemen piling sandbags in Market Square. In January 2005, the sea level rose to its current highpoint of 151 cm in Helsinki. The Rescue Department organised protection of the Market Square, where sea level rise would have had the most costly impacts (Figure 2). Some housing areas and construction sites in different parts of Helsinki suffered various damages (e.g. Marjaniemi and construction sites at Arabianranta, see Figure 1). The winter storm in January 2005 certainly has given an impetus to sea level rise discussions. Currently, new discussions on the lowest construction levels has begun in the City Planning Department. According to the director of strategic urban planning, Pertti Kare, these levels are being currently re-evaluated (Kare 2005).

3.3. Organisational settings relevant to climate change adaptation

Welp's definition of a stakeholder is (Welp 2001): "A stakeholder can be defined broadly as one who: (a) is affected by or affects a particular problem or issue and/or (b) is responsible for problems or issues and/or (c) has perspectives or knowledge needed to develop good solutions or strategies, and/or (d) has the power and resources to block or implement solutions or strategies." For the purposes of this article, Welps' definition is useful because his three latter points underline the importance of city departments and companies responsible for infrastructure. All the institutions or organisations that are involved and responsible for the aforementioned hotspots are identified as stakeholders. As well, one hotspot may relate to many stakeholders.

In Helsinki, no specific single institution or unit exists to handle the effects of a possible future sea level rise or floods. The cooperation is organized ad hoc in the case of a big storm surge and subsequent flooding. In Figure 3, an organisational setting for managing sea level rise issues relevant for Helsinki city planning is presented. As mentioned earlier, the Geodetic Division of the Real Estate Department, the Environment Centre and the Technical Division of the City Planning Department serve as the major actors in developing measures for adaptation and in bringing scientific knowledge into planning procedures. In addition to these groups, the City Building Regulation Department supervises construction permits and the Development Unit of the Helsinki City Office is responsible for managing larger site development projects together with the City Planning Department.

In the case of Helsinki, active institutional actors may vary, for example in the case of active employers moving from one department to another. Hence, active individuals in these departments have been central to the discussion of climate change or future sea level rise during the times when the topic has not been on the official agenda. To manage technical infrastructures in Helsinki, Helsinki Energy, Helsinki Water and the Technical Division of City Planning Department form the core group of responsibility, the first two for technical issues and the latter for planning and steering. Neither Helsinki Energy nor Helsinki Water have their own studies or policies on sea level rise, but they rely firmly on steering from the Technical Division of the City Planning Department, which is the most important actor in implementing the knowledge provided by other city departments or the scientific community (e.g. Finnish Institute of Marine research) (Heinonen, interview 8.11.2004; Saviniemi, interview 4.11.2004). In Welps' terms, the Technical Division "has the power and resources to block or implement solutions or strategies" whereas the other actors seem to have less power in the final decisions. However, it must be noted that the City Planning Department works in accordance with the decisions made in the City Planning Committee. In emergency situations, such as the winter storm in January 2005, the Rescue Department is responsible for organising the necessary precautionary actions, together with Helsinki Energy and Helsinki Water.

The cooperative structures among the institutions have been long-term-developed for other special tasks

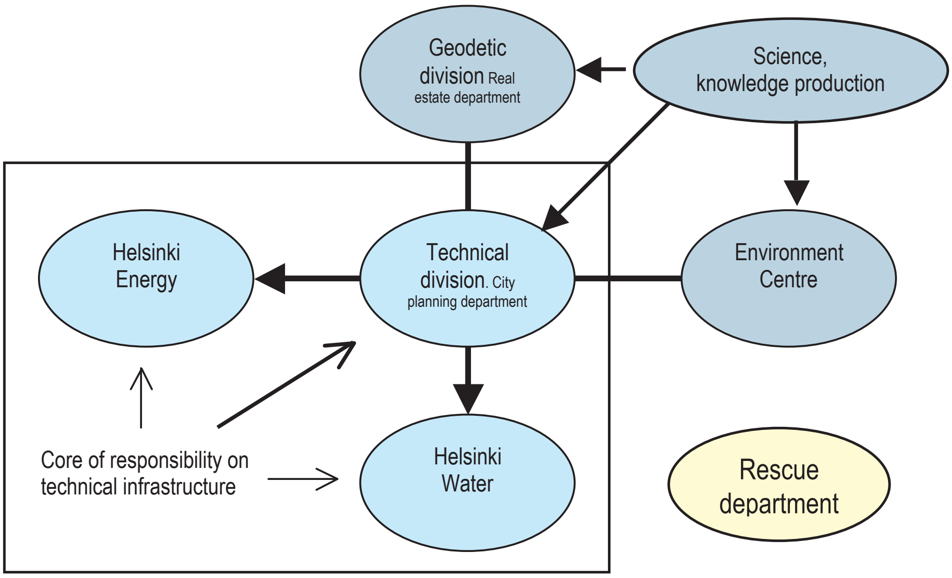

Fig. 3. The institutional actor network relevant for handling issues on sea level rise and climate change in Helsinki. Source: S. Lehtonen.

and emergency cases, but not for the impact of future sea level rise or floods directly. Active cooperation has taken place when planning certain locations or issues on underground development. Here, climate change, future sea level rise and flooding have been on the agenda to a certain degree (e.g. multi-utility tunnel, see 3.2.3). The impact of the future sea level rise is not explicitly taken into account in the Finnish planning laws, even if it is included in the Helsinki building code.

Institutional capacity to cope with sea level rise in Helsinki can be considered good. The coping capacity is also good in the new or future housing areas. The planners have access to relevant knowledge and the building code serves as a regulating factor preventing decisions based on false information. Still, planners' awareness on climate change competes with other needs and demands (political, social, technical etc.). The storm surges in 1990 and 2005 are known among the planners, but some planners do not consider sea level rise a central topic and thus rely on reassuring viewpoints that land uplift still exceeds sea level rise in Helsinki in the next 100 years.

Planned areas, such as Jätkäsaari, which is very close to the inner city, and already built up areas, such as Ruoholahti, Arabianranta and Vuosaari, are constructed in accordance with the new building code. However, the resolution to cope with the impacts of the future sea level rise is more difficult in the old low-lying areas that have already proven flood-prone. According to our interviewees, there has not been an explicit discussion in the City Planning Department on how to prepare the older areas for possible future sea level rise.

3.4. Hotspots of Helsinki

When defining the hotspots in Helsinki, it is useful to make a rough distinction between *old infrastructure* (including housing built before the 1990's) and *new or planned infrastructure*. A 100-year flood would have an impact on some of the old housing areas and public places located in low-lying areas along the coastline. Since the 1990's and especially after the year 2000, regulations from the Helsinki building code 2000 steer future planning. The building code functions as an ordinance, which is however, subordinate to the law and to a legally valid master plan or a local detailed plan. Another division that could be made is *visible urban structures* and *underground constructions*. In the future, attention should focus on the impacts of sea level rise on underground structures, such as pipeline networks or other underground construction, such as the metro-network.

A schematic impact matrix of the Helsinki area was prepared (Table 1). In comparison to other case studies produced in the SEAREG -project (e.g. Itä-

Table 1: Schematic Impact matrix of Helsinki.

Sea Level Rise Effects	Housing in low lying areas		Public areas along coastline	Water supply system	Sewer system		District heating network
	Old	New			Combined	Separated	
Inundation (permanent land loss)	Medium / High	No impact	Medium /High	No impact	No impact	No impact	No impact
Flooding (flood prone areas)	High	No impact/ Low	Medium /High	No impact / Low	Medium / High	No impact	No impact / Low

Uusimaa and Gdansk, Virkki 2006 and Staudt 2006, *this volume*), the Helsinki case study is based on action research methodology compared to the vulnerability assessment methodology. Also, no GIS data for flood mapping was received and thus, the matrix does not draw from GIS analysis as do other aforementioned case studies. However, the impact matrix does reflect the knowledge gathered from the interviewees. The next chapters elaborate the impact matrix in more detail.

3.4.1. Impact on housing and other visible urban structures

The Finnish Environment Institute (SYKE) guidelines on lowest recommended construction levels were implemented in the Helsinki building code in 2000 (see 3.3). The lowest construction height above mean sea level on the Baltic Sea coast was set to +230 cm plus the local wave height of 30 cm or more, depending on the location of the building. A distance of 20 meters from the shoreline is also required (Helsingin kaupunki 2000).

Before the 1990's, housing development in general was not regulated in relation to sea level rise or flooding as explicitly as it is today, and the guideline was then set at approximately 120 cm. This made housing and especially cellars in low-lying areas vulnerable to floods. Flood prone low-lying areas are located for example, in the Marjaniemi area, Kyläsaari (south of Arabianranta), the Market Square and Kluuvi (see Figure 1). The business district of Kluuvi is built on earth fill and is not actually coastal, but approximately 200 metres on-shore. Due to its low location however, specific parts of the area are prone to flooding as water rises through the sewer system. Other areas such as Arabianranta and the southeastern parts of Lauttasaari had also been discussed during the 1989 seminar on sea level rise held at the City Planning Department (e.g. Silfverberg, interview 20.2.2003; Kolu, interview 14.4.2003; see 3.3). To define adaptation measures, the low-lying Market Square area is the most difficult to protect as it is surrounded by many old buildings, such as the city hall and the presidential palace. However, ad hoc protection during the recent storm surges has been successful. The Marjaniemi area consists of smaller scale private housing and hence the overall financial risks are lower, although risky for the private property owners. The coastline of Arabianranta continuing south to Sompasaari is mainly low lying and flood prone. At the moment, the southern part includes harbour functions and wasteland and the area is to be developed during the next 20 years. In the north, the Arabianranta housing area is under development and is built in accordance with the new building code.

The above-mentioned sites are located in the low-lying areas less than 150 cm above the sea level and close to the shoreline. Some have proven flood prone during heavy rains or storm surges. The impact of the 100-year flood might also be considerable to other small-scale private properties that are built in other low-lying sites. In the case of a sudden storm surge, the owner is responsible for the risks and precautions, such as equipping the building with a pumping system and the use of waterproof or other special insulation materials. In relation to sea level rise, final responsibilities are not thoroughly thought out and it is unclear who will finally be responsible for any financial losses (e.g. the planning office, an insurance company, the individual who bought low lying property or the city). Financial risks, however, are largest in areas in the city centre. The impact of sea level rise on the new housing areas, the water supply system, the sewer system and the district heating system is lower as future sea level rise is currently being taken into account during planning processes. As many coastal areas are now being opened for development, Helsinki is certainly moving its new housing more towards the seashore. Hence, planning decisions made today are important.

3.4.2. Impact on the underground pipeline system

In addition to visible urban structures, the impact of sea level change on underground structures raises some concern in Helsinki. Municipal infrastructure, like sewage and heating pipelines, must be considered when making decisions on adaptation policies.

As for district heating, the network in Helsinki consists of both an old and new pipeline system. The old system consists of steel pipes, which can be exposed to saltwater or groundwater. This can cause corrosion and consequently a short life span for the pipe. The old pipeline network in the low-lying area of Hanasaari (near Sompasaari, Figure 1) was constructed with steel pipes in 1974, and had an extremely short life span. The Hanasaari pipeline network was replaced with better insulated new pipes during the late 1980's and early 1990's. So far, no corrosion problems have been found.

The new pipeline is made from better materials and then covered with concrete during the final construction. The insulation materials are waterproof and have high resistance to humidity, and thus are protected from groundwater. The impact of future sea level rise to the district heating in the future is low. While the life span of the old district heating pipelines has, in some cases, been about 25 years, nowadays it is projected to be approximately100 years. Still, the length of the new system is only 17,6 kilometres compared to the total 1200 kilometres length of the system.

The total length of the sewer system in Helsinki is approximately 1760 kilometres. In Helsinki, the sewer network is mostly covered by double piping, where rainwater (44% of total sewer network) and sewage (41% of total sewer network) flow in different pipes. The exception is in the centre of Helsinki, where rainwater and sewage are flowing through the same pipe system (15% of total sewer system) (Heinonen, interview 8.11.2004).

Most of the water pipeline and sewerage pipeline networks built in the early 1990's are still in good condition, and their calculated life span is approximately 100 years. Some of the pipelines built in the 1940's - 1950's are in bad condition because of the poor materials used. Thus, the impact of future sea level rise on the combined sewer system is medium or high. The combined drainage and sewer system in the city centre has shown how susceptible the combined network is even during an annual flood. Therefore, a new pipeline system is being constructed in the new housing areas that are located in connection with the combined network, such as Arabianranta, Ruoholahti and Jätkäsaari (Heinonen, interview 8.11.2004).

When studying sewer networks, elevation and locations of overflow points of the system, which are connected to the Baltic Sea, are relevant. The overflow thresholds in Helsinki are in places 130 or 120 cm above mean sea level. When the seawater level exceeds the overflow thresholds due to sea level rise or flooding, the combination of the sewage water, rainwater and seawater can block the sewer network, causing water to flood into basements and low-lying areas, as well as causing the wastewater to flow straight to the sea without treatment (Heinonen, interview 8.11.2004). Simultaneous sea level rise above the overflow thresholds and a high rainfall could, in theory, cause seawater inflow (via overflow locations) into the sewer and drainage water network and finally to the wastewater treatment plants via the inner city combined sewage and drainage network (Heinonen, interview 8.11.2004). During the winter storm in January 2005, Helsinki Water pumped the excess seawater from the combined sewage and rainwater network back to the sea at the most vulnerable locations, such as the Market Square.

Drinking water from Lake Päijänne is brought to Helsinki in a 120 km long rock tunnel. Hence, there is no risk of saltwater intrusion into ground water deposits that are important for drinking water. The water is purified for use in the public distribution network at Helsinki's Pitkäkoski and Vanhakaupunki water purification plants. Annually, over 70 million cubic metres of water are purified (Helsinki Water 2004). The total length of the water pipeline network in the City of Helsinki is about 1100 km, of which most parts are small size plastic or steel pipelines while about 120 km consists of large main pipes (DN 60 – 100 cm). The most important main water pipelines are built inside the bedrock at depths ranging between 30-80 metres. Eighty percent of the pipeline network is cast iron with a bitumen coated exterior. The pipeline is then covered by cement as a barrier to ensure that these pipes can effectively resist corrosion under the conditions that prevail in Helsinki (Heinonen, interview 8.11.2004).

The impact of future sea level rise on the water pipeline system is low, the problems of corrosion being identical to those of the sewage network. In Helsinki, it is still unclear what would be the main cause of the corrosion, the saltwater, contaminated soil or the groundwater quality itself. In Helsinki, the groundwater surface is at a depth of only 1-3 m (Vähäaho et al. 2002). As a large part of the city's surface area consists of soft clay from the ice ages, the varying moisture content caused by freeze-thaw processes can harm the pipeline networks. The stronger discharges of Vantaa River during the spring increase the risk to the pipelines as well.

3.4.3. Impact on other underground constructions

For overall risk management and sea level rise, underground construction in Helsinki form a very central issue to be studied. In earlier times, underground space was used for storage functions or technical maintenance. Today, other functions such as traffic construction are, in many situations, built underground. According to Tarkkala (2004), free resources for underground development are lacking under the inner city. This also means that the former separate underground spaces are currently forming an underground network (including the metro network for example). A component master plan is in progress to direct underground development in Helsinki (Tarkkala 2004; Helsingin kaupunki 2004).

A local detailed plan and a building permit for underground development is usually needed, with some exceptions, like construction for military purposes. However, the locations of underground military construction are not publicly known. As well, there is no exact mapping of cellar spaces of properties (Tarkkala 2004). In all, public, private, military and technical functions constitute a highly complex system, which was not possible to fully study in the scope of the SEAREG project. It is, however, a central issue in the further study of the vulnerability of underground construction to the possible sea level rise in Helsinki. Also, in Tarkkala's scoping study for the component master plan, it is mentioned that climate change has to be taken into account in planning, as, for example, issues of sea level rise and drainage water management are brought up.

A multi-utility tunnel is part of underground construction work and contains water pipelines from Helsinki Water, district heating pipelines, district cooling pipelines and electric and telecommunication cables from Helsinki Energy. This multi-utility tunnel is separated from the metro network by a wall, which was designed to stand the pressure of the sea. In case of leakage, it will not to leak to other locations (Helsinki Energy 2004). With new technology and better construction material in use, the tunnel working group was confident that there is no impact on the multi-utility tunnel from the sea level rise (Saviniemi, interview 4.11.2004).

4 DISCUSSIONS AND CONCLUSION

Although future sea level rise in Helsinki might not have impacts as drastic as in Pärnu, for example (Klein 2006, *this volume*), it still should be a major factor to be considered when planning new areas. As the winter storms in 1990 and 2005 have shown, sea level rise poses a more serious threat to some older, already built up areas in the inner city and suburbs. Extreme weather events such as winter storm surges are estimated to occur more often in the future. A division must be made between storm surges and the more or less static rise of the mean sea surface over a long time period.

The planning of new areas in Helsinki follows the building code where housing should be situated approximately 3 m above mean sea level. With the current knowledge and available scenarios, the guideline seems to be at a reasonable level for future planning even though every plan should be considered as its own special case, taking into account, for example, local wave fluctuations and soil stability. In some circumstances, discussion on overprotection has risen as well as the notion that some protective solutions might produce uninteresting or unattractive planning solutions (e.g. Kolu, interview 14.4.2003). As to overall attractiveness, two different planning solutions have been taken here as an example. In Herttoniemenranta, a high flood bank has been constructed directly towards the shoreline to reduce the effect of waves. In Arabianranta, housing is located further away from the shoreline. A smaller flood bank is built close to buildings, leaving approximately 70 meters of low land for recreation and direct and easy access to the sea. This lowland is flooded to some extent almost every winter and later this century it would, according to the sea level rise scenarios, be at least partly permanently flooded. Compared to Herttoniemenranta, the Arabianranta-model provides more possibilities for recreational use of the shoreline and the sea, as it has an open green area for public use. Solutions for *protecting* and *attractive* seashore development should be considered further. Considerations should be taken into account when finalizing the plans for new housing areas near the sea (for example Kalasatama and Jätkäsaari).

Currently, the greatest challenges in Helsinki lie in managing the underground constructions and protecting the older infrastructure in the city centre. The complexity of underground networks will be studied during the component master plan process and during that process, identification of vulnerabilities related to the changing climate should be made. Technical weaknesses and surface connections are central factors. If storm surges, such as the one in January 2005, will be more frequent, there is a definite need to think of adaptation measures for the low lying Kluuvi and Market Square areas where the combined sewer and drainage water system may cause challenges. Also, the systems overflow channels might need to be repositioned. Simultaneous sea level rise and strong rainfall would put serious pressure on the water management, sewer system and underground tunnels, especially in the inner city of Helsinki (e.g. Kolu, interview 14.4.2003; Silfverberg, interview 20.2.2003; Heinonen, interview 8.11.2004).

It is not possible for the technical infrastructure to adapt fully to every kind of extreme event, therefore it is important for city planning to co-operate with the rescue department and civil defence among other sectors (Maa- ja metsätalousministeriö 2005). In Helsinki, the existing organisational networks formed for underground development or risk management are useful for managing sea level rise and storm surge related issues. It is important to incorporate the topics mentioned in this article into the working procedures of existing networks, while at the same time it is important to be aware of new stakeholders or new needs to be taken into account. Completely new institutional bodies or networks may not be needed, but phenomena such as climate change, sea level rise and related hazards like storm surges should be on the agenda in ongoing discussions. As approximately 3.3 million floor square meters of new coastal housing is planned over the next 30 years, the timing of the SEAREG project and especially the future decisions are an important topic today. According to the director of strategic urban planning, Pertti Kare, the discussions in the City Planning Department on re-evaluating sea level related threats have taken some impetus from the SEAREG project (Kare 2005). An action research method can thus be considered a valuable tool for raising discussion on underlying not-so-well-known topics like climate change related sea level rise and its impacts on urban structures.

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SEA LEVEL RISE AND FLOOD RISK ASSESSMENT IN ITÄ-UUSIMAA

by

Heidi Virkki[1], Hilkka Kallio[2] & Oskari Orenius[1]

Virkki, H., Kallio, H. & Orenius, O. 2006. Sea Level Rise and Flood Risk Assessment in Itä-Uusimaa. Geological Survey of Finland, Special Paper 41, 95–106, 5 figures and 3 tables.

The Vulnerability Assessment developed by the SEAREG project consists of an Impact Assessment of sea level rise and flood risk as well as assessing the Coping Capacity of stakeholders and institutions to withstand the future hazard. There are three different mean sea level surface height scenarios for the Baltic Sea up to the year 2100 released by the SEAREG project: high case, medium case (ensemble average) and low case scenario. In the case of Itä-Uusimaa, the corresponding measures are a sea level rise of 73-75 cm, sea level rise of 21-24 cm and sea level lowering of 24-26 cm. A Vulnerability Assessment was carried out in the Itä-Uusimaa region, situated on the Gulf of Finland, by interviewing local and regional experts from many different branches. The cities Porvoo and Loviisa represent a local perspective and special attention has been given to local land-use planning.

Spatial planning plays an important role in mitigating the impacts of sea level rise and flooding. This has also been recognised on a national level in the report prepared by the Ministry of Agriculture and Forestry on extensive flooding in Finland. This report proposes seven actions on mitigation in case of extensive flooding that would improve and standardize flood control in the whole country. The most central proposals for action aim to ensure a uniform risk level in preventing damage to housing from flooding. An important tool for regulating construction near shorelines is the building code, which in many cases sets a safety margin for building in municipalities. Although the guidance from planning is quite strong in Itä-Uusimaa and in Finland in general, uniform risk levels are required.

Key words (GeoRef Thesaurus, AGI): Itä-Uusimaa, climate change, sea level rise, floods, impact assessment, Porvoo, Loviisa.

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1 INTRODUCTION

The region of Itä-Uusimaa lies on the coast between Helsinki and St. Petersburg. The whole region of Itä-Uusimaa features more than 3500 km of shoreline. Itä-Uusimaa consists of 10 municipalities, of which Porvoo and Loviisa are the only cities. Porvoo has about 46 000 inhabitants and Loviisa some 7400, which together constitute more than half of the region's population. Porvoo and Loviisa are in many respects similar to each other. Both cities are culturally and historically valuable due to their well-

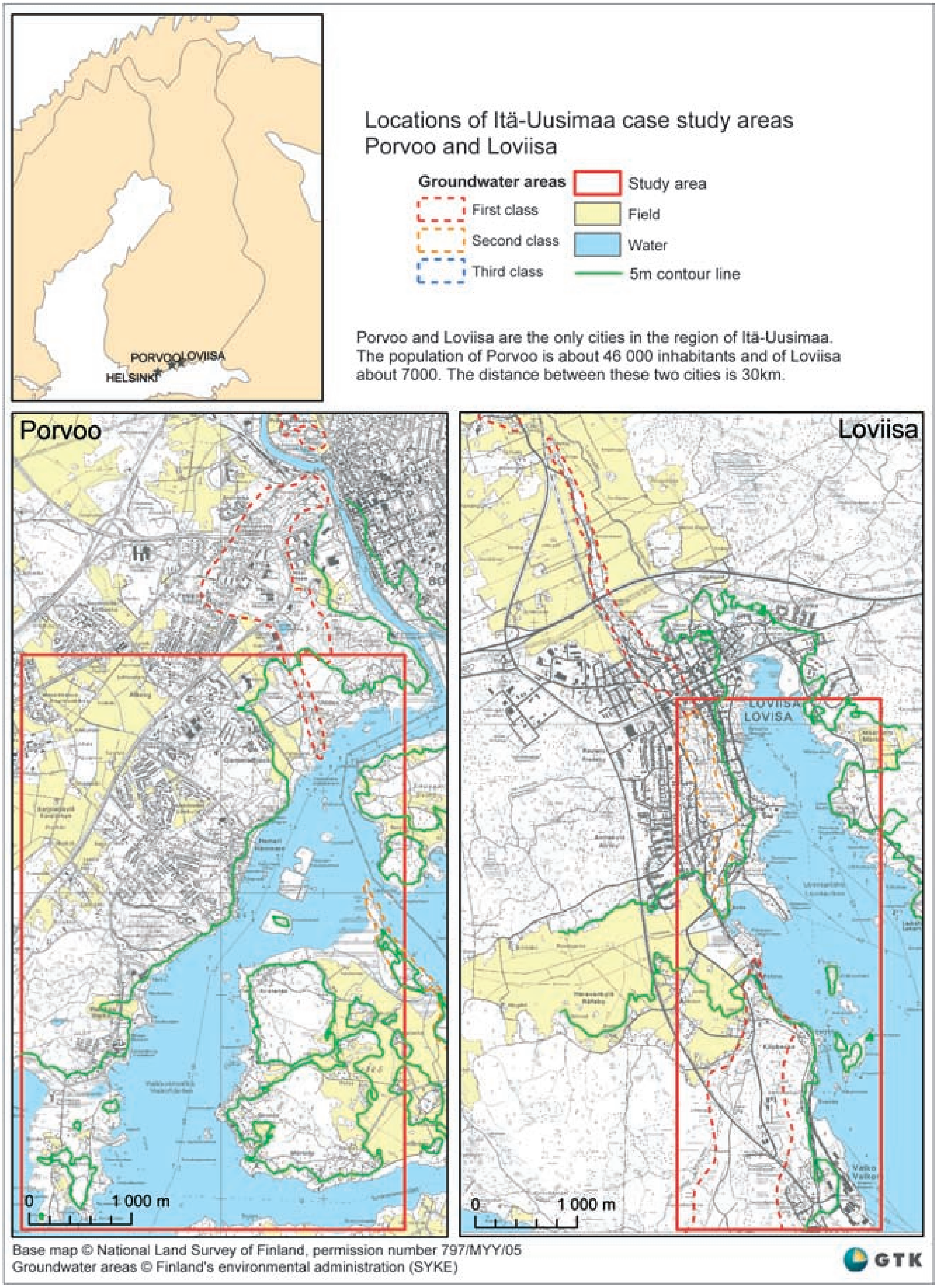


Fig. 1. Case study area locations of Porvoo and Loviisa. Source: H. Kallio.

preserved old towns. Central parts of these cities lie in the vicinity of the water, a river runs through Porvoo, and Loviisa lies on the Loviisa bay. Porvoo is famous for having Finland's largest oil refinery and Loviisa for Finland's first nuclear power plant. Itä-Uusimaa is Finland's second most industrialised region on the industrial gross national product scale.

