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Towards an Integrated Assessment of Climate Change-Induced Sea-Level Rise in the Baltic Sea: An Example for the City of Pärnu (Estonia)

Prepared by:
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CONTENT

1. Introduction

Signals of climate change (CC) have been observed at global and European level during the last decades. Several signs, such as an increase in temperature, changes in precipitation pattern and discharge from rivers, sea-level rise (SLR) and glacier melting, have been recorded. These indicators all tend to show that CC can be expected to have widespread consequences, including impacts on ecosystems and water resources, as well as human health and welfare. CC triggers changes in the frequency and characteristics of extreme weather events. The consequences of CC-induced events like storms, floods and droughts, including economic and environmental losses, have increased substantially in Europe over the past 20 years, to an average of 10 billion Euros in the 1990s, and the number of disastrous events in Europe per year doubled over the 1990s compared with the previous decade (EEA, 2004).

On the other hand, land use changes, such as the recent boom in urbanization and infrastructure development, and shifts in traditional rural / urban land use in Europe, are considered as the main reasons for the increase of vulnerability to natural hazards. Urban land expanded by 20% in Europe during 1990-2000, while population increased only 6% (EEA, 2002). The changing trends in housing to be located out of city centres, and attraction of seashores and river banks for residential development, has made these areas more exposed to the risk of damage. Furthermore, more and more tourist services are located near coastlines. The total value of economic assets located within 500 metres of the European coastline, including beaches, agricultural lands and industrial facilities, is currently estimated at 500 - 1000 billion Euros (COM (2004) 0472).

In response to these growing concerns about floods, the European Commission (EC) has proposed to develop and implement a concerted EU Action Programme on flood risk management[1], and in the Communication “Flood risk management: prevention, protection, mitigation” (COM (2004) 0472), sets out its initial analysis and approach to flood events. Based on a review of recent experiences from flood events, the Communication proposed concerted action at European as well as local, national, regional and river basin level. Improving co-operation, providing adequate information about the areas at risk and increasing awareness of citizens, authorities and organisations, are key points towards protecting society and the environment from the negative effects of floods. The research community is called upon to provide a comprehensive picture of on-going processes as well as to give an assessment of possible consequences in the future.

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[1] http://www.europa.eu.int/comm/environment/water/flood_risk/index.htm#opinion_cdr

Works described in this report are completed in co-operation between the Weather-Driven Natural Hazard group[2] of Land Management Unit of JRC-IES and the INTERREG III B Project SEAREG[3]. Hereafter, in this report we address the topic of integrated assessment of CC impacts in the Baltic Sea area, and estimation of their possible negative effects for the city of Pärnu (Estonia). Pärnu is a health resort and port located on the coast of Pärnu Bay. The considerably low elevation (about 10 metres above sea-level) makes Pärnu city extremely vulnerable to flood events. Several issues are covered in order to give a complete picture about the driving forces and processes involved.

Integrated assessment combines knowledge from diverse scientific disciplines, ranging from the natural and social sciences which often apply different terminology. Therefore, the effort to establish a common terminological framework as well as a methodological overview, are presented in the first chapter.

In the second part of the report, the analysis focuses on CC scenarios for the Baltic Sea, and scenarios of induced sea-level rise and increase of extreme weather events as storm surges, wind speed and waves. The extent of hazard impact is evaluated by producing risk maps for three different sea level rise scenarios.

The issue of growing exposure to hazard by means of analysing trends in urban dynamics for Pärnu city is covered in the third part of the report. Several development scenarios are produced to predict the spatial pattern of land use. The MOLAND urban growth simulation model, based on "cellular automata" (CA), is a key instrument in the forecasting. The results of two simulation scenarios used for analysis of future expose to floods.

The issue of vulnerability illustrate by means of analysis of recent extremely heavy storm which take place in Pärnu at 9th of January, 2005 in fifth chapter.