Since Itä-Uusimaa is located on the Gulf of Finland, the sea is an important element for the region. Central parts of both cities are flood prone even today. In Loviisa, the flood of 1986 is still remembered for the fact that the sea wall could not withstand the rising seawater. The cellars and basements of houses located close to the Laivasilta harbour area in Loviisa were seriously damaged. After the flood of 1986, more attention has been paid to flooding in Loviisa and the dike has been heightened a few times. Also, in Porvoo floods are occurring annually. According to the Marine Research Institute's statistics since 1928, the sea level was highest at 1.41 meters above mean sea level in Porvoo. However, in January 2005 the new sea level maximum values were observed along the Gulf of Finland. In Porvoo and Loviisa, sea level height was measured at 1.70 meters above the mean water level. These are only estimates since the Marine Research Institute does not perform official measuring in Porvoo. According to the Marine Research Institute's statistics, the sea level in December 2003 was the tenth highest in Porvoo since 1928. (Marine Research Institute 2004.)

Within the SEAREG project, the goal is to increase awareness and identify possible impacts and hotspots in the region concerning sea level rise. In Finland, the problem might be that people underestimate the impacts of sea level rise because the scenarios do not appear to be too serious. Still, in an actual situation of storm or flood, even an increase of tens of centimeters in the mean sea level may be significant. Therefore, it is crucial to get the local stakeholders to consider the meaning of sea level rise in the region of Itä-Uusimaa and identify possible local and regional adaptation measures. Furthermore, it is important to examine the overall relevance of this hazard in the Finnish context. Contradictory information and a long time scale makes sea level rise an abstract and distant hazard in the eyes of many people. With the help of the SEAREG project, the stakeholders in the Itä-Uusimaa region have a chance to consider these matters through their own work and perspectives.

2 METHODOLOGY

The Vulnerability Assessment in Itä-Uusimaa was carried out following the Decision Support Frame (DSF) developed by the SEAREG project (Schmidt-Thomé P. & Peltonen 2006, *this volume*). Vulnerability is determined by the potential of a community to react and withstand a disaster, for example its emergency facilities and disaster organisation structure like the Coping Capacity (Schmidt-Thomé 2005). The Vulnerability Assessment in Itä-Uusimaa was carried out mainly by interviews. The qualitative approach and theme interviews suited the meaning well since the topic is still quite new for many stakeholders. Also, the development of the Vulnerability Assessment was easier due to direct feedback. The original idea was also to determine opinions of the decision makers' but only 1 of the 12 members of the Board of the Regional Council returned the questionnaire addressed to them. A questionnaire might have been too difficult to answer because the subject is new and more consideration may have been required before answering. The low response might also indicate the regional decision makers' interest towards the possible sea level rise.

Interviewed experts were chosen among those who can influence the region's ability to adapt to sea level rise. For example, spatial planners in Porvoo and Loviisa, local water works, rescue department and city functionaries are professionally connected to the subject. The Regional Environmental Centre of Uusimaa gives a regional aspect, as does the spatial planning chief of the Regional Council of Itä-Uusimaa. As well, one private person in a potential risk area from each of the cities was interviewed. At the time the interviews were made, these private persons were also city councillors and thus aware of communal politics (see complete list of interviewees on page 106). These experts represented a wide range of local knowledge from different branches.

Concepts defining Coping Capacity helped to guide the conversation in interviews. The experts were also asked to fill in the Finnish translation of the impact matrix, which was designed to estimate the effects of sea level rise on different land use categories of the case study area. In some cases, for example, when the opinions between experts differed greatly, the resulting value is based on the mode that is the most popular value (see Table 1 and 2). Consequently, the impact matrix represents the general view of local experts. As one can notice later on, the City of Loviisa received higher values in the impact matrix than the City of Porvoo. The values in the impact matrix should not be compared as such, but taken as opinions of individual experts. The values of regional Coping Capacity are based on the general view derived from several interviews.

3 RESULTS

The two most important factors affecting the mean sea level on the Finnish coast are the land uplift and the global mean sea level rise. Both of these cause a long-term, trend-like change in sea level – the land uplift a lowering one and the global mean sea level rise a rising one (Johansson et al. 2002). There are three different mean sea surface height scenarios for the 21st century released by the SEAREG project. In the case of Itä-Uusimaa, the high scenario corresponds to a sea level rise of 73-75 cm and the medium case scenario a sea level rise of 21-24 cm. These two scenarios are showing obvious sea level rise whereas the third scenario (low case) corresponds to a sea level lowering of 24 to 26 cm due to the dominant land uplift (see a sea level rise map prepared for Loviisa in fig. 2 and for Porvoo in fig. 3).

The air pressure, winds, the current inwards and outwards through the Danish Straits and the ice cover cause short-term sea level variabilities in the Baltic Sea. The scenarios for short-term sea level variability are of practical importance for coastal construction, planning and safety estimation. In these cases, the probabilities for occurrence of extremely high sea levels are often of special interest. In Loviisa, the sea level rises approximately 50-80 cm on average once a year and the maximum sea level height has been 171 cm above mean sea level. However, the occasions with sea levels higher than 80 cm are relatively unusual. In Porvoo, the short-term sea level changes are very similar. The highest measured water level has been approximately 170 cm above mean sea level.

Table 1. Impact matrix of Porvoo.

Sea Level Rise Effects	**1. Sector** agriculture fishery forestry	**2. Sector** industry, its waste	**3. Sector** services	**Infra-structure**	**Housing**	**Open urban area** incl parks, green fields, waste land..	**Ground water** water supply	**Protected nature areas** National parks, bird nesting areas, etc.
Inundation (permanent land loss)	no impact	no impact	no/ low	no impact	low	no impact	low	no impact/ positive
Flooding (flood prone areas)	low	medium	low	low/ medium	medium	low	medium	low

Table 2. Impact matrix of Loviisa.

Sea Level Rise Effects	**1. Sector** agriculture fishery forestry	**2. Sector** industry, its waste	**3. Sector** services	Infra-structure	**Housing**	**Open urban area** incl parks, green fields, waste land..	**Ground water** water supply	**Protected nature areas** National parks, bird nesting areas, etc.
Inundation (permanent land loss)	no impact	no impact	low	low	low	low	no impact	no impact
Flooding (flood prone areas)	low	low	low	medium	medium	low/ medium	low	no impact

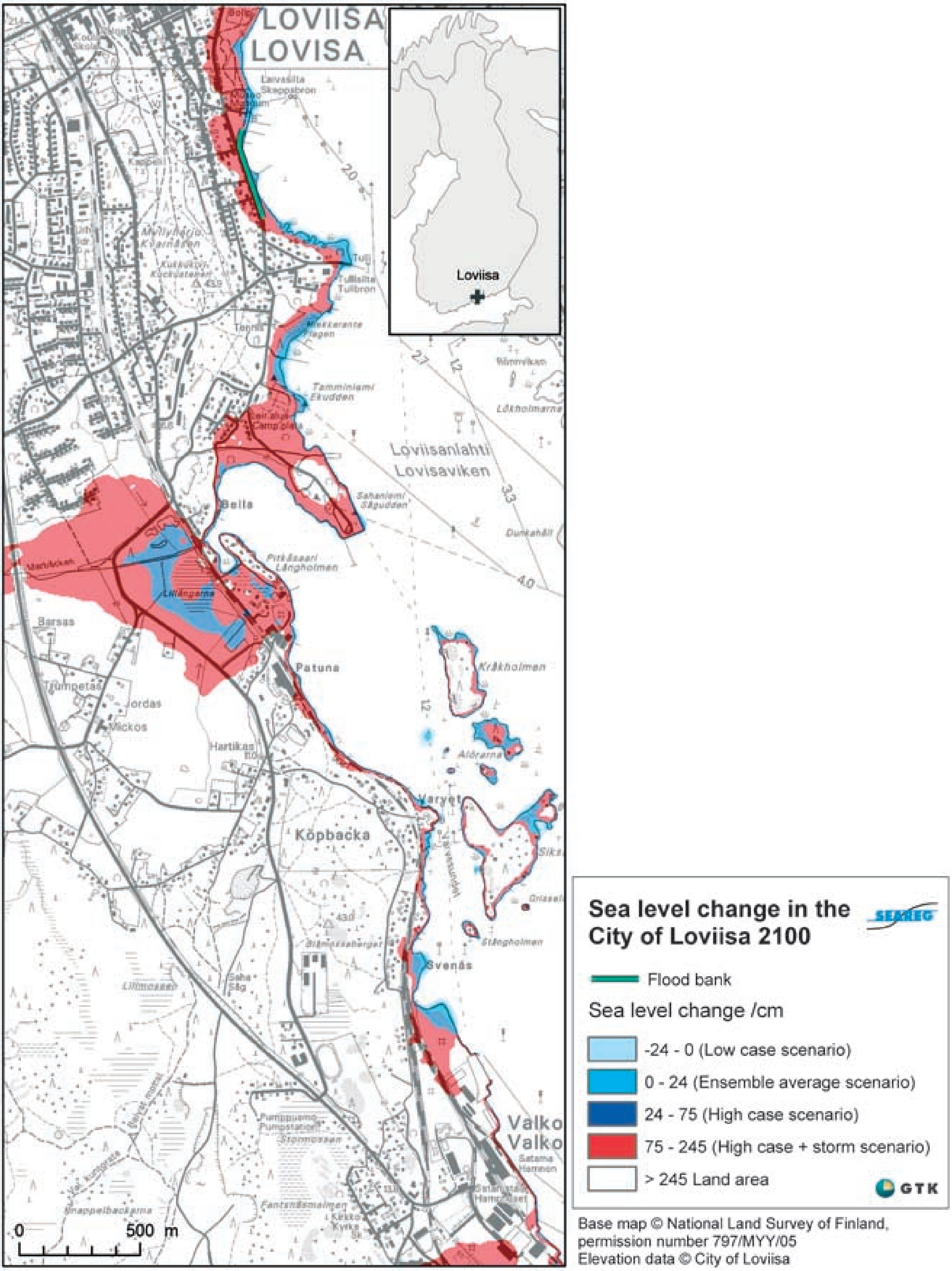
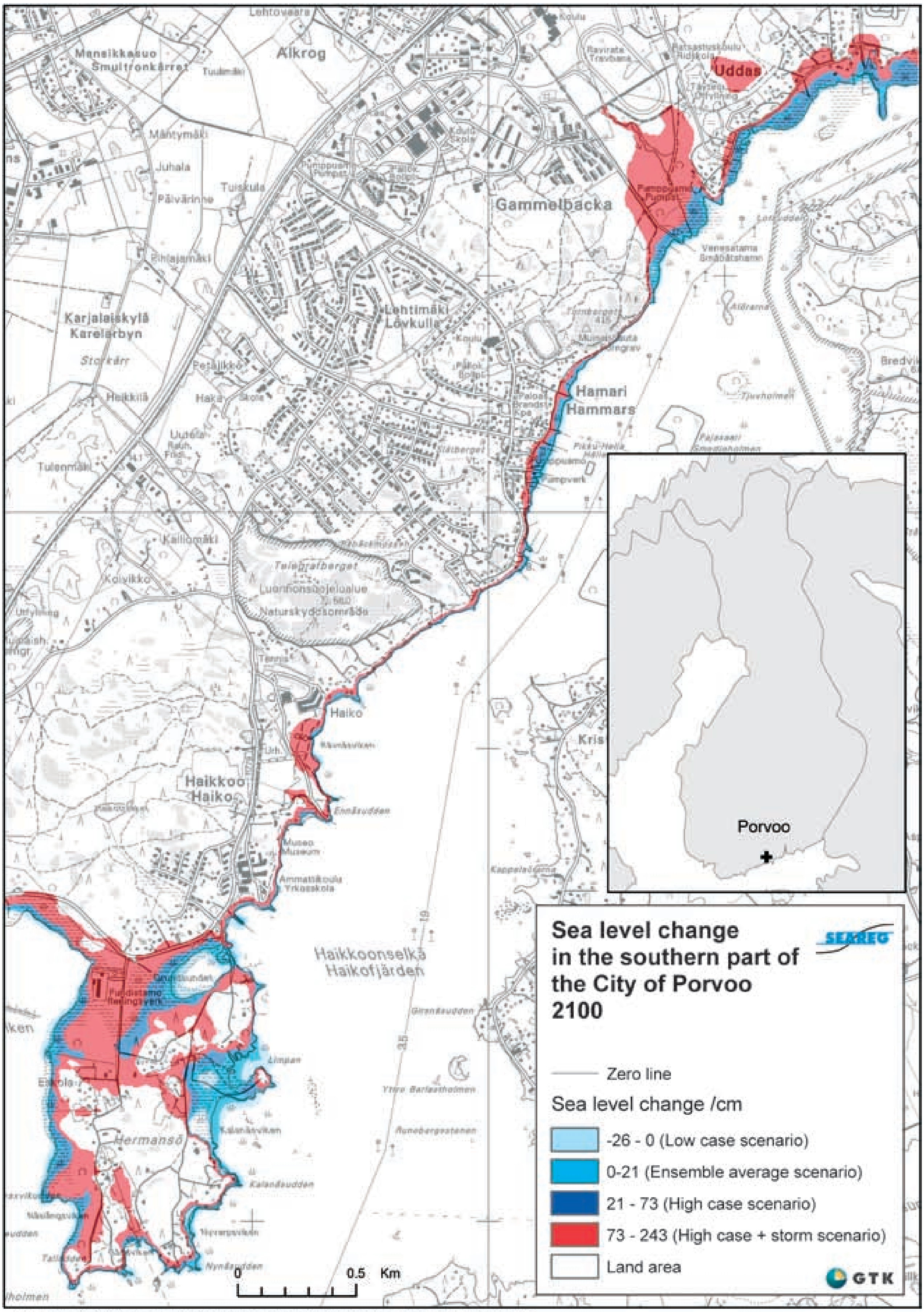


Fig. 2. Map of sea level rise in Loviisa.



Base map © National Land Survey of Finland, permission number 797/MYY/05
Elevation data © City of Porvoo

Fig. 3. Map of sea level rise in Porvoo.

3.1 Impact Assessment in Porvoo and Loviisa

Agriculture, fishery, forestry. Three rivers run through Porvoo into the Gulf of Finland and the river valley is highly cultivated (City of Porvoo 2001, 5). Still, only 2% of the labour force works in primary production (City of Porvoo 2004). Sea level rise will not have an impact on agriculture or forestry in Porvoo, even though the harvest can suffer greatly from the impacts of seawater during long term floods. At the same time, the Porvoo River carries more sediment load of soil washed away from the fields. The floodwater increases the muddiness and nutrient content of the coastal areas, which can cause eutrophication. Usually the load of nutrients in the river mouths has local effects and the influence does not reach further than coastal sea areas.

In the year 2000, 1.2% of the labour force in Loviisa was working for agriculture or forestry (City of Loviisa 2003). The agricultural areas in Loviisa lie further away from the water and as a result, sea level rise alone will have no influence. Agriculture is very small-scaled in Loviisa. However, there is a trawl harbour south of the Valko industrial harbour and according to one expert, it is in a low-lying area. It is important to make sure the warehouses do not contain harmful substances that pose a contamination risk in case of flooding.

Industry. 27 % of the labour force in Porvoo works for industry (City of Porvoo 2004). The industrial area of Sköldvik is one of the largest oil- and chemical industry production areas in the Nordic countries. Also, when measured by the amount of ferried tons, the largest harbour in Finland is located in the Sköldvik industrial area. In addition to crude oil, chemicals and gases are transported via this harbour. (Fortum 2004a.) The industrial area of Sköldvik is located about 20 meters above sea level and is mainly surrounded by rocky hills. Thus, Sköldvik cannot be considered a flood prone area. Still, one of the interviewed experts was worried about the underground storage tanks in the area that need to be safe from sea level rise and sufficiently water proof. Still, a bigger risk in Sköldvik is caused by the industry itself and the ecological hazards arising from it, not the sea level rise.

In the year 2000, 27.7% of the labour force in Loviisa worked for industry (City of Loviisa 2003). The Fortum nuclear power plant is located on the island of Hästholmen, 15 kilometers southeast of the city. The Loviisa power plant produces about 10% of the electricity in Finland and when measured in usability, it is one of the most effective nuclear power plants in the world. (Fortum 2004b). The Loviisa power plant was almost shut down during the storms in January 2005. The sea level rose to 1.71 meters above mean sea level. A two meter sea level rise would have caused a shut down. (Uusimaa 10.1.2005) Future floods can thus cause more challenges for the Loviisa nuclear power plant. There is also a need to consider the harbour of Valko in Loviisa with its warehouses, which need to be safe from possible flooding. The Valko harbour concentrates on timber marine transporting (City of Loviisa 2004). The height of the harbour area varies between 1.8 to 2.7 meters above mean sea level.

The category of industry in the impact matrix can also cover soil contaminated by former industry. In Porvoo and Loviisa, there are numerous areas located by the shore that are contaminated due to the industrial history of the cities. The local experts say that there are possible contamination sources, such as piles of ash near the waterline in Porvoo that can be mobilised in the case of severe floods. There are also former industrial sawmill areas near shorelines in both cities, for example in Sahaniemi in Loviisa and on the west bank of the Porvoo River. In Porvoo a residential area has already been constructed on the west bank of the Porvoo River and eventually more will be constructed in the future. In this area, the elevation of the settlement bases is 3 meters and the gardens 2.5 meters above mean sea level. On the Sahaniemi peninsula, Loviisa has planned construction at the same heights and the ground is going to be cleaned of the contaminated substances and heightened before construction. If these areas remained in their current state, they could pollute the water. According to the expert from the Environmental Protection Department of the City of Porvoo, the most soluble compounds have already caused problems for the water quality.

Services. In the year 2000, 54.6 % of the labour force in Loviisa was working for the service sector (City of Loviisa 2003). In Porvoo, 64% of the labour force works for commerce or for other areas of the service sector (City of Porvoo 2004). Both cities attract tourists, especially during the summer time. Laivasilta harbour area in Loviisa is popular among tourists as well as among local people. It is also the most critical area during floods. At the moment a dike, the capacity of which has been put to the test a few times, protects the area. In Porvoo, restaurants and small shops by the river can be at risk during floods. Fortunately, the historical old part of Porvoo was built at a time when the water level was higher so there is no direct risk to this area. However, when considering this kind of historical environment, it is important to be prepared for the worst and consider possible protective measures. Furthermore, petrol stations for boaters and boat harbours for visitors can cause contamination during floods.

Infrastructure. Experts of both cities are most concerned about how rain and wastewater sewage systems will work in a flood situation. The capacity of the sewage system in Porvoo is already often too low during floods that are mostly caused by heavy rains. When the sewage system's capacity is full, the stream starts to flow in the wrong direction and straight into the river. In Loviisa, the rainwater sewers are quite old in certain parts of the city and are burdening the system. Thus, more attention should be paid to the sewage system in the future. The railway used by Valko harbour occupies a low-lying area and it would be very costly to lift it higher. The importance of the railway depends on the future development of Valko harbour. In both cities, some streets get inundated during bad floods. Routes for pedestrians and bicyclists can also be considered as infrastructure. A large park situated at the end of the bay of Loviisa is a popular place for walking. This park area is currently one of the first places to get inundated when flooding occurs in Loviisa.

Housing. The housing along Rantatie road faces the biggest risk in Loviisa in the case of sea level rise and floods. When the dike collapsed in the 1990's, cellars of these houses were damaged. And the city had to pay compensation to the inhabitants. Although the housing in Loviisa is situated near the water, there is often a green belt in between or the houses are built on higher ground in the surrounding area. The regional architect of the Loviisa subregion says that there is some pressure to build near the coastline. In Porvoo, residential buildings and the basements by the east bank of the Porvoo River are already suffering damages during storms and floods. A representative of the Street and Traffic Department of the City of Porvoo says that along streets by the river, some of the outer doors are only one meter above the sea level. This is why the cellars and basements of these buildings are quite often flooded.

Many of the over 3000 summer cottages in Porvoo are located on the seashore. There were 327 summer cottages in Loviisa in the year 2000 and most of them were located near the coastline. (Regional Council of Itä-Uusimaa 2004.) The waterfronts in Loviisa are quite densely populated. Many of the summer cottages and seaside saunas may be at risk in the future, especially in a flood or storm situation. The damages, however, would probably be relatively minor.

Open urban areas. Open urban areas are often in low-lying parts of the city and sometimes the soils are contaminated. The west bank of the Porvoo River and Sahaniemi peninsula in Loviisa can be at risk in a storm or flood situation and can be temporarily inundated. Soil remediation is usually a question of time and expense. When building new housing in these areas, the ground has to be cleaned and heightened to a safer level. This has already partly happened on the west bank of the Porvoo River and will happen in Sahaniemi in Loviisa as well. There are still numerous open urban areas in the vicinity of the bay of Loviisa. In addition, the large park area at the end of the bay of Loviisa has often been inundated in past floods. Other low-lying, unbuilt areas can be found on the east side of the Loviisa bay. Consequently, the possibility of flooding should be taken into account when drafting new residential areas.

Ground water. One of Porvoo's aquifers that is used as a water supply is relatively close to mean sea level and if the level permanently rose to a higher level, the salinity of the groundwater could be affected. According to the representative of the local water works in Porvoo, up to 60-70% of the drinking water in Porvoo is taken from this aquifer. Also another aquifer may be at risk, but it is only used by a small group of people and is not classified as a first class water supply according to the Finnish national classification of aquifers. Also, an aquifer in Loviisa is located in the possible future flood risk area. The aquifer in question already suffers from high fluorine content and thus is not used as a primary source of drinking water.

Protected nature areas. Experts neither in Porvoo nor Loviisa believe that sea level rise will have an impact on actual conservation areas. To cite one local expert, ”nature adapts better to changes than the human built up environment”. Nature areas can, however, lose their status if they do not fulfil the criteria of a protected nature area. One has to take into account the possible need to enlarge or find new protected nature areas if the natural values of the current ones change.

Hotspots. Hotspots in Porvoo are housing by the riverbank, contaminated industrial shores and the important aquifer. Hotspots in Loviisa are housing by

Fig. 4. Several houses on the east bank of river Porvoo experience floods almost annually (Photo H. Kallio).

Fig. 5. Sahaniemi peninsula is a low-lying area close to sea level and a potential residential area with a great marine atmosphere. The average altitude of the area is 1.6 m above mean sea level. (Photo H. Kallio).

Rantatie road, the railway used by Valko harbour, the Sahaniemi peninsula (the future Meribella residential area) and contaminated industrial shores. The hotspots of Porvoo and Loviisa are based on local experts' opinions and discussions with the spatial planning chief of the Regional Council of Itä-Uusimaa.

3.2 Coping capacity of stakeholders and institutions

All the stakeholders interviewed had heard of the discussion on sea level rise and were aware of the hazard. In both cities, floods already cause problems at certain times of the year and this presumably influences their awareness. In both cities, there is no hurry in preparing beforehand for the hazard. Stakeholders believe that there is still enough time to prepare for possible sea level rise and there is not yet need for large preventive measures or mitigation strategies. There has not been a larger need to budget for sea level rise over the past few years. Only in spatial planning have some extra expenses come up in preparation beforehand. For example, in new residential areas the clean up and heightening of the soil has formed part of the ground construction expenses. Preparation for sea level rise is considered when constructing new buildings, but there are no funds available for the protection or adaptation of existing buildings.

Regional scale co-operation concerning sea level rise does not exist. Co-operation takes place mainly on a local level and is usually about past flooding and not about possible future sea level rise. Co-operation partners change, depending on if it is preparation and mitigation for the future or if the flood situation is already present. Preparing beforehand mainly takes place within the city organisation between spatial planners, the Environmental Protection Department and the Street and Traffic Department. In addition to the city organization, other important co-operation partners are local water works and the Rescue Department. People have adapted to floods in Porvoo and Loviisa and over the years certain routines have developed between authorities. On a national level, the division of responsibility for flood risk management between authorities and other actors is relatively clear. The Finnish Environmental Institute and Regional Environmental Centres are in charge of risk assessment concerning flood protection and embankment safety. The highest authority in flood risk management is the Ministry of Agriculture and Forestry and the subordinated Regional Environmental Centres. Also, the municipal rescue authorities have an important role in flood risk management. (Sitra 2002, 67-69.)

A couple of the local experts critically state that in municipal decision making economy defines when there is “enough money” to think ecologically. This view probably reveals the general interest in environmental matters among some local decision makers. Usually, a budget year serves as a time scale in decision-making. This can lead to short term goals overcoming long-term hazards. Today, sea level rise shows in decision-making only through planning. At the moment, the spatial planners in Porvoo are arguing for heightening the safety margin for housing from 2 metres to 2.5 meters above mean sea level.

4 DISCUSSION

The role of planning seems to be crucial in relation to sea level rise and flooding. According to the new Land Use and Building Act (2000), flood risk needs to be taken into account in planning. The Act does not set a decree for construction height. The Act comprises general regulations for the content of land use plans and requirements for building and building sites. In an area covered by a local detailed plan, the appropriate building site is decided in the plan. When the site is outside the local detailed plan area, some special requirements are named in the Act. The building sites need to be appropriate when considering flood risk. Otherwise, a building permit should not be granted by the communal building permit authorities. There should be no danger of flood or landslide (Maankäyttö- ja rakennuslaki 17/ 116 §).

Table 3. Summary of the regional Coping Capacity in Itä-Uusimaa.

Aspects	**Evaluation** Low, medium, high	**Comments**
Cooperation	medium	Co-operation between local city functionaries exist concerning other matters. Thus, communication channels already exist. Anyway, co-operation is taken to some extent for granted and is not actively developed.
Strength of institutions	medium	Everybody seems to know their own role concerning flooding. Still, beforehand preparation is not common yet. It is a bit unclear for some stakeholders, which stakeholder is responsible for what.
Trust in Decision makers	medium	This is difficult to evaluate. Some experts were a bit skeptical about decision makers’ interest in SLR. The time scale in decision making is usually a budget year. The lowest construction heights in building codes are relevant.
Guidance of planning	high	Planners already take sea level and flood risk into account in planning and their knowledge is rather high. Still, lowest construction heights are not nationally uniform so guidance of planning depends on local spatial planners.

The Regional Council of Itä-Uusimaa is in the process of preparing a new regional plan. In the old regional plan, sea level rise or flooding were not taken into consideration. As a result, there is also a need to revise the plan in this respect. The spatial planning chief of the Regional Council of Itä-Uusimaa believes that the information gathered from the SEAREG project is very useful for planning. Sea level rise and flood risk need to be taken into account when making area reservations for the new regional plan. While sea level rise does not show in the plan as a particular mark, it can guide planning passively. The spatial planning chief has already used the sea level change as a criterion when giving a statement of the planning draft of the Meribella residential area in the low-lying peninsula of Sahaniemi in Loviisa.

Every municipality is required to have a building code that guides planning on a local level. The building code includes regulations that are necessary for the realization and preservation of a good living environment. Regulations related to building near shorelines comprise an important part of municipalities' building codes. In Finland, 95% of the building codes set a minimum distance for residential or holiday buildings from the shoreline. The distance varies from 15 to 100 metres. Eighty-nine percent of the municipalities have also set a lowest construction height for building near shoreline, the most common height being 1.5 metres above the mean sea level. (Rakennusjärjestysselvitys 2003, 23-27.) In Porvoo, the idea is to heighten the safety margin of the building code from 2 meters to 2.5 meters. The building code of Loviisa dates back to 1992. The regional architect in Loviisa does not have an up-to-date building code and a recommended construction height as a guidance. Therefore, actions are decided on a case by case basis and conflicts can occur with landowners.

On the local level, flood risk management happens primarily through planning, since the local level is the main operative planning level in Finland. The main role of planning is to be prepared for sea level rise and a higher flood risk by guiding new construction into safer places. Planning near shorelines needs to be regulated, though it also raises criticism. At the moment, the guidance of planning is relatively strong both in Porvoo and Loviisa, but it cannot be taken for granted. For a small city like Loviisa, it is important to attract new inhabitants and one way to do this is to offer more sea shore lots. This can lead to harmful development in terms of flood risk management. Spatial planners in Itä-Uusimaa both on the regional and local level are very motivated to take sea level rise into account more often when planning new residential areas. Planners are aware of the flood risk and that their work is visible decades or even a century afterwards. The long time scale of sea level rise corresponds quite well with the one of spatial planners.

5 CONCLUSION

Sea level rise does not appear to be the primary future hazard in Porvoo or Loviisa. The dangerous chemicals manufactured in the Sköldvik industrial area, the marine transport of oil by the coastline and the nuclear power plant in Loviisa are considered more concerning hazards in Itä-Uusimaa. Thus, sea level rise is regarded as a rather minor hazard. Many parts of the Itä-Uusimaa shoreline are elevated several meters above sea level and face no imminent threat of inundation. It is more important to take a closer look at future storm surges and flood risk. High sea level combined with storm surges and long-term rain fall is the most threatening combination. Thus, higher sea level can increase the damages of floods and storms in the future.

On a national level, more attention has been paid to flooding and flood prevention during the past few years. Recent severe floods in central Europe and in Sweden (2000) have partly influenced this interest. Extensive flooding has become a possibility also in Finland, and the Ministry of Agriculture and Forestry has prepared a report on extensive flooding in Finland (Suurtulvatyöryhmän loppuraportti 2003). Though sea level rise is still seen as a distant and partly controversial hazard, mitigation strategies against flooding have been developed. The report on extensive flooding proposes seven actions on mitigation in case of extensive flooding that would improve and standardize flood control in the whole country. The most central proposals for action aim to ensure uniform risk level in protecting housing from flooding. The report proposes a risk level for a flood occurring once in one hundred years for new housing areas. The important areas for communities, like hospitals, and plants handling harmful substances, should have a more strict risk level. The importance of spatial planning concerning flood risk management is thus highly recognized on the national level.

While Finland has started to prepare for extensive flooding and the awareness of future sea level rise is rather high, a few weaknesses can be identified. The most important mitigation strategy against sea level rise and flooding is perhaps to regulate housing near shorelines. Nevertheless, the lack of uniform lowest construction heights and the Finnish peoples' desire to live beside water can cause conflicts. The floods caused by heavy rains in the summer of 2004 and floods caused by storms during winter 2004-2005 have, however, awakened people in Finland to the impacts of climate change and the possibility of more severe flood situations in the future. Even though the situation is not comparable to some parts of Europe, more attention needs to be paid to decision making to update regulations and develop new mitigation strategies. The case of Itä-Uusimaa region has shown that local and regional experts from different branches are motivated and willing to be better prepared for the future.

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USEDOM – COASTAL DEVELOPMENT AND IMPLEMENTATION OF GEO INFORMATION IN A DECISION SUPPORT FRAME

by

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Röber[1], B., Rudolphi[1], H., Lampe[1], R. & Zölitz-Möller[1], R. 2006. Usedom – Coastal Development and Implementation of Geo Information in a Decision Support Frame. Geological Survey of Finland, Special Paper 41, 107–119, 9 figures and 5 tables.

Due to the risk of coastal flooding as a consequence of climate change and associated sea level rise, there is a great need to assess the vulnerability of coastal zones with special respect to land use and resource management. The area of investigation is the Island of Usedom at the German-Polish border.

The historical evolution of the shoreline of Usedom was determined using maps and aerial photographs. The development of the future coastline was predicted on the basis of potential sediment fluxes calculated using wind and sea level scenario data from modelling results produced by the Swedish Meteorological and Hydrological Institute.

A high-resolution elevation model of Usedom was generated to analyse the consequences of mean sea level rise. The modelled flood-prone areas were intersected with different data sets. The resulting maps and tables show the economically and ecologically affected areas as well as classification maps. 13 % of the total island area would be affected by a sea level rise of 25 cm or 28 % in the case of an 80 cm sea level rise. 70 % of the land at risk is used for agriculture. Finally, the results were used to assess the vulnerability of Usedom´s coast.

Key words (GeoRef Thesaurus, AGI): climate change, shorelines, sea level changes, transgression, coastal environment, land use, risk assessment, geographic information systems, Usedom, Germany.

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1 INTRODUCTION

The discussion about the future evolution of the sea level and its consequences is becoming more important in recent time. While previous models concentrated on global sea level changes, the INTERREG IIIB project "Sea Level Changes Affecting the Spatial Development of the Baltic Sea Region" (SEAREG) focuses on the regional and local development of the Baltic Sea Region. The main goal of the project is to develop a Decision Support Frame (DSF) for planning authorities. The Swedish Meteorological and Hydrological Institute (SMHI) calculated future climate and sea level heights to the year 2100 on the basis of two different models. Both models are used for different scenarios. The possible physio-geographic and socio-economic consequences of these scenarios were estimated and discussed for Usedom Island. The aim of the first part was to find a practical method to calculate the future development of the sea coast. In the second part, a geographic information system (GIS) shall be implemented in a DSF. In the third part, consequences for the flood-prone areas are compiled as well as a coping capacity and a vulnerability assessment for the planning area. The discussion is about possible reactions to the effects of sea level change.

2 INVESTIGATION AREA

Usedom Island is off the easternmost part of the Mecklenburg-Vorpommern coast. The area of interest extends from Peenemünder Haken up to the Polish border with an area of approximately 375 km^2 and a coastal length of 231.5 km (41.5 km sea coast, 190 km lagoon coast). The island consists of Pleistocene sediments and Holocene deposits (Fig. 1). During the Littorina transgression, the sea level rose rapidly from –20 m around 7800 BP to –2 m at 5800 BP (Lampe 2003). Afterwards, it became more stable, rising with only minor oscillations to about –0.5 m at 1000 BP. In this period, abrasion material was deposited in bay-like depressions, building barriers with dunes on the top. During the following sea level rise, peat accumulated on sheltered lowlands behind the dune belt. Diking and drainage of fenlands started in the 19th century and initiated peat degradation. The surface of the fenland is now at or below the sea level due to strong decomposition. Land use on Usedom is dominated by tourism, farming and forestry. While arable land predominates on the moraine areas, the peat land is used as grassland and feedlot.

Usedom has been populated since the 7th century and approximately 28,000 inhabitants live there today. The older parts of the settlements are located in the upper regions of the island. Since the beginning of tourism in the late 20th century lower areas have also been developed.

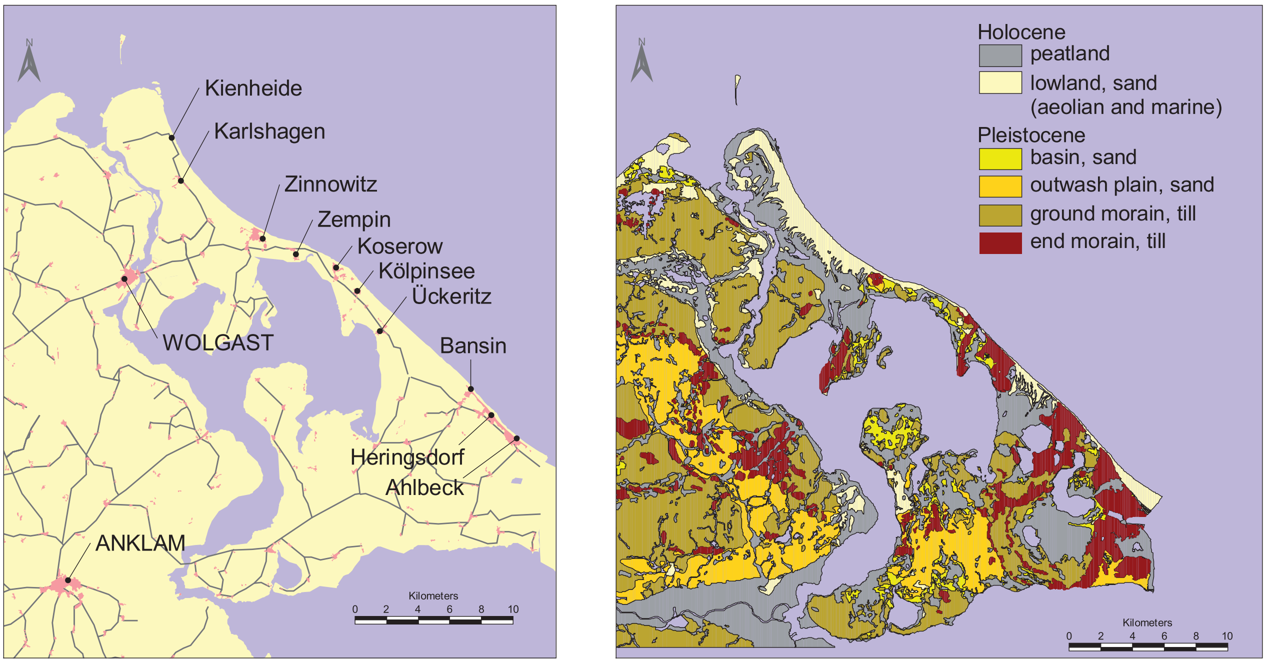

Fig. 1. Topographical and geological maps of Usedom Island. Source: B. Röber.

3 METHODS

3.1 Evolution of the sea coast

a) Coastal evolution during the past 200 years

Romond (1993) investigated the coastal change since 1695 using historical maps. In the SEAREG project, this material was re-evaluated using Arc View, which leads mainly to higher accuracy of the data. However, the re-evaluation started with the maps from 1829, because the maps from 1695 are inaccurate in many details.

The following maps and aerial photographs were used:

Preußisches Urmeßtischblatt	1829
Meßtischblatt	1885
Hansa Aerial photograph	1937
Aerial photograph	1998

Some problems, such as the low number of bench marks needed for georeferencing the maps, distortions due to the scanning process, faults on historical maps and arguable delineation of shorelines on aerial photographs, could not be solved completely and restrict the attainable accuracy.

The maps and images were scanned and combined into a coherent picture using Photoshop software. Based on the Topographical Map 1:10,000 (Transverse-Mercator projection with Bessel ellipsoid), these pictures were then georeferenced in Arc View 3.2 with the Image Warp extension. Afterwards, shorelines were digitised. The distances between the lines were measured every 250 m.

b) Calculation of accumulation and abrasion rates by means of coastal evolution models

To predict future coastlines and to assess how infrastructure will be threatened by coastal erosion, the long-term behaviour of the coast has to be modelled. Sediment transport has to be estimated from wave data, which in turn depends on wind distribution. Sea level variation has to be considered and sediment availability as well. Due to uncertainties, the results mainly reflect the tendency of the evolution.

The following data were available for the calculations: Wind time series with speed and direction of four SMHI-scenarios for the period 2070 to 2100 as well as for the two control runs between 1960 and 1990; data from the wave model SGBAL from Germany's National Meteorological Service (Deutscher Wetter Dienst - DWD) for the time period between 1995 and 1999 (DWD 1995) with wind speed, wind direction, wave height, wave direction and peak periods (no data were available for a longer period). Further, SMHI calculated three scenarios of sea level changes for the next 100 years (1cm, 41 cm and 82 cm rise). These sea level change scenarios are net rates, as land uplift or subsidence rates are taken into account. We also used a sea level scenario with a rise of 24 cm/100 yr as proposed by Stigge (2003).

Classified wind speeds and directions (12 classes each) were used for the consecutive calculations. The SMHI control runs show some significant differences between the observed and the hindcasted wind data in the Pomeranian Bight. To obtain scenario data that fit the regional characteristics as well as the four SMHI scenarios, data sets were subtracted from the control runs data to identify future changes in the wind distributions. These differences were added to the observed DWD-1995 data set to obtain regional forecast data for the year 2100, leading to four different data sets DWD-2100 a-d (see Table 1).

In a next step, the potential sediment transport along the seacoast was calculated using a formula described by Wagner (1999), which assumes that the sediment transport is never restricted due to limited sediment availability. Due to the northeast exposure of Usedom´s coast, 6 wind categories from 0° to 150° and 330° to 360° were used in the following calculations. From the calculated potential sediment flux [m^3a^{-1}], the annual shoreline shift was estimated according to Börngen et al. (1999) and Stephan & Schönfeldt (1999) and extrapolated for a 25-year period and 250 m sections, from which a new shoreline was constructed. Because wind scenarios were available only from 1995-1999 and 2070-2100, shoreline changes were calculated with the DWD-1995 data set for the next two 25-year periods. The 4 DWD-2100 scenarios were used for the two periods 2050 - 2075 and 2075 - 2100. The shoreline shift caused by the sea level changes were calculated separately and added to the previous results (Stephan & Schönfeldt 1999).

Table 1. The four DWD-2100 scenarios and the SMHI scenarios which belong to them. Source: H. Rudolphi.

DWD 2100 scenario	SMHI scenario
DWD 2100a	HCA2
DWD 2100b	HCB2
DWD 2100c	MPIA2
DWD 2100d	MPIB2

3.2 A GIS Tool in the DSF

First, the kind of results spatial planners require was analysed. This analysis was made with the help of interviews, workshops and discussions with German regional planners and other project partners, leading to the following main questions:

- In general, do planners need a GIS based decision support system and are they really going to use it in the future?
- In which shape do planners require the results, related, for example to spatial resolution, administration levels etc.?
- Should and could the results be used by other decision makers and users as well?
- What is the time scale of planners' decisions and actions?
- Does the kind of decision help (the result) fit to the recent legal framework of planners?

The next step was to analyse the data accessible for planners, referring to consistency, resolution, accuracy and coverage. Generally, two types of data are available: geometric data and thematic data. Very often it is difficult to link both types of data, for example statistical data on the number of inhabitants at the community level do not fit to geometrical data (topographic or cadastral maps) at the level of single buildings. So far, there are no practical and reliable ways to disaggregate the statistical data down to the level of the geometric geo-data.

The strategy of the project is to link the geometric data to the sea level rise via an elevation model. In doing so, information of interest (factors, absolute values) is connected to the affected object types.

In the last step, the investigation area is partitioned into a set of comparable grid cells, and the values are summarised equivalent to their geometric properties.

All calculations and geometric operations have been integrated into a GIS-tool.

3.3 Impact Assessment

For the impact assessment, data from the Authoritative Topographic Cartographic Information System (ATKIS) were analysed with the compiled elevation model in Arc View 3.2. Only land use data have been analysed, and values were not considered because the prices of real estates and objects were not available. For the analysis, the data were classified into the seven categories: areas of ecological interest, agriculture, forest, human settlements, industry, infrastructure and other areas.

3.4 Coping Capacity and Vulnerability Assessment

The coping capacity and the vulnerability assessment were carried out in close cooperation with the Regional Planning Office Mecklenburg-Vorpommern (Amt für Raumordnung und Landesplanung Mecklenburg-Vorpommern, AfRLMV), which is the responsible authority for spatial planning, but not for coastal protection, as this is the responsibility of another governmental office.

4 RESULTS

Evolution of the sea coast

a) Coastal evolution during the past 200 years

According to the historical changes of the shoreline (Fig. 2), the Usedom seacoast can be divided into three morphodynamical sections, which can be described as follows:

Northwest Usedom (kilometre 4.0 to 17.50) is characterised mainly by accumulation, which increases from southeast to northwest. The average accumulation rate between 1829 and 1998 is 0.23 m/yr. The highest rate occurred between 1829 to 1885, amounting to 1.87 m/yr (km 8.75). However, an area of abrasion can be observed at Kienheide (km 6.00) with a length of approximately three kilometres. The transition to central Usedom is located in the section between Zempin and Koserow and marks the change from accumulation to abrasion.

Central Usedom (17.50 – 36.00 km): This coastal section is characterized by cliffs with a maximum height of 56 metres at Streckelsberg near Koserow. The average abrasion rate is 0.47 m/yr with a maximum of 1.14 m/yr at Kölpinsee (km 25.00). Southeast of Kölpinsee an accumulation area is attached up to Bansin. Again, abrasion predominates between Bansin and Heringsdorf.

Southeast Usedom (from km 36.00 on): The average accumulation rate is 0.86 m/yr with the tendency to rise in an easterly direction. In the period from 1829 – 1885, the highest increase was found.

Dynamical interactions

The comparison of the abrasion and accumulation rates between the three periods shows temporal variations of coastal behaviour (Fig. 3). Several reasons are responsible for these differences.

Coastal protection

The coastal protection measures in front of the Streckelsberg cliff near Koserow have especially affected all other coastal areas of Usedom (Schuster 1998). In 1865, a fascine fence was constructed off Streckelsberg and in 1895 the first seawall was built at the toe of the cliff. The accumulation rates of northwestern and southeastern Usedom were much bigger in the period between 1829 and 1885 (period 1) than in the periods between 1885 and 1937 (period 2) and between 1937 and 1998 (period 3). The accumulation peaks at the Streckelsberg during the 2nd and 3rd periods were caused by the construction of three detached wave breakers and extensive sand nourishments since 1996 (Fig. 2, km 22). Another example is Lütten Ort, near the village Zempin. In the last 300 years, there have been eight breakthroughs caused by storm floods, which were all closed artificially (Schumacher 2003).

Wave direction

The amount of the sediment transported depends on wave power and direction. Both are coupled with wind direction and fetch. Stephan & Schönfeldt (1999) compared wind data from the period 1885-1939 to those of the period 1940-1984. They concluded that between 1940-1984 the wind from the east and south increased and the wind from the west and

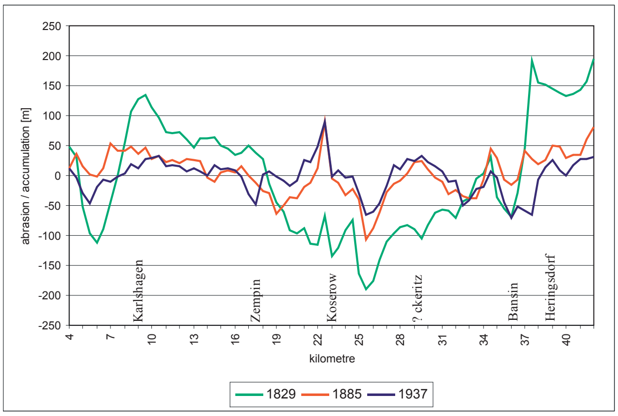

Fig. 2. Shoreline changes since 1829, 1885 and 1937. The x-axis (by y=0) represents the shoreline of 1998. Source: H. Rudolphi.

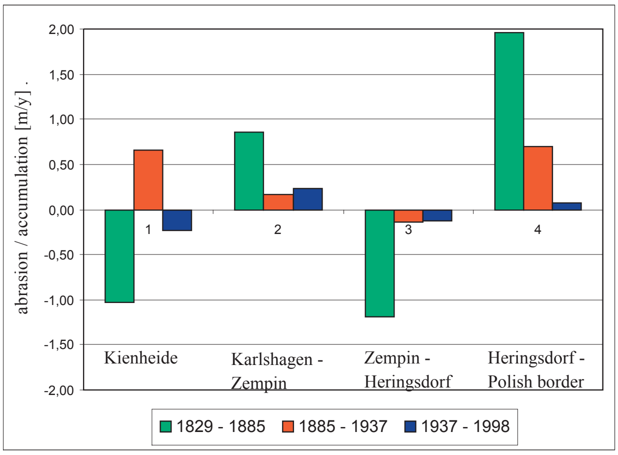

Fig. 3. Shoreline changes of the northwestern areas of Usedom (Kienheide and Karlshagen to Zempin), central Usedom (Zempin to Heringsdorf), southeastern Usedom (east of Heringsdorf) between 1829 to 1885 (1), 1885 to 1937 (2) and 1937 to 1998 (3). Source: H. Rudolphi.

north decreased, which caused alterations in sediment transport directions and quantities. Therefore, for every 250 m along the Usedom coast the angle between the shoreline normal and the north direction was determined (Fig. 4). The curve shows that the angle has the highest value in the northwestern part of the island. The area Kienheide is located there (km 4.00 to km 7.25), where a change from accumulation (1885-1937) into abrasion (1937-1998) took place (Fig. 3). This phenomenon can probably be explained by the wind direction alteration observed by Stephan & Schönfeldt (1999).

Isobathes

The inclination of surf zones is another factor influencing the wave energy. To evaluate this factor, the distance between the shoreline and the 10 m isobath was determined and depicted in Fig. 4. The 10 m-line forms a "funnel" in the area off Kienheide. The 10 m isobath off Kölpinsee is also closer to the coast than in the west or east of this section. This steeper shoreface, caused probably by the spatial distribution of sediments of different resistivity, allows higher wave energy to affect these sections.

b) Calculation of accumulation and abrasion rates by means of coastal evolution models

Only two scenarios DWD 2100 b and c were considered in this case. Figure 5 shows the calculated wind distribution. The impact on Usedom is higher in DWD-2100b because this scenario predicts a higher probability of easterly winds. That means that coasts with a western exposure will experience a higher impact on the DWD-2100c scenario, for example, the coasts of Fischland, Darss and Hiddensee Island. Similar results were found in the distributions of wind speed in the two scenarios.

Figure 6 shows the coastline changes for both scenarios with the additional consideration of transgression due to the rising sea level. In case of a 0.41 m rise, an accumulation of approximately 57 m was calculated for the DWD-2100b scenario and 49 m for the DWD-2100c scenario. In the abrasion area, the landward shoreline shift in the DWD-2100b scenario is 2 m higher than in the DWD-2100c scenario (c. 44 m resp. 42 m). In case of a 0.24 m rise, an average transgression of 39 m and an average regression of 65 m can be found using the DWD-2100b scenario. The results show that the trend in the coastal evolution observed in the historical record will continue over the next 100 years. A contrary trend was found only for the area around Kölpinsee (km 25.00). Due to the exposure of the coastline to the prevailing wind direction, accumulation was calculated instead of the abrasion observed. This discrepancy remains in the predicted coastal evolution and points to the limitations of the method used. Figure 6 also shows the settlements that are endangered by coastal retreat. This is the area around Zempin, whereas both Koserow and Ückeritz are located some hundred meters behind the shoreline. Then again Bansin and Heringsdorf are located directly on the beach.

When comparing the shoreline shift caused by both changes in wave power and sea level in areas characterized by accumulation or by abrasion, sea-level rise is more effective in areas with predominant abrasion. However, areas with accumulation are more sensitive to a changing wave climate because sea-level rise and abrasion cause both a transgressive shoreline and amplify each other whereas sea level rise and accumulation compensate one another.

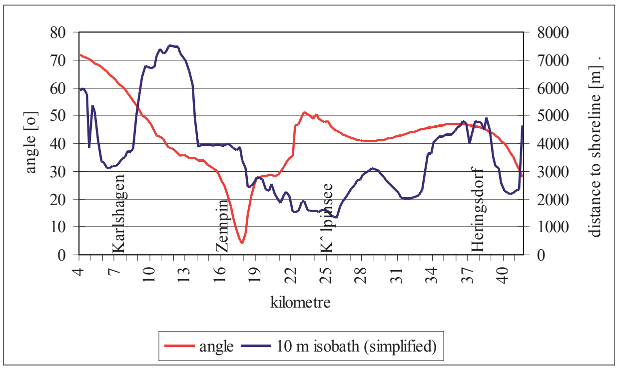

Fig. 4. Angle of shoreline normal related to north and distance of the 10 m isobath to the shoreline. Source: H. Rudolphi.