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[2] http://ies.jrc.cec.eu.int/Action_4336_-_WDNH.73.0.html

[3] http://www.gsf.fi/projects/seareg/

2. Realising and estimating climate change impacts - setting the stage

2. 1 Risk and vulnerability

The assessment of CC impacts on socio-economic and natural systems is a relatively new and broad research topic that brings together different disciplines, including natural and environmental science, management of sustainable resources as well as risk management, social, economic and development science, and policy-making. The terms **vulnerability** and **risk** are two key concepts which are elaborated by the research community in relation to safety and welfare of society and the environment. The concept of vulnerability is extensively used within research in the CC and socio-environmental fields, and estimation of CC impacts is generally referred to as vulnerability assessment. Those who deal with natural hazards and spatial planning prefer to speak about risk and to focus on risk assessment. Moreover, researchers from different backgrounds tend to assign different meanings to the term “vulnerability”, that depend on applications and the particular needs of a wide range of disciplines. Nevertheless, several efforts (UNDHA, 1992; IPCC TAR, 2001; ISDR, 2004) have been undertaken in order to establish common language, but some apparent contradictions are still exist. The key definitions for a vulnerability-based approach (IPCC TAR , 2001) are presented in Box 2.1, and those for a risk-based (ISDR, 2004) in Box 2.2.

Box 2.1: IPCC TAR (2001): Definition framework

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Climate Variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events.

Exposure: The nature and degree to which a system is exposed to significant climatic variations.

Sensitivity: Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).

Adaptive Capacity: The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Thus, in CC literature, vulnerability is defined as a function of the magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2001; Nicholls et al, 1999). In contrary, the natural hazard community uses “vulnerability” to define risk as a product of hazard probability and vulnerability. Some studies introduce the term “exposure” to define physical aspects of the system, and use “vulnerability” only in its social meaning (Kron, 2002; Kelman, 2003).

Box 2.2: ISDR Definition framework

Risk: The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions.

Conventionally risk is expressed by the notation
Risk = Hazards x Vulnerability.
Some disciplines also include the concept of exposure to refer particularly to the physical aspects of vulnerability.

Hazard: A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.

Hazards can be single, sequential or combined in their origin and effects. Each hazard is characterised by its location, intensity, frequency and probability.

Vulnerability: The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.

Exposure: Physical aspects of vulnerability.

To facilitate reduction of apparent confusions Brooks (2003) gives a conceptual framework of terms by means of comprehensive analysis of existing literature. He highlights that both research communities, where one emphasizes risk and another emphasizes vulnerability, are essentially examining the same process - both are ultimately interested in physical hazards and their mediation by means of system properties. Brooks proposed to separate vulnerability into social and biophysical vulnerability in order to appreciate the compatibility of risk-based and vulnerability-based approaches (figure. 4.1).

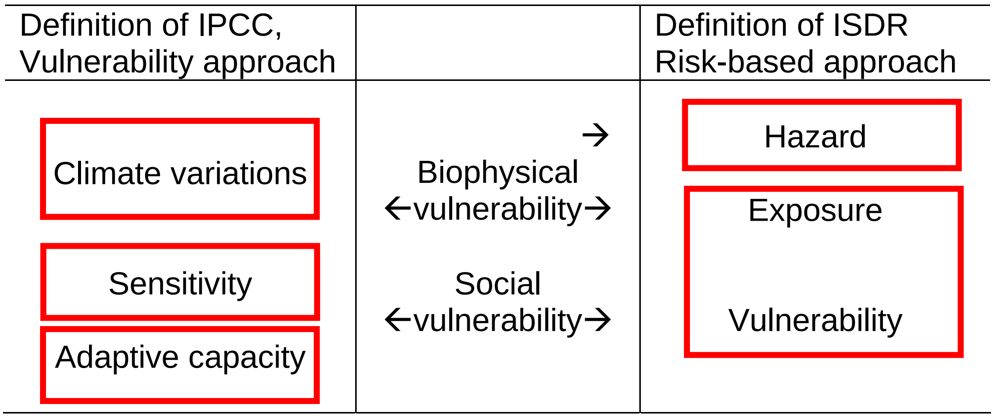

Figure 2.1 Conceptual framework – relationship between definitions

The advantage of risk-based assessment is that it is embedded in a risk management framework. Risk is, by definition, the expected losses, and "units" of risk depend on what is the hazard's likelihood, and its consequences are defined. The likelihood of hazard is a probability of the hazard occurring at a certain magnitude, in comparison to the number of hazard events recorded in the past (FLOODsite, 2005). On the other hand, exposure to hazard and vulnerability can be expressed quantitatively (e.g. in monetary units or as indicators), by category (e.g. high, medium, low) or descriptively (FLOODsite, 2005). Once the probability of risk at a certain hazard-extent is clear, the question about level of acceptance of, and tolerance to, risk arises. The answer to this question determines aspects of appropriable adaptation and mitigation strategies. All that has been mentioned above makes risk-based assessment understandable to social and economic institutions, and allows planers and policy makers to use it as a powerful tool for risk management.