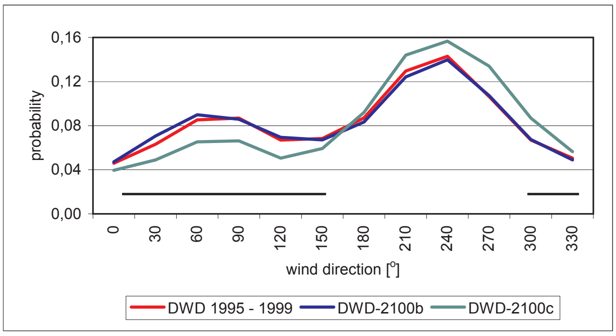

Fig. 5. Comparison of the probability of wind distributions. The bars show the wind directions relevant to the Usedom sea-coast. Source: H. Rudolphi.

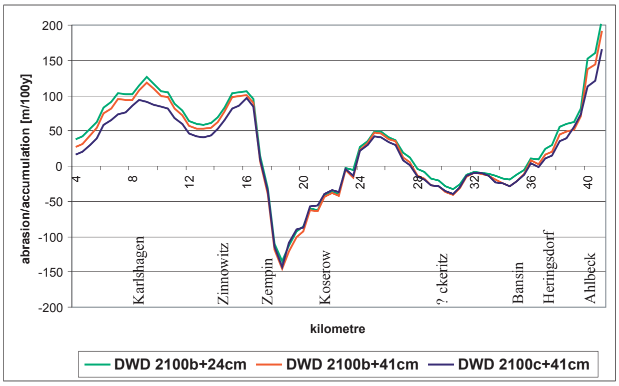

Fig. 6. Impacts of different sea level rise scenarios calculated by the climate scenarios DWD-2100b and DWD2100c and the location of villages near the coast. Source: H. Rudolphi.

4.1 Applying a GIS Tool in the DSF

a) Planners requests

A conceptual problem in the collaboration between planners and modellers is the comprehension of model results and, of course, the responsibility of their own decisions. This fact is shown in the question frequently asked by planners: "What is the probability of the modelled event?" However, the climate models do not work with probabilities, they work with suppositions that lead via a defined development path to a result. These development paths represent the model. Due to the lack of probability information, planners like to use the model results in a very careful and restrictive manner. Therefore, we have to find a way that enables planners to easily use different model scenarios.

The discussion showed that the requirements of planners differ. While one group is satisfied with a neutral display of the affected areas, another group demands assessments in monetary values. Another problem is that the estimation of affected areas depends on the point of view, which means that the same area assessed by a different referee (spatial planning, nature protection, building regulations) leads to different assessment values. The solution to this problem should be a set of different analyses, but it is impossible to consider each possibility.

In the Office of Regional Planning Vorpommern, GIS is still not in routine use, but the development of a GIS based decision support tool does have the potential to raise the acceptance for this technique.

Today, the German planning law has no restrictions on areas endangered by flooding expected from long term sea level rise. Even though the master plan for coastal protection, published by the State Office for Environment and Nature (Ministerium...1994), gives spatial information on a map on flood prone areas *in case of storm surge*, and even though this map is cited in the Regional Development Plans, one has to realize that the content of this map has no legally binding impact for other actors. It is made only for the purposes of coastal protection, like construction and maintaining of dykes and other protection works. However, regional planners are interested in having more information, for example, about scenarios of the future potential sea level rise and its impact on lowland areas because they want to give hints about those areas, which are best to be free of new technical infrastructure, of new housing or industrial areas etc.

b) Data

The elevation models

Currently, 5 elevation models are available for the area of interest. None of these models fulfils the requirements for geometric resolution and/or map projection. Therefore, a new model on the basis of the topographic map 1 : 10 000 was created. This new model was used to test the methods with the other available geometric data layers.

The elevation resolution of this model is at best between 0.5 m and 1 m. This seems to satisfy the needs of a test of our methods. For accurate results in the future, we need better elevation models, like the so-called DGM 5 with an elevation resolution of 0.5 m. This model is still under construction under the responsibility of the State Ordnance Survey and will be available in the near future.

Other geometric data sets

The Office for Regional Planning Vorpommern currently uses the following data sets:

- the digital land register
  The digital land register was set up in 1999. Only planned (new) objects are registered and stored in the database. Due to the lack of pre-existing objects (before 1999), the stock of spatial geo-objects is incomplete.
- data from the regional land use planning

In Germany, additional data sets from other offices are available:

- The Authoritative Topographic Cartographic Information System (ATKIS) of the State Ordnance Survey
- The biotope types and land use types map (BNTK) of the State Agency of Environment, Nature Protection and Geology
- Landscape Information System (LINFOS) of the State Agency of Environment, Nature Protection and Geology
- Medium-scale soil map for agricultural land (MMK) of Leibniz-Centre for Agricultural Landscape and Land Use Research

Statistic data sets:

- community data-base of State Agency of Statistics Mecklenburg-Vorpommern
  Information is available in different administration layers (country, department, district, parish).

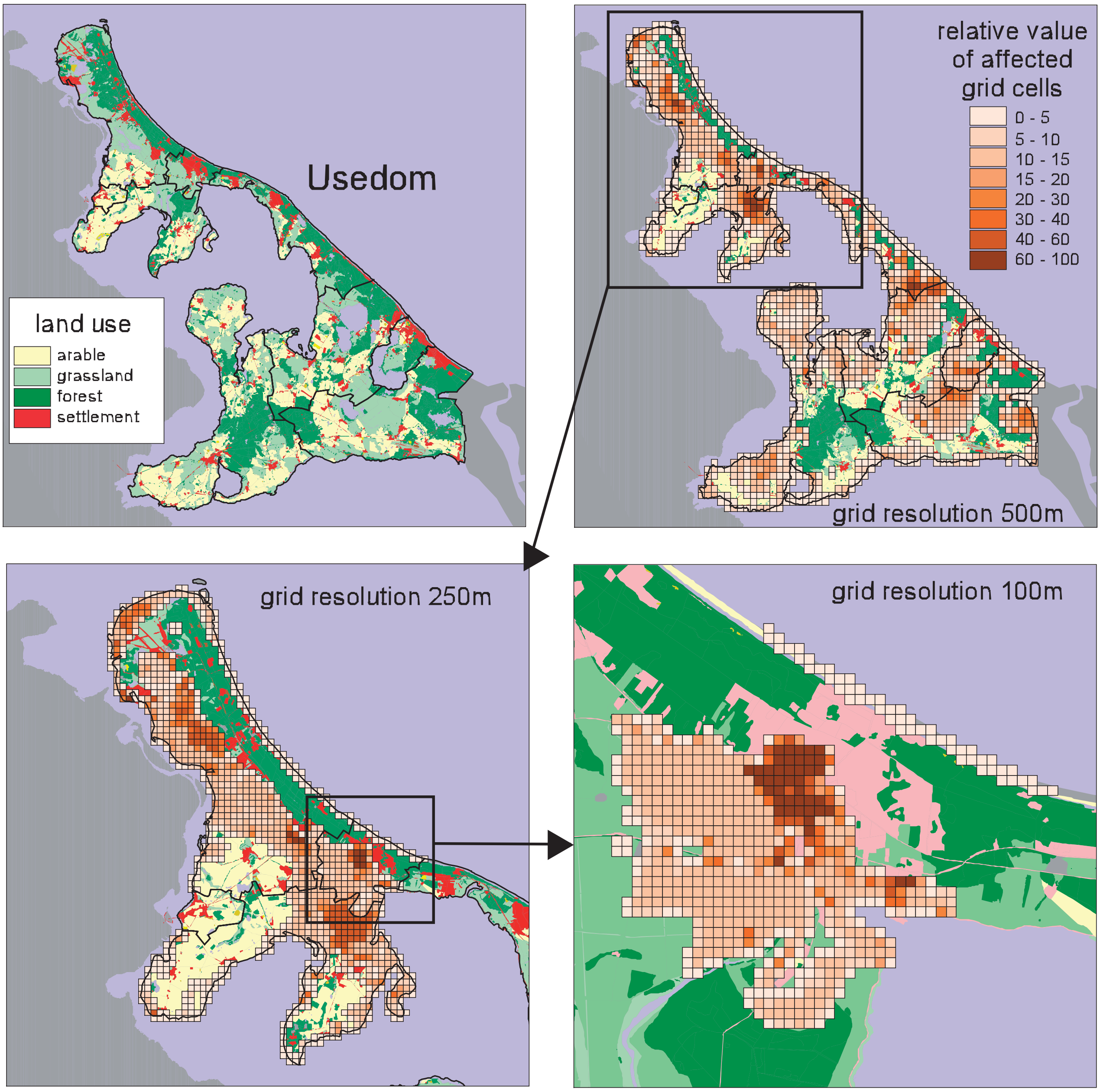

Fig.7. Sample analysis with different areas of interest and different grid resolutions (predicted sea level 85 cm). Source: B. Röber.

This overview of available (geo-) data shows a good situation in Germany, with many different data sets that can be used by planners.

The problems working with these different sources of information are:

– various data resolutions,
– structures,
– projections,
– accuracy and coverage.

Parts of these data sets are inconsistent and redundant. The way to overcome some of these problems could be to do a set of analyses according to the different points of view, and/or to harmonize the data.

The information presented before shows a high diversity in the demands for the results, and on the other hand, a large heterogeneity of the input data and resources. The combination of both demands and data available, leads to a large number of analyses and scenarios. The solution is an open GIS tool, which implements the methods for different analyses, included in an easy to handle user interface.

c) GIS Tool

Requirements of the GIS Tool

– It should be possible to calculate analyses with different datasets for different sea level rise scenarios.

– The user should be able to set his spatial focus (Fig.7), which means to select an area of interest (AOI, a set of parishes, a region etc.).
– The user also should be able to define the spatial resolution of the result (Fig.7). The idea is to divide the AOI into a set of grid cells and normalise the different input data for the theme under consideration. The user should be able to define the extent of the grid cell size.

The analysis of the planners` needs did show that three types of results are required:
– The first type is an intersection between the endangered areas from sea level rise and the input sets. This type does not need any assessments or evaluations. The resulting map only shows the objects of the input theme endangered by the selected sea level rise scenario.
– The second one consists of evaluated, comparable areas with calculations processed with relative values.
– The third one differs slightly from the second one due to the application of absolute values.

According to the workflow of the GIS tool (programmed with Avenue for ESRI´s ArcView 3.2) in the first step, the user sets *basic settings* like area of interest, result grid resolution in meters, sea level rise in centimetres. Then the user selects the input themes, and for each of the themes the attribute field that holds the object types.

In the next step, the tool cuts the input themes with the area affected by the forecasted sea level rise, and generates an empty result raster of the resolution chosen. With this option, the amount of data to be processed is reduced, and the first simple result is completed (ref. chapter 4.1c Requirements).

The tool reads the object types and generates an empty *assessment* table. Now the user should fill in the table or may load a previously saved table. In this step, it is possible to make a choice out of three options for the application of nominal, relative or absolute values.

In the *classification* step, the assessment values will be joined with the geometric objects in relation to the affected proportions (length, area) for each cell of the result raster. For each input theme, a filled result matrix is produced. Result maps for each of the input themes can now be created ("evaluated areas" in Fig. 8).

To enable the tool to generate a complete result map, the user has to select *settings for normalising*. To normalise the values of each theme, the user sets the maximum value (the minimum value is always set to zero). With this setting, the themes are weighted against each other.

Finally, the tool summarises the raster of the different themes vertically, filling the cells of the result raster with the sums. This step generates the complete result map ("result raster" in Fig. 8).

4.2 Impact Assessment

The Figure 9 shows the flood-prone areas of northwest Usedom. The island has an area of 360 km² (without water bodies), and 13 % will be at risk from a sea level rise of 25 cm and 28 % by a sea level rise of 80 cm (Table 2).

An analysis of the affected areas shows that in all three scenarios, approximately 70 % of the area is used for agriculture (Table 3). The areas of ecological interest (not being used) are from 15 % to 25 %, and less than 1 % is existing human settlements. Nevertheless, knowledge about the potentially affected areas is not only important referring to existing land use and infrastructure, but also with respect to future planned settlements and infrastructure.

The agricultural areas are used as grassland and feedlot. This is fenland that has been drained (see chap. 2). The farmland consists of tilly soil, which is found on higher areas. Thus, these areas are hardly ever affected by inundation (Table 4). This is a factor of great importance for developing strategies.

The prices of the land usage are shown in Table 5. It is possible that with a sea level rise of 80 cm, the loss of value is significantly higher for the building land (with an area of 0.6 km²) than for the agriculture land (with an area of 72 km²). As well, the prices may change during the next 100 years.

Table 2. Sizes of flood-prone areas on Usedom (total area and proportion to Usedom) by a sea level rise of 25, 40 and 80 cm. Source: H. Rudolphi & B. Röber.

SLR [cm]	Total Area [km²]	% of Usedom
25	46	13
40	58	16
80	102	28

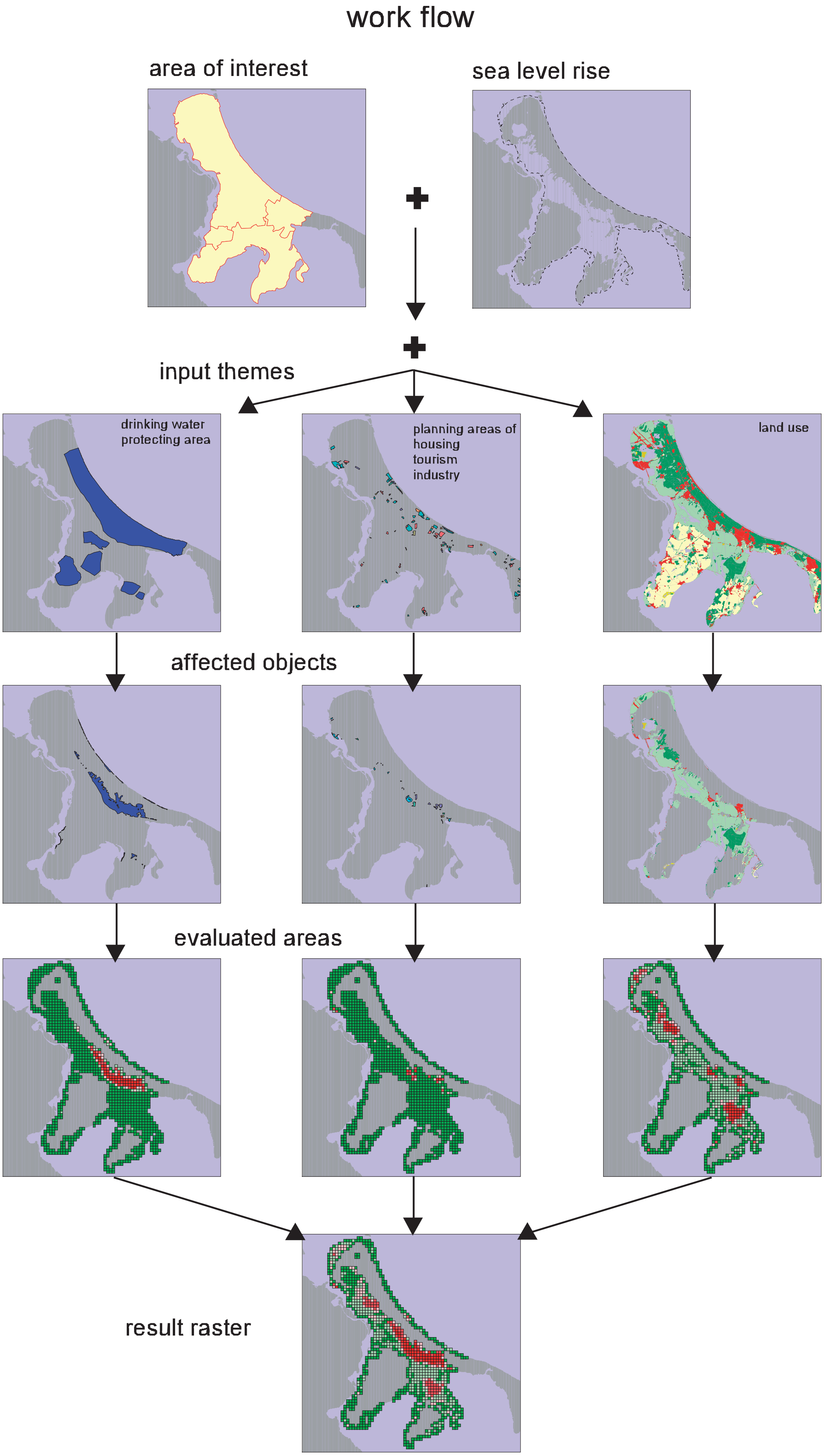

Fig.8. Schematic application flow with different sample input themes. Source: B. Röber

Table 3. Affected parts of the different land usage [%] by the sea level scenarios 25, 40 and 80 cm. Source: H. Rudolphi & B. Röber.

SLR [cm]	Area of Ecological Interest	Agriculture	Forest	Human Settlement	Industry	Infrastructure	Other Areas	Total Area (=100%) [km²]
25	25.55	69.07	4.34	0.14	0.24	0.44	0.22	45.65
40	22.28	71.81	4.89	0.21	0.28	0.37	0.16	57.88
80	15.66	71.13	11.27	0.62	0.69	0.05	0.13	101.51

Table 4. Affected parts of different agricultural usage [%] by the sea level scenarios 25, 40 and 80 cm. Source: H. Rudolphi & B. Röber.

SLR [cm]	farmland	grassland	Total Agriculture Area (=100%) [km²]
25	0.77	99.23	31.53
40	0.94	99.06	41.56
80	2.78	97.22	72.21

Table 5. Value of land of different usage. Source: H. Rudolphi & B. Röber.

Object	Price [€/m²]
Grassland, farmland, forest	0.5 – 5
Building land	60 – 80
Building land in tourist centres	110 - 500

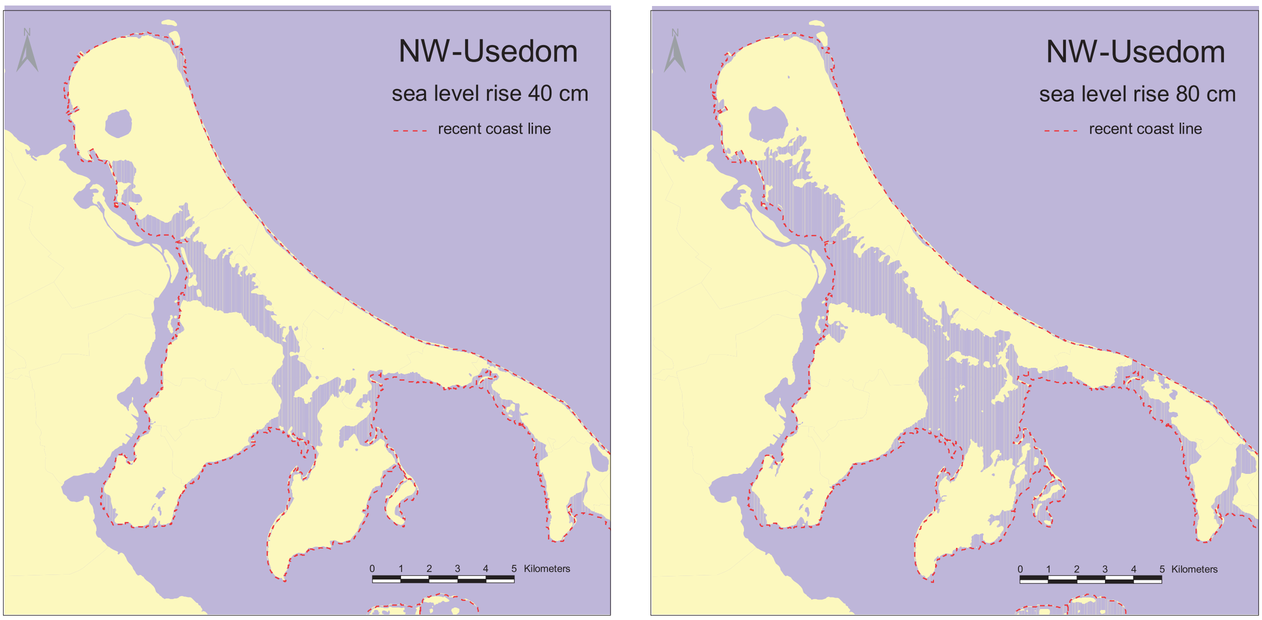

Fig. 9. The flood-prone areas on Usedom Island by a sea level rise of 40 cm and 80 cm. Source: B. Röber.

4.3 Coping Capacity and Vulnerability Assessment

The project results refer to potential sea level changes during the next 100 years. The time scale for regional plans is just 15 years, after this period they have to be updated. However, the tasks of regional planning do require a much longer time horizon. In this context, an expected sea level rise is not the only subject that calls for long-term and strategic thinking in planning; nature protection or covering of non-renewable resources do require a large time scale in planning at this stage.

Coastal protection is not a task of regional planning, but regional planning comments on the plans for coastal protection, particularly those which are extensive and far-reaching, like the master plan for coast protection. Moreover, regional planners are supposed to display flood prone areas in the regional plans. This spatial information in the regional plans do not have the legally binding status of so-called “aims of regional planning”, which for example could strictly forbid new housing areas in the these flood prone areas. However, the plans include “principles of regional planning”, which every public stakeholder (like a local community setting up it’s preparatory land use plan with new housing areas or tourism infrastructure) has to take into account.

Thus, coastal protection and regional planning now come into closer contact with each other, and the SEAREG project results become more useful for planning on a practical level.

The project did deal with scenarios of sea level changes, not with prognosis. Nevertheless, it should be mentioned that the scenarios have not been set up arbitrarily, but directed towards a sea level rise in Vorpommern, not a decrease. While the evidence strongly suggests a higher sea level, no forecast uncertainty can be indicated for the amount of sea level rise at the coast of Vorpommern. This would be a problem for regional planners, if they only wanted to set up restrictions against land use plans of individual municipalities. Instead regional planners rely more upon information than on interdictions. They look forward to including the project results concerning future sea level rise and potential flood prone areas in the text and maps of the next regional plan. This at least generates an indirect effect, because a municipality that prepares its own preparatory land use plan has also to take into account these statements of the regional plan. Such statements as “principles of planning” do not have the status of legally binding “aims of planning”, but for public actors it is not allowed to neglect them when setting up local land use plans.

From the view of planners the explanatory power of the developed computer program and of its results is good in respect to content, provided that up-to-date data are available. The spatial resolution is even higher than the map scale of the regional plans. On the other hand, for the purpose of an individual coast protection plan the significance of the results gained by the program should be higher to identify individual buildings and to make up the balance of their values.

5 DISCUSSION

The coast of Usedom Island is characterized by higher elevated active cliff sections consisting of Pleistocene till and sand and low lying beach ridge barriers in between that were built by the accumulation of marine sand during the Holocene. The recent phase of sea level rise causes coastal retreat not only along the cliffs but in some barrier sections too. To analyse how the coastline has reacted in the past 200 years, historical maps and aerial images were analysed. To predict how the coastline will change its position and morphodynamics in the next 100 years, a model was developed that considers both alternating wave climate and sea level rise, but not coastal protection measures. Based on scenarios provided by the Swedish Meteorological and Hydrological Institute the trend observed in the past will most likely continue in the future. However, the main wave energy impact might get lower due to a changed wind direction distribution, whereas the accelerated sea level rise will lead to higher transgression rates.

The GIS tool could be helpful for planners for long-term planning. First, the flood-prone areas are determined and at the next stage the areas are assessed. The tool can be used with each data sets and scenarios currently available for planners. The analysis of the data sets has shown that in all scenarios mainly the agriculture areas, especially grassland developed on drained fens, are affected. That has historical reasons: the old settlements are situated on the higher places in this region. Only since 1991 new areas for tourism, settlement, industry and trade have expanded to areas below 1 m above sea level.

There are two possible solutions for the agricultural areas. One solution is that the flood protection by means of dikes will continue. In this case, the areas can be used as before. However, the costs for drainage will continuously increase along with the sea level rise.

The second way is to retreat from the areas and to revitalize the coastal fenlands. The disadvantages of this solution are high costs for building new dikes around the villages and the need for the farmers to change their production from an intensive to an extensive type. The advantages are the reduction of the costs to enforce the dikes and to drain the areas, and secondly the reinitiated growth of the peat according to the rising sea level. In addition, fens do accumulate CO_2 (Succow & Joosten 2001), which can be an important fact for planning authorities when acting on the Kyoto-Protocol.

The decision between "protect or retreat" must be solved in the near future. The reinitiation of peat accumulation in the fenlands takes a lot of time and when the sea level becomes too high there is no chance for future revitalization.

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ASSESSMENT OF MODELLED SEA LEVEL RISE IMPACTS IN THE GDAŃSK REGION, POLAND

by
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Staudt[1], M., Kordalski[2], Z. & Zmuda[2], J. 2006. Assessment of modelled sea level rise impacts in the Gdańsk region, Poland. Geological Survey of Finland, Special Paper 41, 121–130, 4 figures and 3 tables.

For the Gdańsk region, the SEAREG project's sea level rise (SLR) scenarios vary from 0.04 m (low case), 0.49 m (ensemble average) and up to 0.98 m (high case). Several local digital elevation models were calculated with the help of GIS, and five SLR maps were produced. The impact assessment revealed the strongest impacts on the service sector, mainly tourism, since all beach areas will be affected, as well as the water supply. The vulnerability of the region is high since these impacts meet a coping capacity lacking the awareness, motivation and resources to identify sea level rise as a threat in future.

Key words (GeoRef Thesaurus, AGI): climate change, sea level changes, transgression, floods, groundwater, coastal environment, risk assessment, coping capacity, Gdansk, Poland.

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1 INTRODUCTION

The region of Gdańsk was one of the case study areas of the SEAREG project that was partly co-financed by the INTERREG IIIB Programme of the European Union. Gdańsk is the largest city in northern Poland and is situated on the southern coast of the Baltic Sea in the Gulf of Gdańsk. Together with Gdynia, Sopot and smaller suburban areas, Gdańsk forms the Tri-City with approximately 800,000 inhabitants. In 2002, Gdańsk alone had a population of 457,000 and is the capital of the Pomeranian voivodship. With a long tradition as one of the members of the Hanseatic League, Gdańsk played a major role in the trade and economy of the Baltic Sea Region (BSR) and today is still the largest transport node in Poland.The main industries are found in the harbour area and along the Martwa Vistula river shores. Gdańsk has also experienced a boom in the tourist industry in recent years. The harbour is one of the largest and deepest of the Baltic Sea, taking ships up to 150,000 DWT (Dead Weight Tonnage). In terms of economical attractiveness, Gdańsk ranks third nationwide and accounts for 13% of the foreign capital invested in Poland.

Famous for its shipyard and as an industrial location, there currently is a trend from shipyards and refinery to know-how-based economy and tourism.

Sopot is one of Poland's premier seaside resorts and is located north of Gdańsk and has approximately 40,000 inhabitants. Sopot is a big health and tourism resort, well known for the longest wooden pier (Molo) in Europe (515.5 m). Since the 1800s, baths and spas of this health resort have attracted tourists, visitors and spa guests. After an economic decline during communist times, Sopot gained the official spa status in 1999, and the economy and tourism industry has flourished since then.

In contrast to the northern SEAREG case study areas of Helsinki and Stockholm that are uplifted due to the still ongoing isostatic rebound of the Fennoscandian Shield (Ekman 1996), the Gdańsk region experiences land subsidence of an average magnitude of 1-2 mm/year (Wyrzykowski 1985). There are several serious flood hazards for the low-lying parts of the City of Gdańsk (see Figure 2)

- Strong and long lasting northern winds can cause the intrusion of Baltic waters into the Vistula river mouth. In unfavourable conditions, the rise in sea level during these floods may exceed 1.5 m, which has occurred during many floods (Rotnicki 1995).
- Cloud bursts from the hills west of Gdańsk occurred during the last flood event in 2001. The impact of these flash floods also rises in combination with storm surges.
- Dangerous storms increased in the Gulf of Gdańsk from 11 incidents in the 1960's-70's to 38 in the 1980's-90's (Wróblewski 1994). Along with a rising sea level, future storm surges might reach heights of up to 2.5 m.a.s.l. (Cieślak, interview 2004).
- When ice jams in the Vistula coincide with the spring high water stages of the rivers, there is an elevated flood risk in the region. Climate change will lessen this hazard in the future.

Currently, 880 ha of urban and industrial areas in the city lie below 1 m above sea level (m.a.s.l.), 1020 ha of them lie between 1.0 and 2.5 m.a.s.l. Within these areas lie port facilities, urban districts, industrial areas, warehouses, transportation routes, the old town, drainage water systems and sewage plants. The most important groundwater recharge areas for the water supply of Gdańsk are located on the coastal terrace and on the Vistula Delta Plain and are vulnerable to an accelerated sea level rise and flooding. Industrial sites, several waste sites, including illegal and reclaimed ones, are all situated in locations below or just above 1 m a. s. l. Since the high case scenario estimates flood prone areas up to 0.98 m.a.s.l, the dumped or stored contaminants in these sites pose a certain environmental risk. Water intrusion can lead to the mobilization of contaminants into the shallow aquifers and therefore may be a threat to future drinking water supply.

From 1895 to 1996, the average sea level in Gdańsk rose about 1.5 mm/year (Wróblewski 1994). This value correlates precisely with the estimated value of the worldwide eustatic sea level rise (Church et al. 2001). Since the beginning of the 1950's, this rate rose to 5 mm/year and the increasing trend is still ongoing (Dziadziuszko et al. 1996, see Figure1).

For the greater Gdańsk area, the following sea level rise scenarios have been calculated:

1) low case: 0.04 m 2), ensemble average: 0.49 m and 3) high case: 0.98 m (Meier et al. 2004).

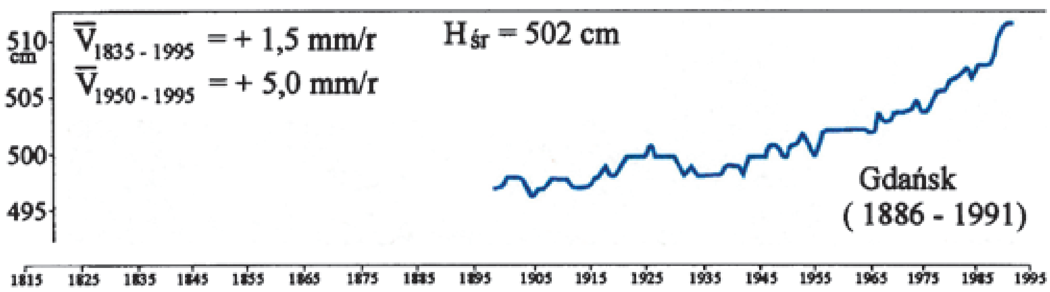

Fig. 1. The recorded sea level at Gdańsk- Nowy Port gauge for the time period 1895-1995 (after Dziadziuszko et al.1996).

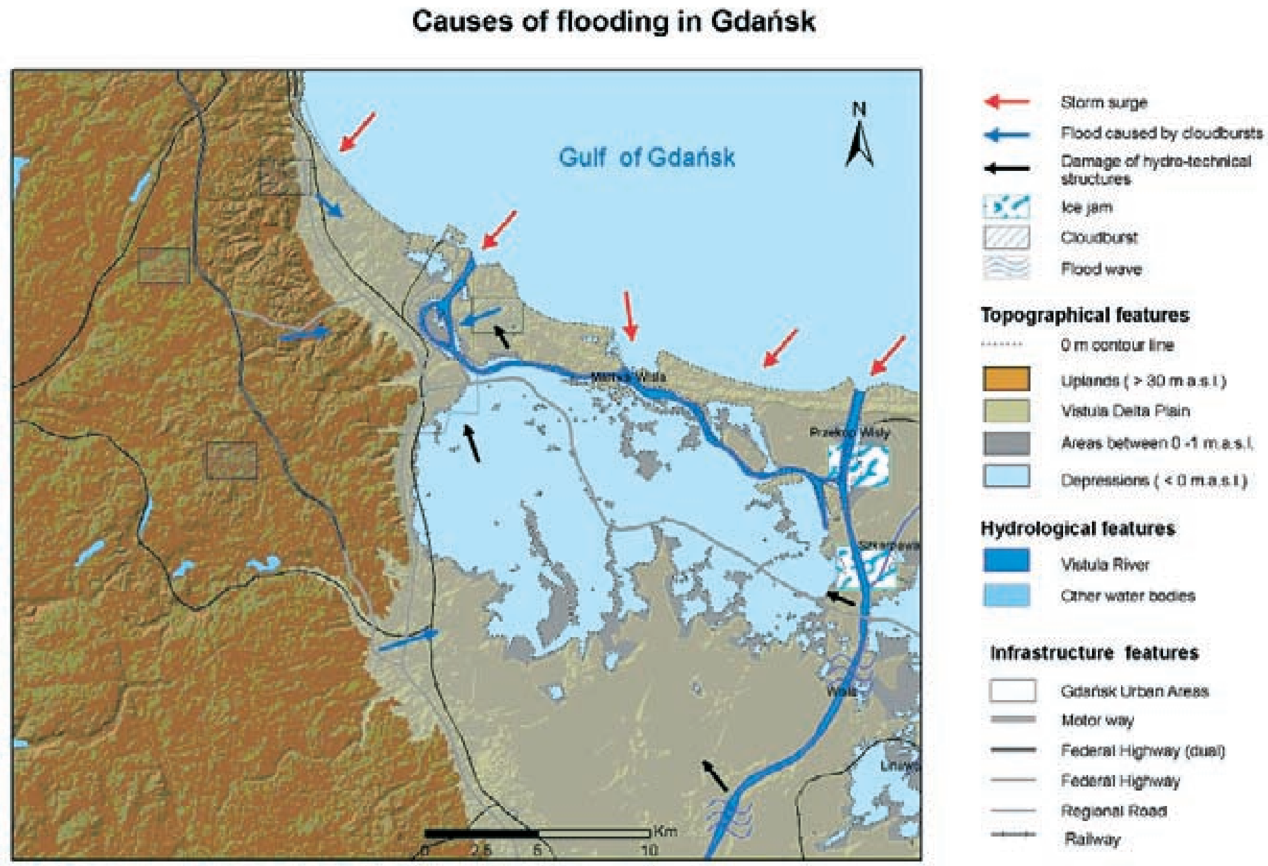

Fig. 2. Causes of flooding in the Gdańsk region, modified after: Polish Geological Institute, Gdańsk.

2 METHODOLOGY

The Decision Support Frame (DSF) was applied in the Gdańsk Region to discuss the effects of sea level rise with spatial planners. The Decision Support Frame (DSF) endorses decision making with a firm scientific background by finding appropriate mitigation strategies in the case of sea level rise in the BSR. The DSF consists of four major parts: Modelling and GIS applications, Impact and Vulnerability Assessments, Knowledge Base and Discussion Platform (Schmidt-Thomé P. & Peltonen 2006, *this volume*, Schmidt-Thomé et al. 2005). In the first phase of the assessment (screening phase), all fundamental data such as topographic maps, existing GIS data, land use data or maps, regional development plans, locations of dumpsites, polluted areas, historic flood event data, current flood prone areas, hydrological data (river runoff, river transport data), tidal gauge data (wave height, mean sea level), water recharge areas, as well as protected or nature conservation areas such as national parks or NATURA 2000 areas, has to be collected in an ideal case and transferred into the GIS environment to be overlaid with the processed digital elevation models. For the Polish case study area, not all of these data sets could be provided or did not exist. The Polish Geological Institute provided their GIS data sets consisting of geological and hydrogeological information as well as location of dumpsites and maps of polluted topsoils. Neither flood prone area maps nor historic flood event data nor hydrological and tide gauge data were available. Digital Elevation Models (DEMs) were produced by digitizing topographic maps, coastline and embankments in a 1: 10 000 scale for the case study areas of Gdańsk and Sopot. The DEMs were processed with a grid resolution of 10 x 10 m with TOPOGRIDTOOL in the Arc/Info GIS environment. Furthermore, all data provided (hydrogeological information, locations of dumpsites, soil contamination and city maps) were overlayed in the GIS. Five sea level rise scenario maps for Gdańsk and Sopot were produced and the hotspots were identified. For the three map sheets located directly on the coastline, the area impacted by a possible future storm surge of 2.5 m was additionally outlined (Cieślak, interview 2004). The sea

Table 1. Coping capacity subcategories for stakeholders and institutions used in the vulnerability assessment. Source: M. Staudt GTK.

Coping capacity categories of stakeholders:	Coping capacity categories of institutions :
Awareness	Co-operation
Knowledge	Strength of institutions
Motivation	Trust in decision makers
Resources	Guidance of planning

level rise scenario heights were transformed into the local Polish height system Kronstadt 86 according to Ekman (1994, 1999).

Following the DSF approach, these maps were discussed with local experts (spatial planners, scientists) and interviews were performed. So far climate change, and specifically sea level rise, is not a topic for the spatial planners in the region. During a case study meeting in Gdańsk in October 2004, the sea level rise scenario maps for the region were presented to planning and environmental authorities of Gdańsk and Sopot municipalities and interviews were performed with local experts. At the Polish Geological Institute, a geologist, a hydrogeologist and a water engineer were interviewed (see Interview reference list). At the Regional Water Management Board in Gdańsk, interviews with a representative of the City Development Office, Gdańsk, two representatives of the Regional Water Management Board and two spatial planning specialists of the Maritime Office in Gdynia were conducted (see Interview reference list). In the Sopot case study area, the chief architect, an ecologist and a representative of the Department of Engineering and Environmental Protection were interviewed (see Interview reference list.)

The local experts were asked to fill out impact matrices that were divided into two rows showing the two effects of sea level rise: 1) inundation (permanent loss of land) and 2) flooding (flood prone areas). The columns are divided into the following socio-economic sectors: first, second and third sectors, infrastructure, housing, open urban areas, groundwater and protected nature areas. The experts were asked to fill out the impact matrix according to the expertise with a classification consisting of the values: “no impact”, “low”, “medium” or “strong impact”, (see table 3).

The impact matrixes reflect the local expert’s opinion of a possible future sea level rise and its affect on the different sectors. The vulnerability of the municipalities was also assessed. Since there was no land use data available, the impact on the different sectors can only be described in a qualitative way.

Vulnerability is defined as a function of the coping capacity of the involved stakeholders and institutions (table 1).

In interviews, questions concerning the subcategories have been asked and evaluated in the vulnerability assessment. Questions asked in these interviews are available on the SEAREG DSF website (www.gtk.fi/slr/).

3 RESULTS

3.1 Impact assessment:

Table 2 shows the values of sea level rise scenarios and the size of affected areas for the three map sheets situated directly on the coast. Figure 3 shows the highly affected area of the Nowy-Port in Gdańsk. Figure 4 illustrates the impacts of sea level rise on the City of Sopot. The hatched areas are areas situated between 0.98 m and 2.5 m that are possibly affected during a future storm surge event.

The following points summarize the main outcomes for the Polish SEAREG case study areas:

1. All beach areas will be strongly affected, having a big impact on tourism of the region.
2. Industrial areas located near the coastline or the city canals might be affected.
3. Groundwater wells drawing their supplies from the shallow Quaternary aquifers along the shoreline can be affected by a rising water table caused by a brackish water intrusion due to sea level rise.
4. Areas where embankment walls are less than

Table 2. Calculated sea level rise scenarios and size of areas affected in the Polish case studies (coastal strip). Source: M. Staudt GTK.

Case study	Low case / Size of area affected	Ensemble Average/ Size of area affected	High Case/ Size of area affected	Size of area affected during a future storm surge of 2.5 m
Sopot	0.04 m / 0.45 ha	0.44 m / 5.8 ha	0.93 m / 8.86 ha	208.81 ha
Gdańsk -Nowy Port	0.04 m / 9.5 ha	0.49 / 53.71 ha	0.98 m / 84.36 ha	991.82 ha
Gdańsk- Port Polnocy	0.04 m / 2.08 ha	0.49 / 26.8 ha	0.98 m / 35.4 ha	319.16 ha

Table 3. Weighted evaluation of impact matrices filled out by the local experts (n= number of local experts interviewed) for Gdańsk and Sopot. Source: M. Staudt GTK.

Impact matrix Gdansk								
Land use	1. Sector	2. Sector	3. Sector	**Infra-structure**	**Housing**	**Open urban area**	**Ground water**	**Protected nature areas**
Sea Level Rise Effects	Agriculture Fishery Forestry	Industry, Waste deposit	Services			Incl. parks, Green fields, Waste land	Water supply	National parks, Bird nesting areas, etc.
Inundation (permanent land loss)	Low	Medium	Medium	Medium - Strong	Low - Medium	Low	Medium	Low - Medium
Flooding (flood prone areas)	Low	Medium	Medium	Medium - Strong	Medium	Low - Medium	Medium - Strong	Low - Medium
Values: “No impact”, “Low”, “Medium” or “Strong”; n=6								
Impact matrix Sopot								
Land use	**1. Sector**	**2. Sector**	**3. Sector**	**Infra-structure**	**Housing**	**Open urban area**	**Ground water**	**Protected nature areas**
Sea Level Rise Effects	Agriculture Fishery Forestry	Industry, Waste deposit	Services			Incl. parks, Green fields, Waste land	Water supply	National parks, Bird nesting areas, etc.
Inundation (permanent land loss)	Low	No impact	Medium - Strong	Medium - Strong	Medium - Strong	Medium	Medium - Strong	No impact
Flooding (flood prone areas)	Low - Medium	No impact	Medium - Strong	Medium	Medium	Medium	Medium	No impact
Nalues: “No impact”, “Low”, “Medium” or “Strong”; n=3								

1 m a.m.s.l. may be seriously affected during river floods and storm events.

5. Low-lying areas in the hinterland (Vistula Delta Plain) are especially vulnerable for river floods.

The results of the evaluation of the impact matrix for the cities of Gdańsk and Sopot are presented in table 3 and are described below.

Agriculture, fishery, forestry:

According to the available information, in the economic share of these industries is minimal in Gdańsk and Sopot. Therefore, the impact is low.

Industry:

The economic share of this sector in Gdańsk is 13.5 %. The industry is dominated by the traditional

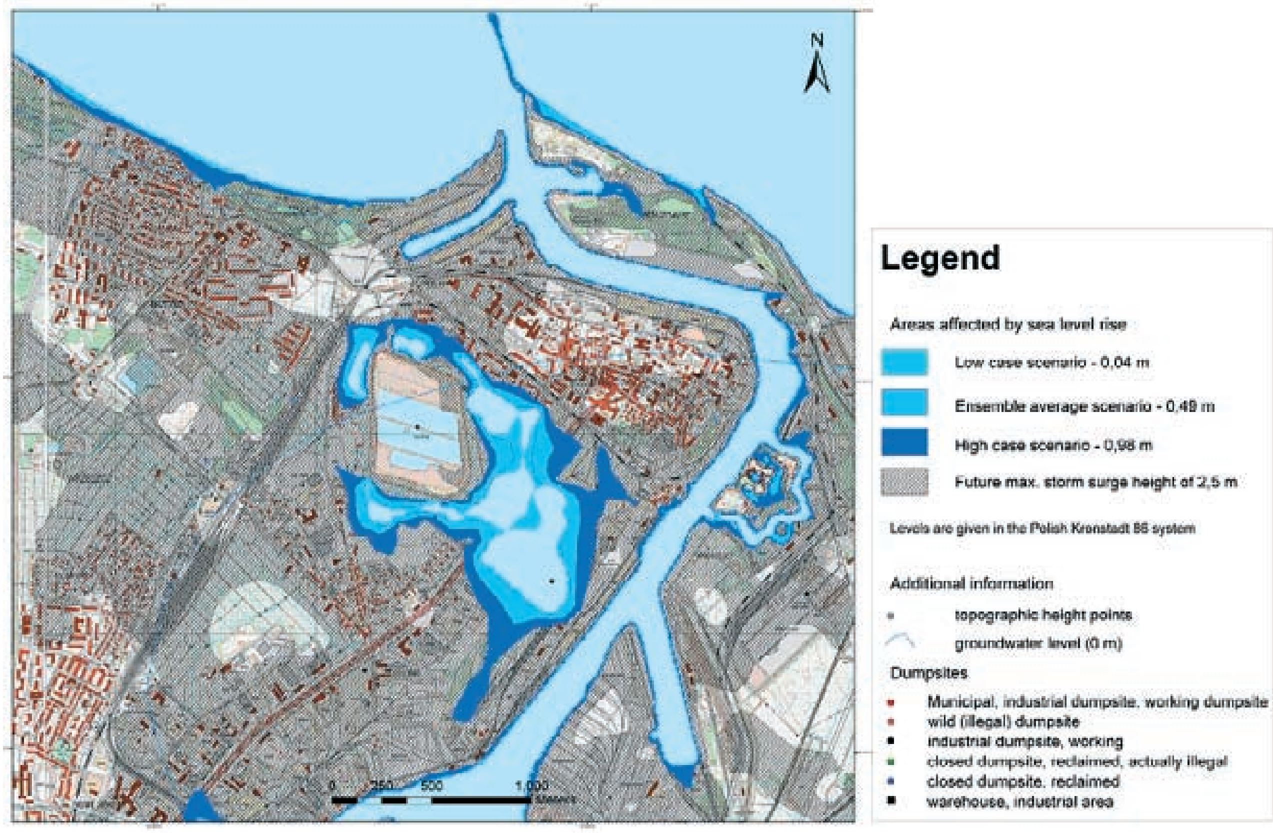

Fig 3: Sea level rise impact map for the Gdansk-Nowy Port area. In the high case scenario, the depression zone in the middle of the map might be completely flooded since embankment heights are just 1 m above sea level.

industries like shipbuilding, petrochemical and chemical industry. The biggest employee, Rafineria Gdańska, is located near the Vistula River and may be affected by river floods. Other industries located near the shoreline or the river might be also affected. Industrial dumpsites located at the depression zone in Nowy Port might be completely flooded and pose a certain environmental risk in the future. The impact is medium for Gdańsk and there will be no impact for Sopot.

Services:

For the year 2004, an estimated 1.4 million tourists were expected with an increasing trend in the coming years (estimate of 1.7 million tourists up to 2007). Since the beaches of Gdańsk attract many tourists and inhabitants, sea level rise will have a major impact in this sector. Some areas of the historic old town may be also affected where embankments heights are just 1m above sea level. In Gdansk, the impact is medium, for Sopot , being one of Poland's famous beach resorts, the impact is medium to strong.

Infrastructure:

The main infrastructure features will be affected by sea level rise. In case of river floods or flash floods, infrastructure is more vulnerable, as seen during the 2001 flood where the central railway station and main streets were seriously affected. In the case of a future storm surge of 2.5 m, the map results show that the impact is strong for both municipalities.

Housing:

Housing will not be directly influenced by sea level rise, but in case of a future winter storm of 2.5 m there will be a severe impact. Future housing plans, like the post-industrial estate reclaimed from the former Gdańsk Shipyard, include a so-called New City located near the Vistula River shore. According to city planners, there are also new housing projects planned near the coastline and the Vistula River. The local experts are assessing a low to medium impact in Gdańsk and a medium to strong impact in Sopot for this sector.

Open urban areas:

Some parts of parks and recreational areas will be affected, especially in the high case scenario in Gdańsk. The impact is low for Gdańsk, and medium for Sopot. During future storms, large areas will be affected.

Groundwater/water supply:

The low lying areas endangered by flooding on the coastal terrace and on the Vistula Delta Plain contain

Table 4. Identification of hot spots and stakeholders for Gdańsk. Source: M. Staudt GTK.

	Hotspots	Stakeholder 1	Stakeholder 2	Stakeholder 3
I	Beaches, coastal zone	Municipality	Tourism services	
II	Water supply	Regional Water Board in Gdańsk	Water supply company	Private well owners
III	Industrial dumpsites	Dumpsite owner		
IV	Refinery	Rafineria Gdańska		
V	Industries located near river shores	Several industry owners		

Table 5. Identification of hot spots and stakeholders for Sopot. Source: M. Staudt GTK.

	Hotspots	Stakeholder 1	Stakeholder 2	Stakeholder 3
I	Beaches, coastal zone	Municipality	Tourism services	Spa
II	Water supply	Regional Water Board in Gdańsk	Water supply company	Private well owners
III	Illegal dumpsites	Municipality		

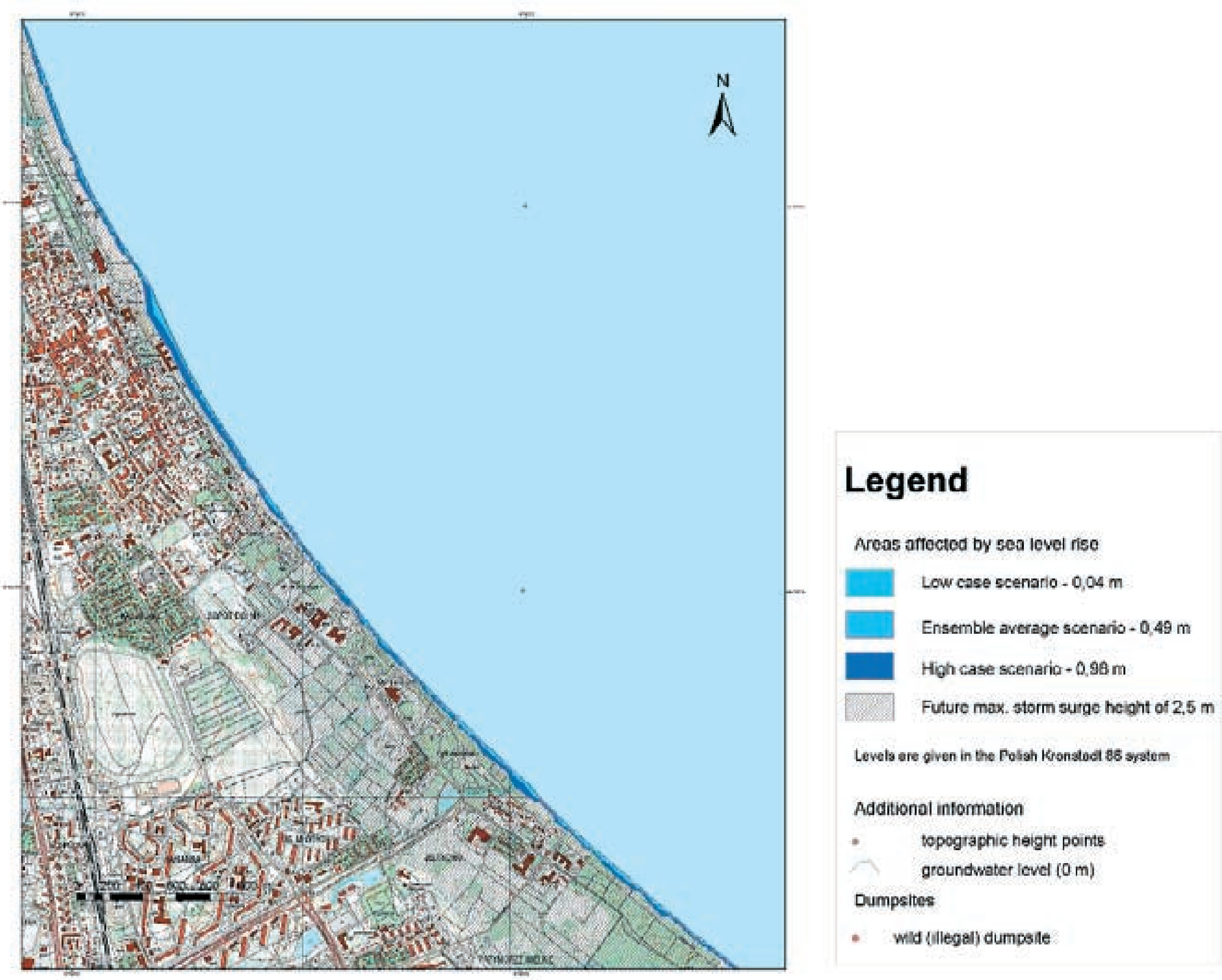

Figure 4: Sea level rise impact map for the Sopot area. In the high case scenario, the beach area will be strongly affected with a severe impact on the service sectors (tourism industry, spas). In case of a future storm surge, the whole town of Sopot will be highly affected (see hatched areas)

Table 6. Summary of the stakeholder's and institution's coping capacity in Gdańsk and Sopot. Source: M. Staudt GTK.