The integration of terminology is essential if we are to address the issue of vulnerability as an integrated part of the causal chain of risk, and combines the advantages of different disciplines in order to manage better the threats posed by climate variability and change.

2.2 Looking to the future - uncertainty and scenarios

If we are to foresee the future, we need to acknowledge the fact that, despite all scientific knowledge, it is not possible to predict accurately the behaviour of complex systems. The world is full of **uncertainly**. It is possible, however, to make statements about the expected outcomes with a reasonable level of certainty. The application of **scenarios** can address this situation, where each scenario is one alternative image of how the future can unfold and what would happen if a certain hypothesis is proved correct.

Scenarios are widely used in CC-related assessments. Climate scenarios make use of outputs from general circulation models (GCMs) and represent changes in mean climate. Some recent scenarios also have incorporated changes in variability and extreme weather events, which can lead to important impacts for some systems. Long-term mean sea level changes are caused by global climate variations such thermal expansion and reduction of ice stocks in glaciers and polar ice caps. SLR scenarios concern global sea level changes along with local land movements and water circulation models. At the end of long chain there are socio-economic and environmental systems threatened by climate change effects and sea level fluctuations.

Whilst most studies apply scenarios of future CC and SLR, the majority of them tend to estimate impacts on the basis of the *current* environmental and socio-economic situation (IPCC, 2001). But one can not avoid the fact that environmental and societal systems will evolve at the same time with CC, and baselines will change because of ongoing development. In this study we propose to use scenarios of spatial pattern of land use produced by cellular automata (CA)-based spatial modelling tool. Defined through narrative “story-lines” about future socio-economic development, these scenarios allow us to simulate the development of different land use types such as residential, industrial, commerce etc., and as a result, to estimate what structural impact to the system CC might have.

3 Driving forces of increasing risk

The recent climate change and especially its effects for the next 100 years trigger new environment and social-economic threads in Baltic Sea region. On the long-term are expected phenomena such as the sea level rise (SLR) and more frequent and intensive winter storms as consequences of climate change. It is projected for the Baltic Sea region a gradual sea level rise accompanied by higher winds speed during winter and spring and also will come along with shorter time of ice coverage (Schmidt-Thone, 2003).

3.1 Sea level rise scenarios for Baltic Sea

The sea level rise scenarios used in this study were developed in the frame of INTERREG III B Project SEAREG. The three factors affecting SLR are eustatic sea level rise, water balance of the Baltic Sea and post-glacial land uplift. An anthropogenic eustatic sea level (mean sea level relative to geoid) rise is caused primary by thermal expansion, since water balance is closely related to the regional wind and sea level pressure patterns over the North Atlantic. Abovementioned parameters have been calculated using RCAO regional climate model for Baltic Sea region developed by Rossby Center, Swedish Metrological and Hydrological Institute, SMHI (Meier et al., 2004). The atmosphere, ocean, sea-ice, and land surfaces are simulated within the three-dimensional high-resolution model. Due to the fact that RCAO geographical coverage is limited to Europe, the data of two of global climate models (GCMs) were downscaling for input at the borders of the regional model area. For each of two driving GCMs, named HadAM3H and ECHAM4/OPYC3, one control run (1961-1990) and two scenario runs based upon the SRES emission scenarios A2 and B2 were conducted.

The post-glacial land uplift of Scandinavian shield is the Earth's response to past changes of the ice and water loads. Ekman (1996) estimated the uplift of Fenoscandia using the observation data of 56 tide gauges during the period of 1892-1991, levellings and lake tilts. It was found that a maximum uplift of 9 mm yr^{-1} take place in the Bay of Bothnia. (figure 3.1) According to his results land uplift in Pärnu is about 1 mm yr^{-1}.

Finally, three SLR scenarios were calculated in relation with the uncertainty aforementioned global and regional model: (1) A "High case" scenario illustrating the combination of maximum values of impact factors; (2) An "Ensemble average" calculated on the base of the four regional scenarios; and (3) A "Low case" scenario (figure 3.2). The "High case" scenario uses the regional model results fed with the A2 emission scenario and the largest monthly mean sea level increase together with the upper limit for the global average sea level rise of 0.88 m projected by IPCC. The "Low case" scenario using the regional model (B2 emission scenario) with the smallest (i.e. zero) monthly mean sea level change, together with the lowest limit of global average sea level rise of 0.09 m. The "Ensemble average" case consists of 0.48 m global SLR representing the average of global SLR and average results of RCAO simulations. This does not imply that the “Ensemble average” scenario is the best estimation. So far the selection of the three scenarios is only to illustrate the range of uncertainty.