Category	Evaluation Low, Medium, High	Comments
Coping capacity of stakeholders		
Awareness	Low	People have heard about the discussion on sea level rise, but do not see it as a real threat. Awareness is more concentrated on river floods and accidents in industrial areas.
Knowledge	Medium	In general, knowledge is there, the responsible authority for sea level rise and protection measures is the Maritime Office in Gdynia.
Motivation	Low	Sea level rise is not seen yet as a threat, river floods and other hazards have a higher priority.
Resources	Low	There are no earmarked resources for sea level rise or floods.
Coping capacity of institutions		
Co-operation	Medium	Co-operation between local city authorities exist concerning other matters.
Strength of institutions	Medium	There are already existing Polish sea level rise studies and people are aware of problems such as coastal erosion and protection. Responsible authority is the Maritime Office in Gdynia
Trust in Decision makers	Low	SLR is not a topic for decision makers.
Guidance of planning	Low-Medium	The Act on Marine Areas of the Polish Republic and Maritime Administration and Protected Belts Act law regulates what is and is not allowed in the coastal zone. There is a division of the coast into a technical belt and a protective belt. The responsible authority is the Maritime Office in Gdynia. Planners are not taking sea level and flood risk into account yet and their knowledge is rather low. There is no building code (minimum ground elevation for new buildings).

the most important groundwater water recharge areas for the water supply of Gdańsk.

Currently, the Gdańsk drinking water is partly supplied from Lake Straszyn, an artificial reservoir fed by the Radunia River. This water has no drinking water quality and has to be treated to reach quality standards. There are future plans to change the water supply completely towards the coastal aquifers. Thus, the water supply of the region will be even more vulnerable to sea level rise than at present. Depending on future development, the local experts are indicating a medium impact for Gdańsk and a medium to strong impact for Sopot.

Protected nature areas:

There will be no impact for this category in Sopot due to the absence of protected areas in the city. For Gdańsk, the impact is low to medium since a nearby national park might be affected.

3.1.2 Identification of hot spots

Following the SEAREG impact matrix approach, the hot spots in Gdańsk and Sopot and their stakeholders have been identified in table 4 and 5.

3.2 Vulnerability assessment

Referring to information gathered in the interviews, the vulnerability was assessed for the Polish case study areas. Table 6 is summarizes the main outcomes of the vulnerability assessment.

4 DISSCUSSION

The reliability of the sea level rise maps depends on the reliability of the overall sea level rise scenarios used in the project and on the quality of the processed digital elevation models. The quality of the data was restricted to topographic maps with a scale 1:10 000, which have been digitized and further processed. For better DEMs, more precise survey levelling data, especially for areas in the old town, would be needed. Unfortunately, the data situation for the Polish case studies was not as ideal as in the case of Pärnu (Klein

& Staudt 2006, *this volume*). Nevertheless, the maps produced received very positive feedback from the local experts and gave a good idea about the possible impact of sea level rise in the Gdańsk region. Since the tide gauges data were not accessible, the future possible storm surge height could not be calculated. According to information from a Polish sea level rise study for the Bay of Gdańsk, a possible storm surge height of 2.5 m was used. Taking this value and adding the impact zone to the existing maps illustrates a strong impact on all sectors in the case of a future storm surge. The impacts of sea level rise on the different economic sectors could only be assessed in a qualitative way or descriptive way since land use data and economic data were not available or not provided in a usable format.

5 CONCLUSION

The co-operation with planners and decision makers during the SEAREG project has shown that the DSF is a potential tool to estimate and assess possible impacts of changing sea levels. The outlined flood prone areas in Gdańsk should be protected and countermeasures have to be taken to mitigate the danger of flooding in the Gdańsk region in the future. The topic of brackish water intrusion into the Quaternary coastal aquifers and the current and future situation of water supply are issues where local experts' opinions vary. Future impacts research studies should be initialised after the end of the SEAREG project to assess the vulnerability of the water supply with the help of water resource modelling. The results of such studies will enable involved stakeholders to plan appropriate mitigation and management strategies to lower the vulnerability for the cities of Gdańsk and Sopot. At the moment, the topic of climate change is still be underestimated in the cities along the Baltic coast and the SEAREG project could help to raise awareness and illustrate the problem and extent of future sea level rise in the case study areas. So far, the DSF approach is applied in several cities in the Baltic Sea Region (e.g. Klein & Staudt 2006, *this volume*) and it would be an interesting task to develop it further and apply it in other regions.

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IMPACTS OF FUTURE CLIMATE CHANGE AND SEA LEVEL RISE IN THE STOCKHOLM REGION: PART I - THE EFFECT ON WATER LEVELS IN LAKE MÄLAREN

by

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Graham[1], L.P., Andréasson[1], J. & Persson[1], G. 2006. Impacts of future climate change and sea level rise in the Stockholm Region: Part I - The effect on water levels in Lake Mälaren. Geological Survey of Finland, Special Paper 41, 131–141, 7 figures and 3 tables.

Changes in the water level for Lake Mälaren in Sweden impact on the infrastructure of both the capital city of Stockholm and other municipalities situated along its shoreline. Recent events with high water levels in the lake have shown the system to be more vulnerable than previously thought. This paper addresses the question of how the water level in Lake Mälaren will potentially be affected by future climate change by focusing on the following three contributing components for analysis: 1) changes to hydrological inflows to Lake Mälaren, 2) changes to downstream water levels in the Baltic Sea, and 3) changes in regulated lake outflow capacity. The first component is analyzed using hydrological modelling, while the second and third components make use of a lake discharge model. An important conclusion is that although increased sea level in the Baltic influences water levels in the lake, increased hydrological inflows show a greater impact on lake water levels than increases in sea level. Furthermore, an identified need for increased outflow capacity from the lake in the present climate does not decrease with scenarios of future climate change. These results provide critical input to regional planning in the Stockholm-Mälar region.

Key words (GeoRef Thesaurus, AGI): climate change, lakes, hydrology, lake level changes, runoff, discharge, sea level changes, Lake Mälaren, Sweden.

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1 INTRODUCTION

Lake Mälaren lies just to the west of Stockholm and outflows into the Baltic Sea to the east, as shown in Figure 1. Runoff from a total of 22600 km^2 drains into the lake. With an average surface area of 1140 km^2, this is the third largest lake in Sweden. Two of its four outflow points lie to the north and south of the islands of Gamla Stan, which is the old town in central Stockholm. The other two outflow points are the navigation locks in Södertälje and Hammarby Canal in Stockholm. Aside from Stockholm, there are numerous smaller cities that are situated along its shores. In total, some 2.5 million people live in the vicinity of this lake. For most of them, Mälaren is also their source of drinking water.

The average elevation difference between Lake Mälaren and the Baltic Sea is only 0.66 m. To maintain a stable water level, the lake has been regulated by a collection of locks and floodgates since 1943. This allows for year round navigation on the lake and inhibits saltwater intrusions from the Baltic Sea during periods of high sea level. The regulation also allows for the release of higher outflows than previously possible under natural conditions. Reoccurrence of the high lake levels from the 19th century and early in the 20th century has thus been avoided since regulation began. Municipalities along the lake have adjusted to the more stable water levels and modern infrastructure now encroaches into the historical floodplain regions along the lakeshore.

Operational rules for the regulation of the water level in the lake are dictated by decrees handed down by the Swedish Water Court. The original decree was established in 1941. This was followed by an additional decree in 1966 (Ehlert 1970), which was slightly modified in 1989. The water decrees are official documents that stipulate, in detail, the relative lake levels for either releasing or storing water in Lake Mälaren. Henceforth, they will be referred to collectively as the Water Court Decree. The aim of the water court was directed at: 1) maintaining a minimum water level for navigation between the Baltic Sea and Lake Mälaren communities, 2) allowing for controlled releases to avoid high lake water levels resulting in flood conditions, and 3) prohibiting inflow of saltwater from the Baltic during periods of high sea level to preserve quality in the municipal water supply.

In recent years, the water level in Lake Mälaren exceeded levels specified in the water court decrees. In particular, in 2000 the lake level came close to causing major damage to local infrastructure. There is renewed emphasis on examining both the regulation rules for the lake and the hydraulic capacity of the outflow structures. This paper, as a result of activities conducted within the SEAREG project, investigates these issues in the context of how the water level in Lake Mälaren could be affected by climate change. Three contributing components were looked at in detail: 1) changes to hydrological inflows to Lake Mälaren, 2) effects from changes to downstream water levels in the Baltic Sea, and 3) changes in outflow capacity from Lake Mälaren.

Fig. 1. Location and basin maps for Lake Mälaren. Shown with red numbers are the approximate outflow points from Lake Mälaren to the Baltic Sea at 1) Gamla Stan in central Stockholm, 2) Hammarby and 3) Södertälje. Source: P. Graham SMHI.

2 ANALYSIS APPROACH

To carry out the first step of the investigation, hydrological modelling was used to analyze changes of inflow to Lake Mälaren due to climate change. The modified inflows were input into a lake discharge model that simulates in detail the regulation of outflow from the lake to maintain stipulated water levels. The lake discharge model was used to carry out the second and third steps of the analysis, which looked at how climate change could affect operation of the hydraulic structures and resulting lake levels. Although the question of maintaining a minimum water level in Lake Mälaren is also important for future management, this study focused primarily on high water levels and the potential for flooding.

2.1 Future Climate Scenarios

Inputs on changed climate came from regional climate modelling studies performed with the Rossby Centre Atmosphere Ocean Model, RCAO (Döscher et al. 2002). Data from two global general circulation models (GCMs), HadAM3H (Pope et al. 2000) and ECHAM4/OPYC3 (Roeckner et al. 1999), were used as boundary conditions to drive the regional RCAO model (Räisänen et al. 2004). Control simulations of the present climate and scenario simulations of the future climate spanned 30 years, representing 1961-1990 and 2071-2100, respectively. The A2 emissions scenario from the IPCC (Intergovernmental Panel on Climate Change) suite of SRES scenarios (Nakicenovic et al. 2000) was used. Henceforth, these simulations will be referred to as the RCAO-H/A2 and RCAO-E/A2 scenarios for HadAM3H and ECHAM4/OPYC3 driving conditions, respectively.

An integral part of SEAREG included the use of the Rossby Centre Ocean Model for the Baltic Sea, RCO (Meier et al. 1999) to provide estimates of sea level rise for future climate scenarios (Meier et al. 2006, *this volume*). The projected maximum mean sea level rise at Stockholm from these ocean model simulations for the future period of 2071-2100 occurred in winter and was estimated as 46 cm (Meier et al. 2004). Although sea levels can vary considerably during short periods of time, this value was used here in the lake discharge analyses to test the sensitivity of Lake Mälaren regulations to changes in sea level.

3 HYDROLOGICAL ANALYSIS

The hydrological HBV model (Bergström 1995, Lindström et al. 1997) was used to interpret hydrological change from the climate scenarios. This is a conceptual semi-distributed runoff model that was originally developed for operational runoff forecasting. It has since also been used for impact studies both for climate change assessments (Andréasson et al. 2004, Bergström et al. 2001, Vehviläinen & Huttunen 1997) and for water quality (Arheimer & Brandt 1998), and for combinations of the two (Arheimer et al. 2005). Operated on a daily timestep, it includes routines for snow accumulation and melt, soil moisture accounting, groundwater response and river routing. Model inputs are precipitation, temperature and potential evapotranspiration estimated with a temperature index method.

HBV is typically calibrated against river flow observations with the help of an automatic calibration routine to obtain optimal performance in terms of a combination of seasonal dynamics and water volume balance. For Lake Mälaren, this calibration was performed against total inflow to the lake for the period of 1963 to 1990. This resulted in an efficiency criterion, R^2 (Nash & Sutcliffe 1970), of 0.70 and a relative volume error of 0.1 %.

3.1 Linking Hydrology to Climate Scenarios

Transferring the signal of climate change from climate models to hydrological models requires an interface. Although the performance of climate models has improved considerably in recent years, systematic biases still persist in precipitation, the most important climatological variable for hydrological applications. The hydrological impact studies were done with offline simulations from the HBV model, using an observed database as a reference climate. Changes in meteorological variables between the control and the scenario simulations from the RCAO Model were processed in a model interface before being transferred to the observed climate database, as depicted in Figure 2. This can be referred to as the delta change approach (Hay et al. 2000) and is a common method of transferring the signal of climate change from climate models to hydrological models (Arnell 1998, Bergström et al. 2003, Gellens & Roulin 1998, Graham 2004, Middelkoop et al. 2001).

The monthly average relative change in precipitation was smoothed to a 3-month-running-mean and then applied to each daily observation via the interface. As a relative change was applied to an observed database, the method does not alter the number of days with precipitation in the scenario climate. A drawback of this procedure is that information about changes in climate variability is lost in the process. The temperature change was transferred using a set of seasonal linear transfer functions in which the magnitude of the temperature change varies according to the daily temperature in the reference climate. This represents the phenomenon that the change in temperature in the scenarios is strongest at low temperatures and less pronounced at higher temperatures (Andréasson et al. 2004).

Changes in evapotranspiration can be as important as changes in precipitation for the outcome of hydrological impact simulations. To preserve consistency between the climate model simulations and the HBV simulations, actual evapotranspiration calculated from the HBV model was adjusted so that it results in the same yearly increase as given by the respective climate model simulations.

3.2 Hydrological Modelling Results

Both of the RCAO climate scenarios indicate an increase in the future mean temperature over the Lake Mälaren region, with annual values ranging from +3.8ºC to +4.8ºC, as shown in Table 1. Precipitation shows an annual increase of about +10% to +18%, as does evapotranspiration from about +14% to +22%. These changes, when interpreted with the hydrological model, resulted in a decrease in annual inflow volume for the RCAO-H/A2 scenario (-7%) and an increase for the RCAO-E/A2 scenario (+2%).

Regarding changes in seasonality, the hydrological impact simulations showed similar tendencies towards higher autumn and winter inflows, although the magnitude of changes differed depending on scenario, as shown in Figure 3. Winter precipitation, which in the present climate often accumulates as

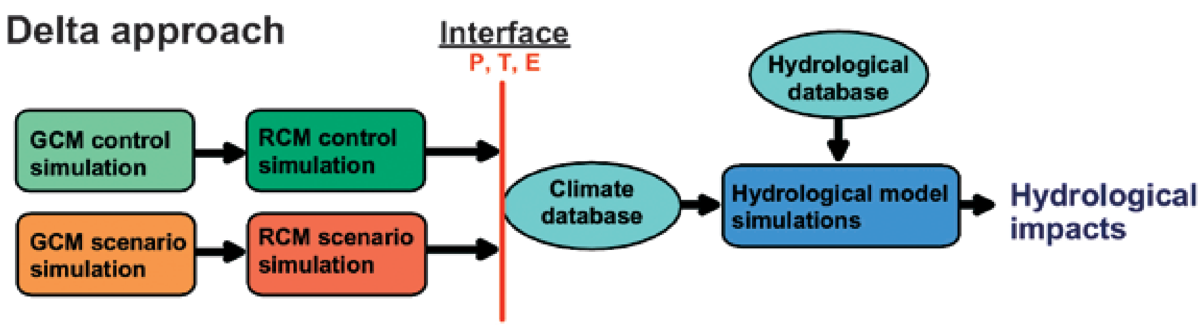

Fig. 2. The analysis chain for assessments of hydrological impacts from climate change simulations (P = precipitation, T = temperature, E = evapotranspiration). Source: J. Andréasson SMHI.

Table 1. Mean annual change in temperature, precipitation and evapotranspiration from RCAO climate scenarios for the Lake Mälaren drainage basin. The change in mean annual inflow to the lake resulting from HBV hydrological modelling is also shown.

Variable	RCAO-H/A2	RCAO-E/A2
Temperature (°C)	3.8	4.8
Precipitation (%)	6.3	14.9
Evapotranspiration (%)	14.4	22.1
Inflow (%)	–6.7	2.4

Table 2. Percent change in peak magnitude for the 100-year inflow to Lake Mälaren from two climate change scenarios.

Period	RCAO-H/A2	RCAO-E/A2
Spring	–13	–16
Autumn	15	51
Year	–14	–12

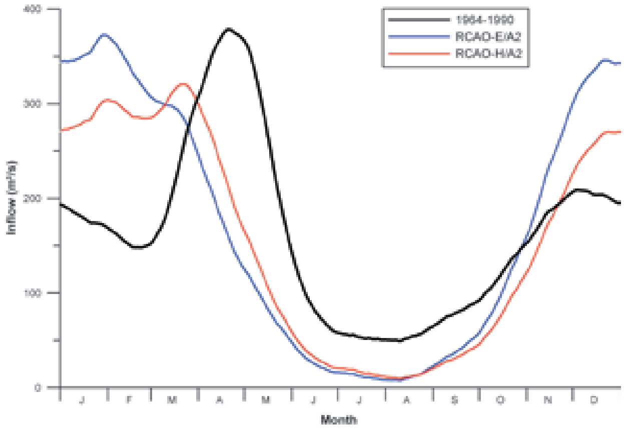

Fig. 3. Modelled seasonal river inflow to Lake Mälaren from HBV simulations for present-day conditions (1964-1990) and two climate change scenarios (representing 2071-2100). Shown are smoothed daily means over the modelling period. Source: J. Andréasson SMHI.

snow, fell mostly as rain in the hydrological impact simulations, resulting in a reduction in the spring peak flow in the mean hydrographs. Inflow during summer was considerably lower for both hydrological impact simulations.

The changes in seasonality were also reflected in the results from a frequency analysis using the Gumbel distribution. The inflow corresponding to a return period of 100 years was evaluated on an annual basis, as well as for spring (January-July) and autumn (August-December), as shown in Table 2. The scenarios show a decrease in the magnitude of the 100-year spring flood and an increase in the 100-year autumn flood. The change was so large that the scenarios also show a shift for the occurrence of the highest flood from spring to autumn.

4 LAKE DISCHARGE ANALYSIS

Due to the number of structures involved and the specifications outlined in the Lake Mälaren Water Court Decree, it is not a simple matter to calculate the discharge from the lake at a given point in time. A model was therefore set up that simulates the different physical and legal conditions required in regulating the water level of the lake. This incorporates the specific hydraulic equations of all of the hydraulic structures together with appropriate timing of releases as dictated by water level according to the Water Court Decree.

Lake Mälaren has its own elevation reference system that is based on the threshold of Karl Johan Lock located just south of Gamla Stan. This is the defined “zero” point for this system, which corresponds to an elevation of -3.48 masl in the RH70 elevation reference system. Lake water levels are typically expressed in centimeters, so that the mean lake water level is 414 cm in the Mälaren reference system (i.e. 66 cm above mean sea level). All results from the lake discharge modelling are given in the Mälaren reference system.

4.1 Regulating Lake Mälaren

According to the Water Court Decree, Lake Mälaren should be regulated under normal conditions such that the water level is maintained at a desired target of 415 cm, and with high inflows should not be allowed to exceed 470 cm. Navigation locks and floodgates control the outflow of water from Lake Mälaren at four different locations as mentioned above. These are shown as three points on the map in Figure 1 since the two central Stockholm points are quite close to each other. In total, there are eight different hydraulic structures that are used in combination to regulate lake levels, as listed in Table 3. As four of these are locks used for navigation, the Ports of Stockholm is the agency in charge of coordinating all of Lake Mälaren's regulation structures.

The combined outflow capacity from these hydraulic structures is currently estimated at 710 m^3s^{-1} for average water levels, but this capacity varies according to the water levels in both Lake Mälaren and downstream in the Baltic Sea. At a water level of 470 cm (target maximum), this can reach more than 840 m^3s^{-1} for a low water level in the Baltic. However, at a high water level in the Baltic, this can be less than 710 m^3s^{-1}. If water levels exceed the desired maximum of 470 cm, outflow capacity can attain higher values.

An important stipulation of the Water Court Decree is that outflow through each of the locks at both Hammarby and Södertälje should not exceed 70 m^3s^{-1}. Although higher flows are physically possible, doing so results in excess velocities in the downstream channels that can cause scour erosion and lead to safety problems. This has happened on occasion, but only under emergency conditions; it should be avoided whenever possible.

4.2 Existing Flood Studies

For preparedness planning, coarse scale overview maps of floodplain extent were previously created by SMHI for the Swedish Rescue Services (SRV 2001). These maps are based on hypothetical extreme inflows to Lake Mälaren that were calculated to represent both the 100-year design flood and the estimated maximum probable flood (MPF). According to this study, water levels in Lake Mälaren's reference system resulting from these two design floods would reach 480 cm (1.32 masl) and 563 cm (2.15 masl), respectively. These two levels were used in SEAREG flooding sensitivity studies by Viehhauser et al. (2006, *this volume*).

Table 3. Locks, floodgates and estimated outflow capacity under normal operating conditions for the regulation of Lake Mälaren. The numbers under location correspond to the numbers shown on the map in Figure 1.

Location (no. on map)	Name	Approximate Capacity (m^3s^{-1})
Norrström (1)	Riksbron	200
(north of Gamla Stan)	Stallbron	100
Slussen (1)	Karl Johan Discharge Canal	120
(south of Gamla Stan)	Karl Johan Lock	140
Hammarby (2)	Skanstull Culvert	5
	Hammarby Lock	70
Södertälje (3)	Södertälje Lock	70
	Maren Culvert	5
	Total	710

4.3 Lake Discharge Modelling Results

To confirm that the lake discharge model could reasonably represent actual operations, it was first tested with observations as input. The high inflow situation from the year 2000 was chosen as a case study. Results are shown in Figure 4. As seen in the plot to the left in the figure, operations can be simulated with good accuracy as demonstrated by the close match between simulated and observed water levels. The maximum level reached was 473 cm, with a simulated total outflow of 851 m^3s^{-1}. This was achieved by knowingly violating the guidelines for releases stipulated in the Water Court Decree. Specifically, releases were begun at some locks before the specified water levels were reached. In addition, the flow capacity at both Hammarby and Södertälje locks were allowed to exceed the stipulated 70 m^3s^{-1} limit. These violations were also made in reality, so the simulations mimic actual operations.

If the Water Court Decree had been strictly followed during this event, the water level for Lake Mälaren would have reached higher levels. This was reproduced with a simulation by the lake discharge model as shown by the red curve in the plot to the right in Figure 4. As a simple sensitivity study, the observed water levels in the Baltic Sea were increased by 46 cm, which resulted in the blue curve on the same plot. The corresponding maximum water levels for these two cases are 478 cm and 483 cm, respectively.

For the investigation of the influence of climate change on water levels in Lake Mälaren, the hydrological results described above were fed into the lake discharge model. Figure 5 shows results from both RCAO scenarios. The simulations mimic the actual operations that occurred during the 2000 event, which means that the Water Court Decree was violated. As the figure shows, water levels rose to 478 cm (maximum discharge of 864 m^3s^{-1}) for the RCAO-H/A2 scenario and 515 cm (maximum discharge of 900 m^3s^{-1}) for the RCAO-E/A2 scenario.

If the Water Court Decree was strictly followed in the changed climate, water levels for Lake Mälaren would be as shown in Figure 6. This figure shows results using both observed Baltic sea level and sea level with a 46 cm increase according to the climate scenarios. The resulting levels are 478 cm (maximum 816 m^3s^{-1}) and 520 cm (maximum 981 m^3s^{-1}) for existing sea level, and 490 cm (maximum 806 m^3s^{-1}) and 527 cm (maximum 976 m^3s^{-1}) for increased sea level for the RCAO-H/A2 and RCAO-E/A2 scenarios, respectively. Note that results for RCAO-H/A2 using observed sea level are the same regardless of whether actual (Figure 5) or the Water Court Decree (Figure 6) operating rules are used.

Analysis of the required outflow capacity that would keep the lake water level from exceeding 470 cm for this event was also performed, as presented in Figure 7. The required outflow capacity was 933 m^3s^{-1} for the RCAO-H/A2 scenario and 1237 m^3s^{-1} for the RCAO-E/A2 scenario. Although 470 cm was not exceeded, the figure shows that long periods of high water level still occurred. For instance, periods that the water level exceeded 450 cm and 460 cm are up to twice as long for the future climate than for observations of the actual event.

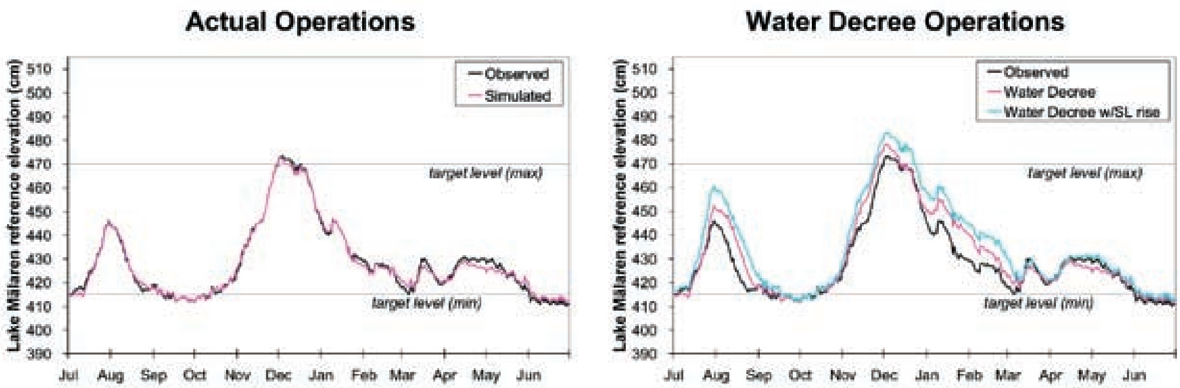

Fig. 4. Water levels in Lake Mälaren from lake discharge modelling of actual conditions for the high water event in December 2000. Shown to the left are simulated actual operations. Shown to the right are simulated operations that strictly follow the water decree for observed Baltic Sea level and an increase in the Baltic Sea level of 46 cm. The desired operational water levels for high and low flow conditions are identified as "target levels" on the plot. Source: P. Graham SMHI.

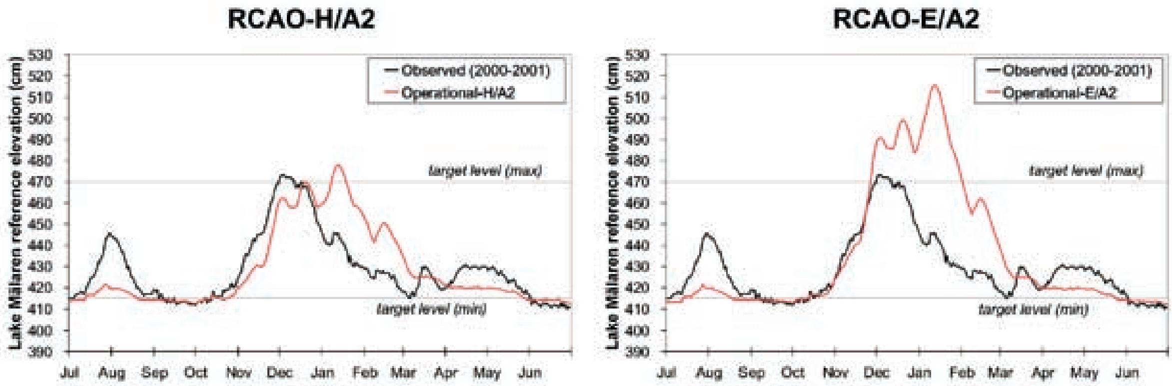

Fig. 5. Water levels in Lake Mälaren from lake discharge modelling of future climate conditions using operational rules that mimic actual conditions (i.e. as in the plot on the left in Figure 4). Results are shown for both the RCAO-H/A2 scenario (left) and the RCAO-E/A2 scenario (right). These simulations represent the year 2000 modified with climate change scenarios. Source: P. Graham SMHI.

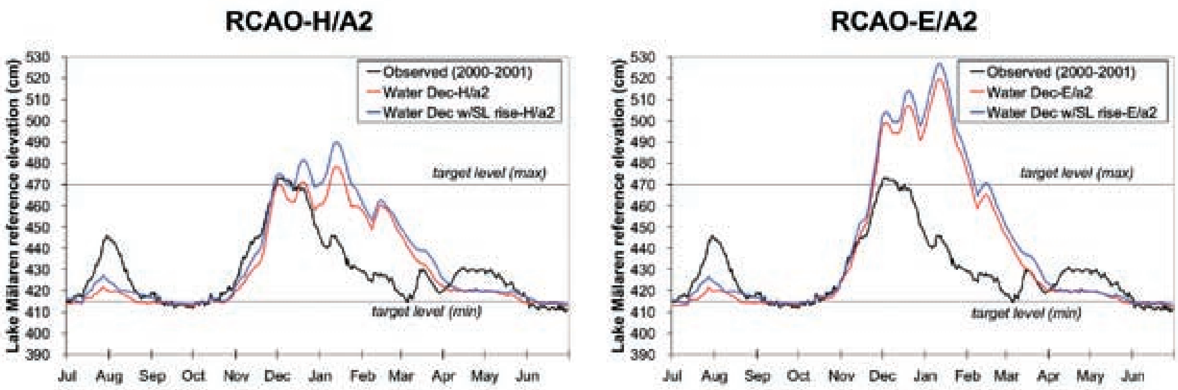

Fig. 6. Water levels in Lake Mälaren from lake discharge modelling of future climate conditions with strict adherence to the water decree (i.e. as in the plot on the right in Figure 4). Shown in red are results with observed Baltic Sea level and in blue for an increase in Baltic Sea level of 46 cm. Results are shown for both the RCAO-H/A2 scenario (left) and the RCAO-E/A2 scenario (right). These simulations represent the year 2000 modified with climate change scenarios. Source: P. Graham SMHI.

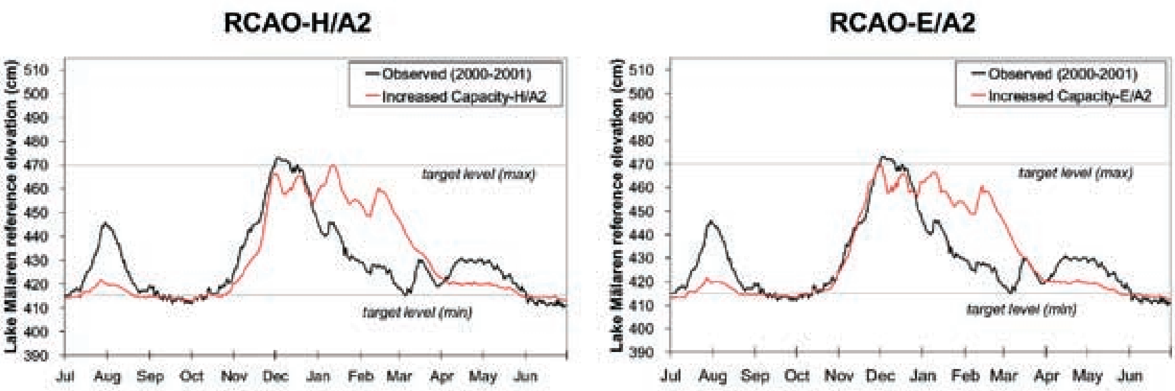

Fig. 7. Water levels in Lake Mälaren from lake discharge modelling of future climate conditions with increased outflow capacity from the lake. No increase in sea level was assumed. Results are shown for both the RCAO-H/A2 scenario (left) and the RCAO-E/A2 scenario (right). These simulations represent the year 2000 modified with climate change scenarios. Source: P. Graham SMHI.

5 SUMMARY AND DISCUSSION

This work focused on investigating the effects of changed climate on the water level in Lake Mälaren by examining a specific inflow event in detail. By using a combination of hydrological modelling and lake discharge modelling, simulations of the expected response could be made. The results present a depiction of how this observed event would vary given the changes in climate simulated by two future scenarios. This does not represent the most extreme inflows that can occur within the Mälaren basin as no attempt was made here to represent either the 100-year flood event or the maximum probable flood.

Regarding the characteristics of inflows during the year 2000 event, results from the hydrological analyses indicate that this type of autumn, high flow event will likely become more common with the future climate. Results of both the change in the pattern of mean inflow shown in Figure 3 and the change in the magnitude of autumn 100-year inflows in Table 2 suggest this. This means that even if the magnitude of the annual 100-year inflow decreases, as is the case for both scenarios, the risk for flooding events can still increase due to enhanced autumn inflows. Of more importance than the actual magnitude of peak inflows is how long inflows of relatively high magnitude are sustained, as it is the total inflow volume over a given period that can give rise to lake flooding. A compounding effect is that as autumn progresses, temperatures drop and evapotranspiration from both Lake Mälaren and upstream lakes will tend to decrease at the same time as increased inflows are expected.

The lake discharge model results confirm that under actual operations it was necessary to deviate from the Water Court Decree to maintain desired water levels. Had this not been done, the water level in Lake Mälaren would have risen another 5 cm (478 cm) during the year 2000 event, as shown in Figure 4. Had the sea level been higher, the Lake Mälaren level could have risen another 5 cm to a total of 10 cm (483 cm) above that observed. This corresponds to a level that exceeds the present-day estimated 100-year flood level by 3 cm.

Considering simulations for the future climate, applying the relaxed operational rules used during the actual year 2000 event would still result in higher water levels than desired, by some 5 cm (478 cm) for the RCAO-H/A2 scenario and some 47 cm (520 cm) for the RCAO-E/A2 scenario. A simultaneous rise in sea level would increase these values to 17 cm (490 cm) and 54 cm (527 cm), respectively, as shown in Figure 6. These levels exceed the present-day estimated 100-year flood level, but are still far below the estimated level for the maximum probable flood. To get a perspective on the extent of potential damage due to such flood levels, Viehhauser et al.(2006, *this volume*) used GIS techniques to prepare floodplain maps of both the 100-year and maximum probable flood levels.

With an increase in discharge capacity and modifications to the operating rules specified in the Water Court Decree, it was possible to keep the water level of Lake Mälaren from exceeding the target of 470 cm, as presented in Figure 7. For these lake discharge simulations, the maximum outflow required was 930 m^3s^{-1} and 1240 m^3s^{-1} for the RCAO-H/A2 and RCAO-E/A2 scenarios, respectively. In relative terms, additional capacity of some 70 m^3s^{-1} or some 340 m^3s^{-1} was required for the RCAO-H/A2 and RCAO-E/A2 scenarios, respectively. The effect of an increase in sea level occurring at the same time would inhibit increases in outflow capacity, which implies that an even larger capacity would be required. Again, these numbers only correspond to this specific event, which is of lower magnitude than both the 100-year and maximum probable flood events.

The two future climate scenarios used here represent realizations of the same SRES-A2 emissions scenario as specified by the IPCC. Differences in the two originate primarily from model differences in the two GCMs used to generate the global scenarios. Both are state of the art models and it is not currently possible to determine if one is more likely to occur than the other. Thus, these differences represent the range of uncertainty currently associated with studies of this kind. There is, in addition, uncertainty originating from the hydrological modelling. Examination of hydrological results generated by using the control simulations indicates that the scenario inflows may tend to be underestimated in the hydrological model. In other words, the increased inflows from the changed climate may represent the lower bound of uncertainty and future inflows could be even higher than indicated here.

As mentioned above, no attempt was made here to re-calculate how climate change may affect the design floods that form the basis for extremes used in existing floodplain mapping. Such calculations are not trivial to perform and were outside the scope of this study. However, work to do this has been initiated and results will be available in the near future.

6 CONCLUSIONS

From this work, valuable tools have been developed that can assist in planning for both present and future operations of the water level in Lake Mälaren. The hydrological component provides for evaluation of hydrological change to inflows to Lake Mälaren and will be used in continuing studies to better define changes to extreme inflows. The lake discharge component provides a tool that represents both the physical and legal structures of regulation from Lake Mälaren and can be used to further evaluate scenarios of changes in the physical structures as well as modifications to operating rules.

A summary of specific conclusions for Lake Mälaren concerning high flow situations follows below:

- Increased sea level in the Baltic can influence water levels in the lake, however, increased hydrological inflows show a greater impact on lake water levels than increases in sea level.
- Future climate scenarios indicate increased runoff inflow to Lake Mälaren during autumn and winter, and decreased inflow during spring and summer.
- Changes in climate will likely require modifications to the operational rules for regulating the lake.
- An identified need for increased discharge capacity from the lake for the present climate does not decrease with scenarios of future climate change.

Acknowledgements

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IMPACTS OF FUTURE CLIMATE CHANGE AND SEA LEVEL RISE IN THE STOCKHOLM REGION: PART II - GIS ANALYSIS OF FUTURE FLOODING RISKS AT REGIONAL AND MUNICIPAL SCALES

by
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Viehhauser, M., Larsson, K. & Stålnack, J. 2006. Impacts of future climate change and sea level rise in the Stockholm Region: Part II - GIS analysis of future flooding risks at regional and municipal scales. Geological Survey of Finland, Special Paper 41, 143–154, 8 figures and 1 table.

The potential for flood damage due to future climate scenarios were analysed for both the Baltic Sea coast areas of Stockholm County and Lake Mälaren. GIS and vulnerability assessments for both areas indicate a potential for only minor damage. However, this investigation only provided a rough assessment of the effects along the Baltic Coast and used only two specific water levels in Lake Mälaren as indicators of potential flooding. Strong involvement of participants from all parts of the Stockholm-Mälar region led to an increased understanding that flood risks must be considered with more systematic application in the design of municipal plans, regional supervision of local plans, and risk management.

Key words (GeoRef Thesaurus, AGI): climate change, floods, risk assessment, coastal environment, sea level changes, lakes, lake level changes, geographic information systems, Stockholm, Lake Mälaren, Sweden.

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1. INTRODUCTION

This case study includes two areas of analysis: the Baltic Sea coast of the Stockholm County including the Stockholm Archipelago islands and Lake Mälaren, which drains into the Baltic Sea at Stockholm and Södertälje. The Stockholm Mälar region was chosen for this study because of its high population and infrastructure densities compared to the rest of Sweden. The high monetary values of existing spatial structures and many ongoing real estate projects gave rise to two issues that have been assessed: 1) how will higher Baltic Sea levels due to climate change affect the coastal areas and 2) where is potential flooding likely in case of high water levels in Lake Mälaren?

Important for the regional case study was the co-operation with concerned regional and municipal stakeholders, with a focus on spatial planners. This co-operation had several practical objectives, as listed below:

- Raise the awareness among planners and decision-makers concerning climate change, sea level rise and potential flooding risks.
- Communication of climate modelling and flood-risk results and uncertainties through newsletters, seminars, presentations at conferences and result discussions with concerned actors.
- Support of various actors, including all spatial planners, risk managers and technical administrations, to include flooding issues in ongoing work processes.
- Maximise the usefulness of SEAREG results in the region through addressing specific questions from various stakeholders.

Major input to the GIS and vulnerability assessments came from the Rossby Centre Regional Climate Model, land uplift estimates and modelled estimates of future changes in runoff to Lake Mälaren, as described by Meier et al. (2006) and Graham et al. (2006), *this volume*.

2. METHODOLOGY

The central task was the production of regional and local GIS-maps. A regional GIS model (scale 1:50,000) was used for an overview assessment of the Baltic coast areas and Lake Mälaren. The regional GIS model's vertical accuracy was only 0.5 m, the horizontal grid lengths is about 50 – 100 meters. The resulting assessments were therefore uncertain and only usable for general reflections. However, they identified potential risk areas, which were the basis for selected local GIS assessments. This approach made it possible to discover "hot spots" and to determine local needs. Municipal needs generally included: more detailed maps of potential risk areas and local vulnerability assessments.

The used municipal data of selected municipalities was of much better quality (accuracy varies between 2 and 25 cm vertical resolution) and allowed detailed studies of flood risk areas. The scales are between 1:1,000 and 1:5,000. The identified flooding areas were matched with relevant spatial data such as population, work places, infrastructure, housing estates, industrial sites, waste deposits and other spatial facilities.

Problems with the GIS models and data have been:

- Accuracy – regional height data is only useful for very general analysis, and even the municipalities' height data must be regarded critically due to partly insufficient exactness.
- Reliability – GIS data alone often only reflect an "electronic" truth, local surveys and discussions with local planners must complete the digital height model results.
- Usability – the achieved results have to be included in planning activities for example, the usage is dependent on the quality and fulfilment of the prior in-data.

An important part of the work has been the collaboration with regional and local stakeholders. The crucial input to the project was the delivery of relevant height and spatial data by the municipal and regional authorities. A dissemination strategy supported the co-operation. Continuous contacts with certain actors from the beginning of the project, focused meetings and dissemination activities (e.g. newsletters) helped to understand the actors' needs and at the same time spread information about climate change, uncertainty and related future flooding risks. The approached used is shown in Figure 1.

3. FLOODING RISK DUE TO SEA-LEVEL RISE AT STOCKHOLM'S BALTIC COAST AND ARCHIPELAGO

There is no overall national legislation specifically for coastal zone planning in Sweden. The crucial legal framework is the Environmental Code (1999) and the Planning and Building Act (1987), which apply to both terrestrial and marine areas. According to the Planning and Building Act, chapter 3, all municipalities must produce a comprehensive plan that covers their entire area and can be used as a decision making tool. A major part of the coastal zone has been identified as an area of national interest (Environmental Code, chapter 4) and there are many planning restrictions within these zones but no strict set back line rules.

The management provisions in the Environmental Code include regulations on placement of new industrial installations, tourism and recreational functions and restrictions on summer cottage developments. Shore protection strictly comprises all land and water areas (inland and off-shore) up to 100 meters from the shoreline (Environmental Code, chapter 7). This can be extended to 300 m in individual cases. No height measurements are related to the protection rules, and future sea level changes are not considered in the regulations. The detailed definition of the various coastal zones is a task for comprehensive municipal (physical) planning.

The officials in the municipalities along the inner Baltic coast and in the Stockholm Archipelago know about the temporary flooding risks of the Baltic Sea. However, there are reports of many new housing estates along beautiful shore areas that are very close to the shoreline. This might include high risks of flooding especially when sufficient height measures are not given (Figure 2). The map below shows potentially affected current real estate due to a sea level rise of 0.5 m and 1 m. It shows a lot of affected real estate, but in reality often only the non-built areas of estates are affected, not houses. Therefore, further assessments do not appear to be worth doing, instead flooding risk assessments concerning Lake Mälaren were made.

The highest Baltic water level since measurements in Stockholm was in winter 1983, when the sea rose 1.16 m relative to the normal water level. This was due to extreme low pressure over the Baltic, which

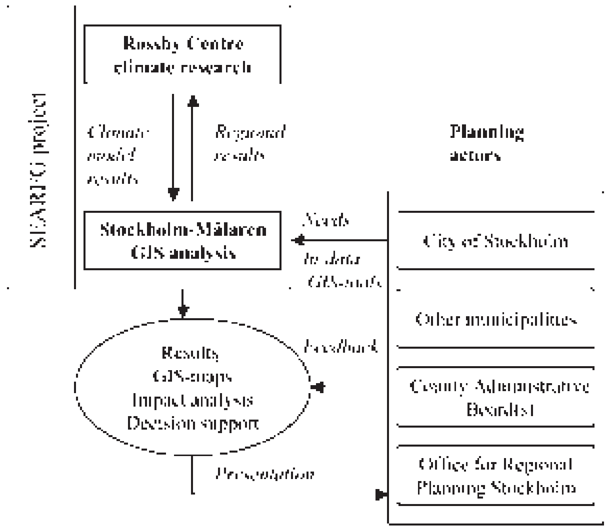

Fig. 1. Co-operation approach in the Stockholm-Mälar Region. Source: Inregia.

quite frequently occurs during winter periods. The high water level caused no major problems to the harbour facilities (piers are higher than 1.8 m) or other shorelines, while saltwater intrusion into the Lake Mälaren was observed. This indicates that a future sea level rise of 0.5 m and extreme winter conditions probably does not cause important risks according to the high case scenario. Coastal protection has a long tradition in Sweden. Thus, real estate and other spatial facilities are only built directly at or near the shoreline in exceptional cases. In combination with the constant land uplift, the risk of flooding due to a higher sea level in the future is very small. According to planners in the Stockholm Archipelago's municipalities, the construction of buildings, marinas or port facilities always includes a sufficient margin. However, in the mid-Stockholm Archipelago a lot of real estate is quite close to the shores and their vulnerability has to be further assessed. Moreover, the impact of coastal storm surges on the outer Stockholm Archipelago can widely exacerbate the sea level rise.

4. FLOODING RISKS AROUND LAKE MÄLAREN

The hydrological situation of Lake Mälaren for both present and future climates is described by Graham et al. (2006), *this volume*. The project's regional mapping of potential flood prone areas of Lake Mälaren is comparable to the results of the flood mapping made by the Swedish Rescue Service Agency (SRV 2001). The results of this broad GIS assessment show those areas that need to be further assessed to analyse risks and vulnerabilities. Basically, all municipalities around Lake Mälaren are more or less concerned, but four were chosen within this project.

The importance of Lake Mälaren as a water resource (Stockholm Water 2001) and highly attractive living area is well described (e.g. Tilly 2000 and 2001). At present, a large number of new housing estates are built close to attractive waterfront areas around Lake Mälaren. Also, many of the current summer residences near the water are being converted to permanent housing. However, discussions with municipal planners showed that the authorities rarely use flooding scenarios for the planning of housing estates despite the fact that flood risks have to be considered both in comprehensive and detailed planning. High water levels, near a 100-year flood (Lännergren 2000), reminded the public in the Stockholm-Mälar region and also the responsible planning institutions that flooding risks are of relevance.

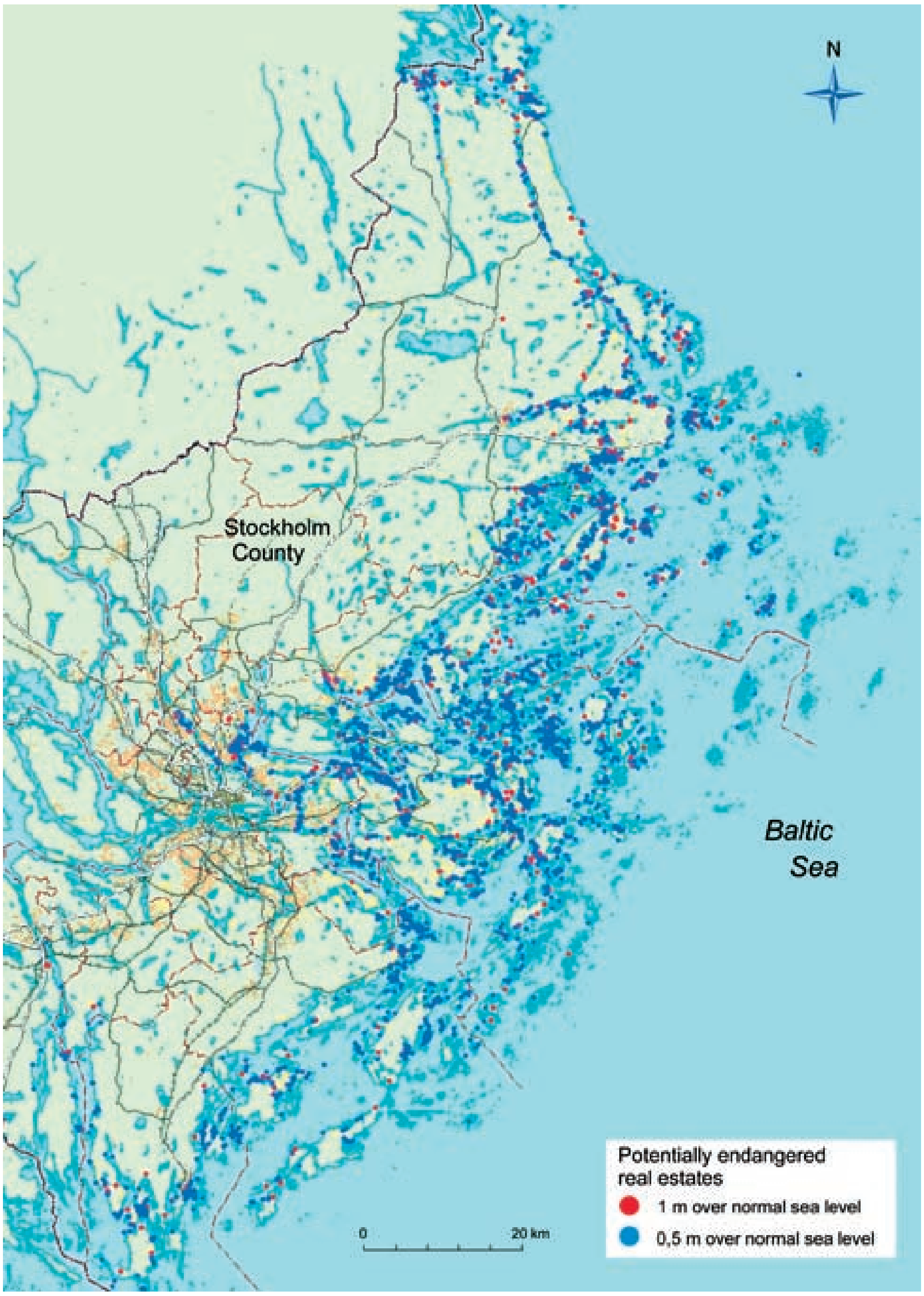

Fig. 2. Potentially affected real estate due to future sea level rise in the Stockholm Archipelago (blue dots: 0.5 m and red dots + 1m over present mean sea level)[1]

[1]All maps except those for City of Stockholm: Copyright – Ur Terrängkartan och Översiktskartan © Lantmäteriverket Gävle 2002, medgivande M2005/2186

4.1 Assessment of flood risks

Due to the uncertainty associated with evaluating climate change impacts (Bergström et al. 2001, Gardelin et al. 2002), no single value can be placed on how inflows to Lake Mälaren will change in the future. This fact, combined with different future operating strategies for regulating outflow from the lake, leads to a range of potential lake levels for future conditions, as presented by Graham et al. (2006), *this volume*. Rather than trying to map all of the possibilities, the impacts of floods were analysed in two specific cases. These cases could then be used as an index for comparison to future water level projections. The two flood situations used in the GIS assessments were the 100-year flood and the maximum probable flood defined by previous studies (SRV 2001). These correspond to the following in Lake Mälaren's height system (mean water level is 4.15 m):

- 100-year flood is at a level of 4.80 m or 0.65 m over the Lakes' mean water level
- Maximum probable flood at 5.63 m or 1.48 m over mean water level.

As it is uncertain at exactly what water level damages begin occurring, future work would benefit from more sensitivity studies to comprehensively map the extent of flooding at regular vertical intervals. For example, if one chose the interval of 0.2 m, flood risk maps for the levels 5.0, 5.2, 5.4 and 5.8 m could be produced to complement those presented here. Analysing such maps would provide insight into determining critical thresholds where damages occur.

The continuous measuring of Lake Mälaren's water level is interesting for many stakeholders in the city. The guarantee that the water levels are kept within the margins of the water decree is an important precondition for many sectors like the harbours, the water supply, the inland water shipping and not at least for real estate owners (Wedin & Björklund 2001).

The performance of the locks in Stockholm and Södertälje is crucial for these areas. Today's maximum estimated outflow of 710 m^3/sec will be insufficient in the future, as stated in Graham et. al 2006 *(this volume*). This value can actually be higher depending on the downstream water level in the Baltic Sea. Estimates based on extremes for the present climate indicate that close to a double the present capacity is needed. Estimating the maximum discharge capacity needed for the future climate was beyond the scope of SEAREG.

One current new construction plan for two of the locks, the so-called Slussen project in Stockholm, is one step towards higher outflow capacities. Two recently renovated lock gates do not implicate higher capacities. Thus, the Slussen project has to provide a much higher outflow than today's maximal capacity of 310 m^3/sec. This is recognised in the preconditions of the new lock and outflow canal's architectural design. The finalization of the new construction is expected, at the earliest, in the year 2015.

4.2 Four municipal vulnerability assessments

Based on these assumptions, a series of GIS based assessments were made for four municipalities. The results have been commented upon and discussed with municipal planners and other concerned experts.

The four municipalities and cities have the following characteristics:

- Ekerö, four major islands, rural municipality with two major settlements and many smaller settlements and farms, 23,000 inhabitants
- Stockholm, dense urban environment with many crucial infrastructure facilities, many housing areas along shores, seven major densely populated islands, 758,000 inhabitants
- Uppsala, dense urban settlements along Fyrisån, 182,000 inhabitants
- Västerås, dense urban settlements along the water fronts, 131,000 inhabitants

3.2.1 Ekerö

Due to its morphology the municipality of Ekerö is especially exposed to flooding events. Large areas are former lake bottoms that, in historic times, fell dry due to the steady land uplift (0.4 m in 100 years). More than 140 islands make travelling and goods supply difficult. Big parts of the municipality's land area (213 km^2) are either open areas such as natural zones or nature protection zones or agricultural areas. Many new dwellings (around 100 single family dwellings and 30 multi-story dwellings per year through the last years) are constructed in areas near the water.

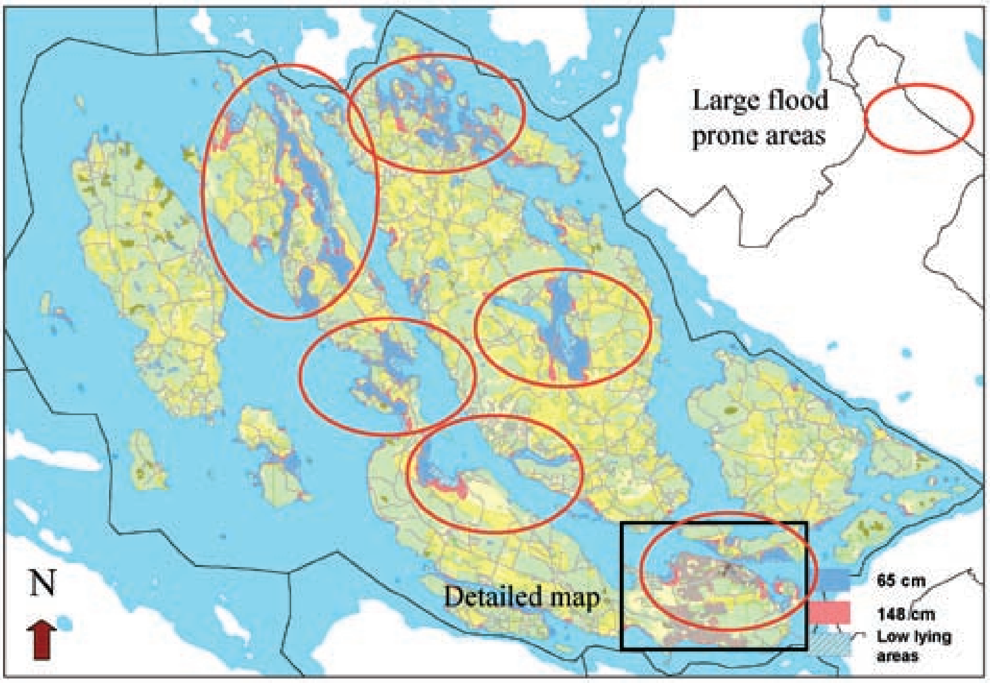

Fig. 3. Overview map of Ekerö municipality showing two flood levels.

The conducted GIS based vulnerability assessment showed that large parts of Ekerö would be flooded, even at a level of + 0.65 m. However, high water levels are quite common for Ekerö and people are used to the fact that larger areas stand under water, especially during late winter and early spring. Most of these concerned areas are not used economically and such minor flooding events do not bring any harmful effects.

At +1.48 m above normal water level around nine percent of the municipality's surface risk flooding (compare Table 1 and Figure 3). During Lake Mälaren flooding events, it is typical for the water levels to rise and fall slowly. Flooded areas can be under water for days or even weeks. Mostly affected is arable land, pastureland and woods and about 18 km^2 would be under water in the high case scenario. Some housing areas, mostly summer cottage zones are concerned. Some industrial estate may also be impacted by such a potential flood event. However, only a shipyard at the northern part of Färingsö, will be most affected. The very low lying northern parts of Färingsö are widely affected with many summer houses flooded and parts of Färingsö becoming small islands in the flood water (particularly areas of Händaskär and Hända). Even bigger parts of Munsö would be flooded as shown in the figure below.

The vulnerability of Ekerö is relatively low despite large overflowed areas as shown in the table below. There exists a certain isolation risk for some parts of the islands, which only have one access road. However, most roads have an own embankment, meaning they are situated on a higher level than the surrounding surface. These embankments are, however, endangered through possible destabilisation due to water damages. High water levels do not negatively

Table 1. Affected land use types (in ha) due to flooding in Ekerö municipality.

Land use type	+0.65 m (ha)	% of total area	+1.48 m (ha)	% of total area	Total area (ha)
Housing	1	0	3	1	340
Industry	1	4	4	15	27
Arable land	501	8	797	13	6 195
Pastureland	111	8	484	14	3 500
Conifer. woods	192	2	394	4	10 737
Hart woods	111	21	174	34	518
Total	1 102	5	1 856	9	21 316

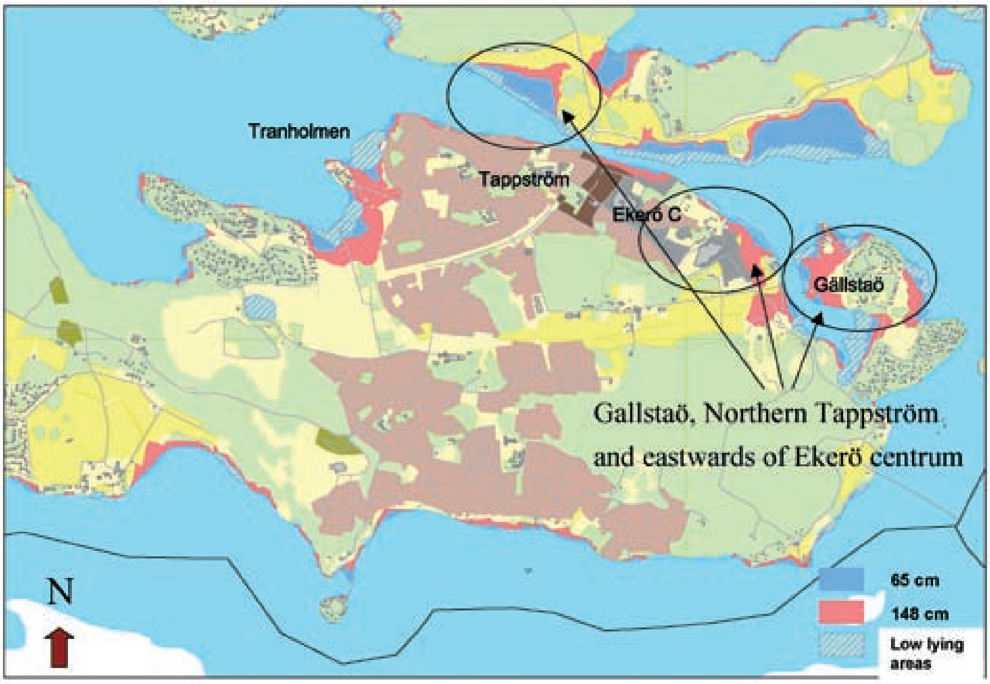

Fig. 4. Ekerö centrum / Tappström, one of two major settlements of the municipality.

affect technical infrastructure, such as the sewage plant, telecom, electricity facilities and car ferry harbours. However, while higher floods influence many marinas, the damage risks are small.

Basically all farms are situated on higher land sites, thus there is no immediate flooding risk. The situation for up to 100 summer cottages is different as they are situated on low sites close to the water. At a level of 1.48 m over normal level, 60 permanent houses might be affected. The GIS based assessment still cannot estimate how these buildings are concerned or analyse which real damage risks exist.

One of the municipal's water protection areas, northern Munsö, which is quite close to Lake Mälaren, can be affected through a higher flooding event due to infiltration of surface water into the ground water. The water quality in private wells can also be impaired. Only 17,000 of 23,500 estates are part of the municipal sewage and fresh water supply system. How the private sewage systems will be affected depends on their location and state.

Ekerö's farmers might have problems when flooding events occur in autumn instead of spring. The autumn sown grain is affected. High humidity levels throughout the winter and spring impair the fieldwork during springtime and there are risks that such areas are not cultivable. The biological effects of flooding of open spaces and woods are positive as it contributes to the maintenance of wetlands and swampy areas.

Most of the Mälar and Ekerö municipalities plan and allow new construction quite close to the water. The coastal protection regulation, 100 – 300 m protection zones inward from the water line, has to be followed. In its new comprehensive plan, Ekerö suggests new housing areas in very low-lying areas near the water (examples of new building sites: Gallstaö, northern Tappström and eastwards of Ekerö centrum, see Figure 4). The municipality's risk margin for flooding is 1.6 m over the normal water level or 0.1 m higher than the anticipated maximum probable flood level. New detailed plans contain regulations that take this margin into account. Moreover, the municipality together with the road authority works to adapt the island's road network so that embankments withstand upcoming flooding events.

4.2.2 Stockholm

Stockholm's comprehensive plan from 1999 does not mention flood risks (City of Stockholm 2000). As no major flood events occurred since the start of the Lake Mälaren regulation, flooding within the city's various administrations is not a priority issue. So far, flooding is not a part of the planning routines, but is recognized as important to include in the work for the next comprehensive plan, which starts during 2005 (pers. comm. B. Göransson, Planning department, City of Stockholm).

Many low-lying areas in Stockholm are situated in potential flood plain areas of Lake Mälaren (see fig-

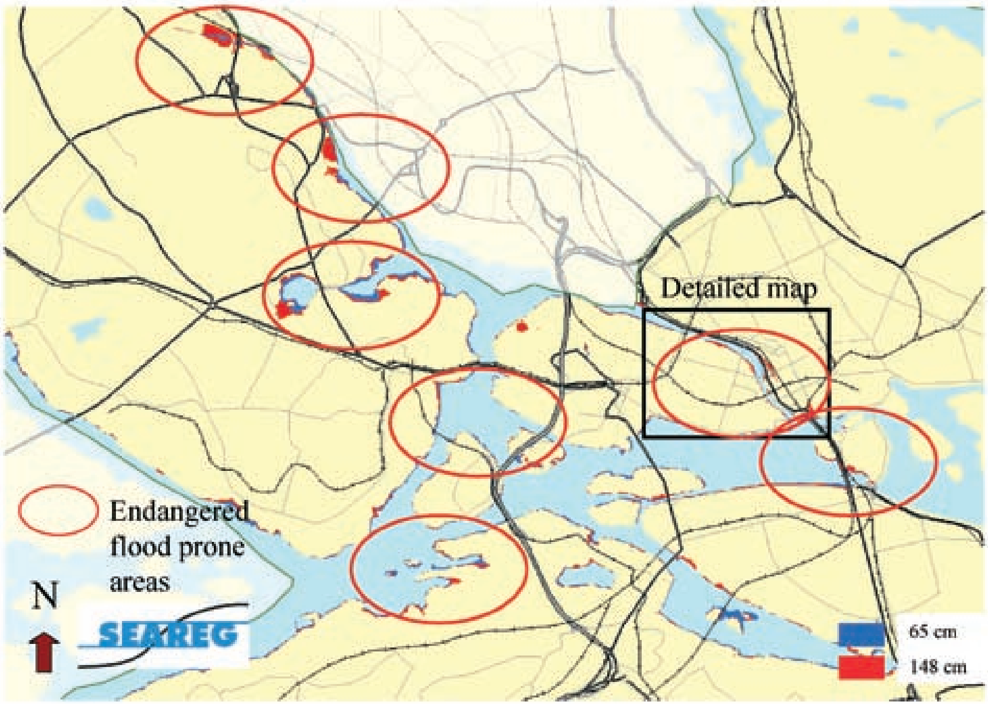

Fig. 5. Overview map of Stockholm with endangered areas. Source: City of Stockholm.

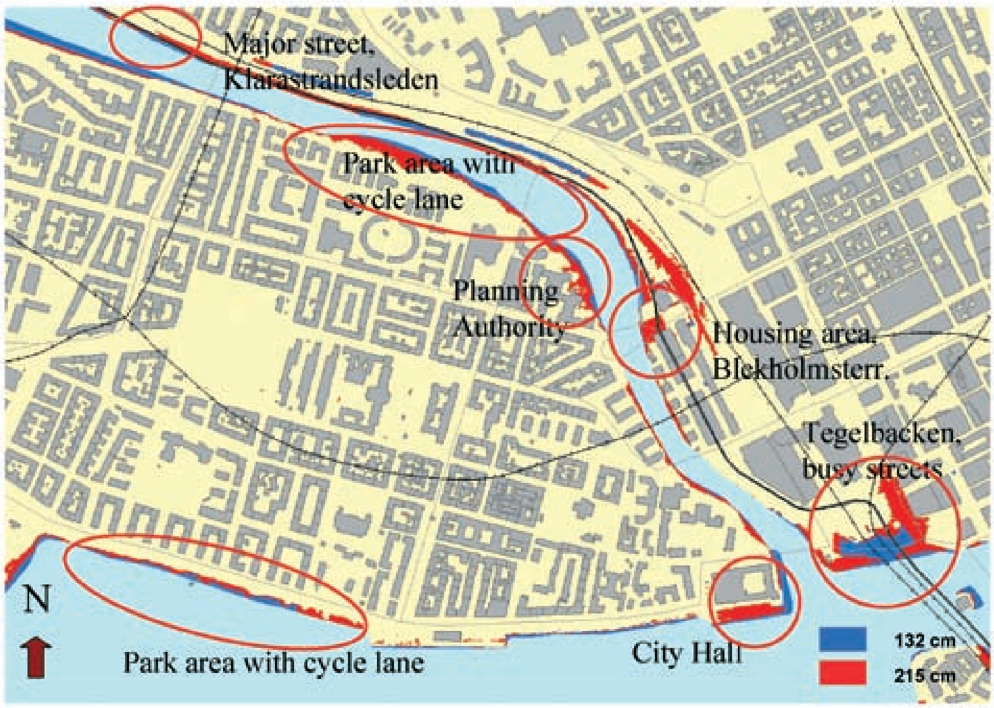

Fig. 6. Example of Stockholm's inner city area, as one of the endangered flood prone areas. Source: City of Stockholm.

ure above). Flood risk areas in the city of Stockholm are of particular interest as the area is very densely populated and has many important infrastructure facilities.

At a flood level of 5.63 meter a row of crucial facilities, such as central streets near the Central Station (e.g. Tegelbacken, Klarastrandsleden), the Old Town's metro station (Gamla Stan), the garden of City Hall and the planning authority building with an integrated restaurant would potentially be at risk (see Figure 6).

In the high level case, several marinas, leisure facilities, walkways and park along the shores would be flooded (compare Figure 5, e.g. Årstaviken, Vinterviken, Traneberg, Kungsholmen). In some areas of the city, residential areas (e.g. Blekholsterrassen and Stora Essingen) and garden cottage areas (e.g. Ulvsunda) are at risk. Several industrial estates would be affected (e.g. Ulvsunda, Bällstaån, Solvalla).

A rough analysis of Stockholm's large tunnel system (telecom, electricity, water, sewage, metro, broad band), made by the city's expert tunnel group, showed that there is a very high risk if the water level rose to a maximum probable flood level. As the tunnels are owned and operated by various stakeholders and as the risk communication among and between the stakeholders is very limited due to confidential information, this study cannot comment on concrete risk and vulnerability. It is clear, however, that Stockholm has decreased the vulnerability of its tunnel systems during the last decade to avoid sabotage risks. The flooding risks will be further examined (pers. comm. K. Kärnsund 2005).

In Stockholm, the potential damage risks seem to be relatively small. The coping capacity of the city is high and risk management structures are well developed. Moreover, Lake Mälaren's potential floods are "slow", meaning that the water rises slowly and counter measures can be organised in due time. Thus, spatial planning has a minor role as the resulting risk has to be management mainly by sectoral authorites and institutions like the rescue administration, environmental administration, fire brigade, and Stockholm Water Ltd.

4.2.3 Uppsala

Uppsala has had problems with the Fyrisån River, which passes right through the city centre. The river becomes a canal within the city limits and has to pass several weirs. In times of extremely high flows (200 m^3/sec), these weirs convert into barriers, and the water is dammed and submerged over the embankments. High water levels, particularly after heavy rains or periods of rapid snow melting, inundate central parts of the city. In such situations, many buildings are threatened, including old ones with cultural heritage status and many important office and commercial amenities. The traffic through the central parts may then be endangered or even blocked.

The risks of flooding are well known among the city's planners and risk managers. The city's recent comprehensive plan includes a chapter on risks due to flooding. Politicians recognise flooding risks as an important subject within planning. The issue is broadly discussed and regarded in a wide perspective:

- There is a flooding committee (mostly physical planning)
- A large area (Kungsängen) is retained for the river's expansion during flooding events
- Plans in case of flood emergencies exist

Risks due to high water levels in Lake Mälaren are a minor trouble for Uppsala. Even the maximum probable flood level does not cause any major problems. The ground water levels in some of the drinking water areas are affected, but on the whole not troublesome. In Uppsala, water levels have to be kept low even in normal times since the beginning of the ground water level regulation in 1956, which was the start of the modern fresh water supply through wells. The map below illustrates which areas of Lake Mälaren would be flooded at levels of + 0.65 m and + 1.48 m.

Extraordinary flooding situations are handled with expertise and high competence in Uppsala. Future planning projects in Uppsala, which strives after higher densities in the inner city parts and new housing areas near the waterfronts, must respect high water levels as an essential planning condition. Lake Mälaren is probably no threat, while the Fyrisån River may cause inundations, which is taken into consideration by local planners. The vulnerability of Uppsala needs a "living" GIS map that describes risks and pre-conditions for forthcoming planning actions.

4.2.4 Västerås

The analysis for Västerås shows that there are no negative effects of a possible 100-year flood event. During the 1990s, the city planning established a risk margin of +1.5 m over normal water level for new housing areas. During higher flood events, Västerås has good crisis management. All relevant stakeholders are informed and called together. Over the past few

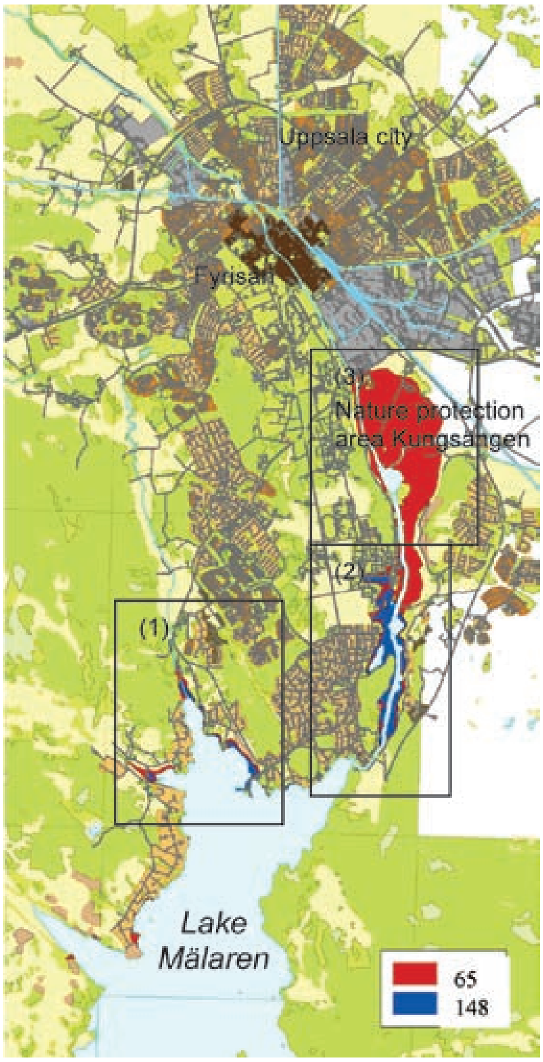

Fig. 7. Flood prone areas in Uppsala due to high water levels in Lake Mälaren.

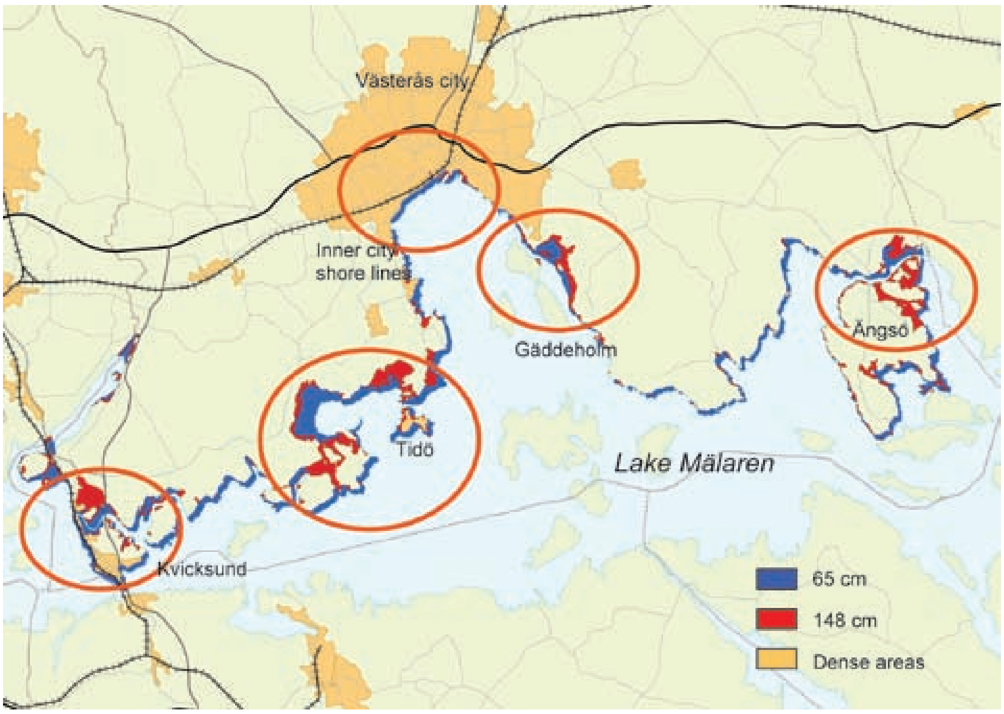

Fig. 8. Overview map of Västerås, flood prone areas along Mälaren's shore.

years, embankment improvements in known risk areas (e.g. Björnön) were made.

Västerås is an expansive city, with 600 – 700 new dwellings being built annually. As the previous examples show, Västerås´ new investments are mainly made at waterfronts. An urban renewal project uses a peninsula in the city centre for the conversion of former harbour facilities into housing and office facilities.

High water levels of +1.5 m mainly affect arable land and open spaces. However, in some parts of the municipality, real estate is at risk, mainly in Tidö, Gäddeholm, Kvicksund and Ängsö. Fortunately, the damage risks are estimated to be small.

The risk administration of Västerås has established their own decision-making support instrument. Flood maps (0.25 m steps up to 2.5 m over normal water level) for the entire areas along Lake Mälaren's shores can be matched with spatial data. The instrument is open to all other city administration units. The maps will above all support physical planning activities, such as the elaboration of plans and the estimation or risks for new and existing buildings and infrastructure.

5 CONCLUSIONS

The SEAREG project contributed to the discussion of possible future climate change impacts on the water levels of the Baltic Sea and the runoff of Lake Mälaren. However, no extreme scenarios were used because the analysis was based on potential current flooding levels. A central part of this assessment has been the production of GIS-maps and related assessments. The communication with planners has been a major effort, however it was only the start of awareness raising, understanding and incorporating of flooding issues in ongoing planning processes.

Several workshops, seminars and discussion rounds with participants from all part of the Stockholm-Mälar region led to the understanding that the flood risks have to be addressed in the design of municipal plans, regional supervision of local plans and risk management. A cross-sectoral discussion of potential risk is still necessary to estimate the vulnerability of a municipality. Impact matrices like those developed in the SEAREG project should be used to indicate the vulnerability.

The risk for flood damage to the Stockholm-Mälar region, both along the Baltic Sea coast and adjacent Stockholm Archipelago, and along the shores of Lake Mälaren are small, as assessed here. This is an important piece of information for spatial planning and risk management in the municipalities around Lake Mälaren and along the Baltic Sea coast. However, many new housing projects along the waterfronts make thorough risk analysis indispensable. No-regret options should become standards for future planning initiatives. The use of cost / benefit terms in the assessments would be important for planners and decision-makers, however the identification, quantification and valuation of damages and adaptation measures associated with future flooding risk due to climate change is difficult.

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This publication presents examples of applying sea level change scenarios in spatial planning. The project "Sea Level Change Affecting Spatial development in the Baltic Sea Region" developed a "Decision Support Frame" (DSF) to facilitate this process. The DSF structures research efforts and provides an interface between for practical applications. It demonstrates the connections between climate change induced sea level rise in the Baltic Sea region and planning concerns on local and regional levels. The DSF also builds on facilitating a communication process. It includes guidelines for communication between different stakeholders and provides information and case study examples to demonstrate the interactions between the changing global climate and local planning drawing conclusions on eventual necessities for mitigation strategies.

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