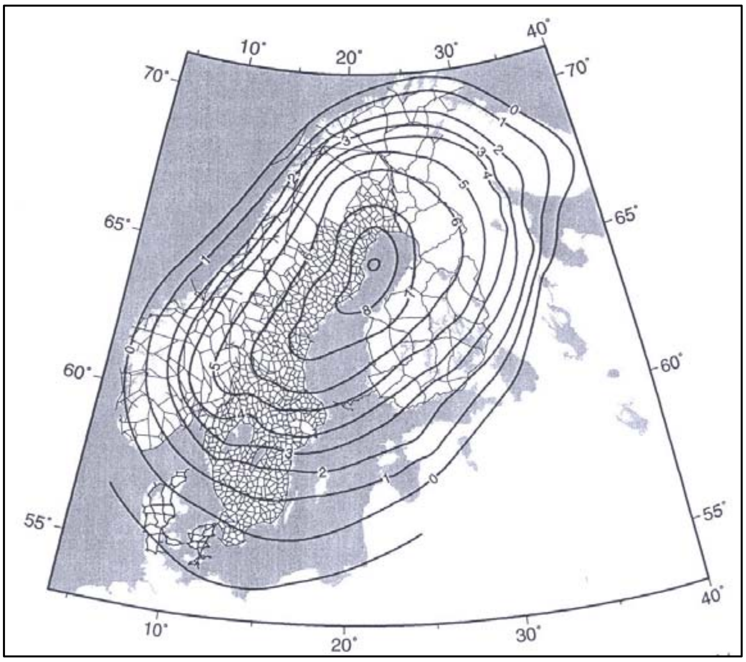

Figure 3.1 The map shows the apparent land uplift, i.e. the uplift relative to sea level. Source: Ekman, 1996

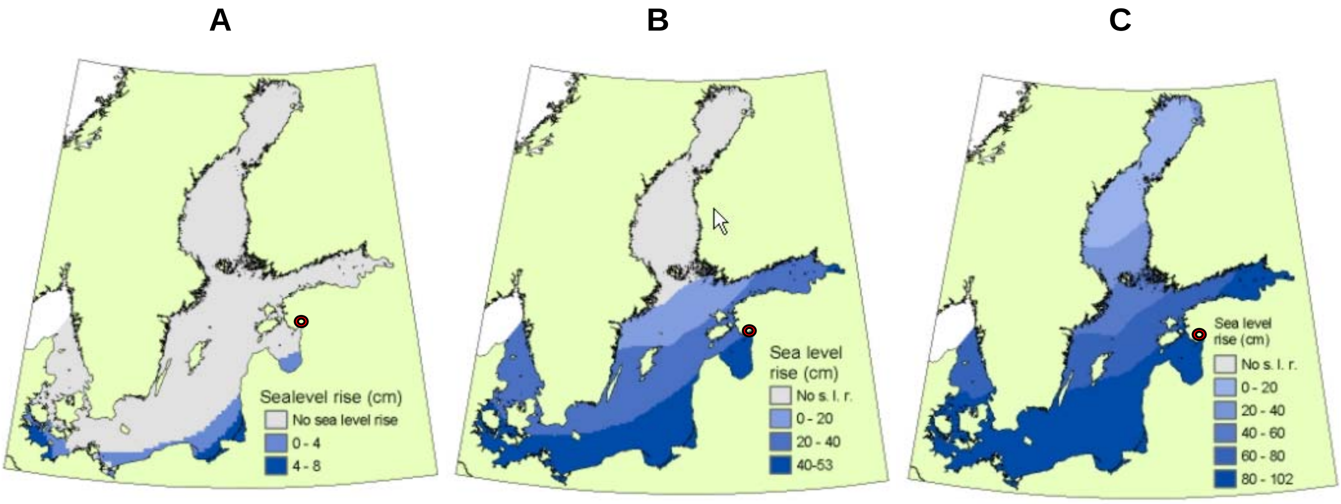

Figure 3.2 The three SLR scenarios of SMHI, winter mean sea surface height relative to the mean sea surface 1961 – 1990. Source: Meier et al, 2004. A- “Low case”; B-“Ensemble average”; C- “High case”. The location of the city of Pärnu is indicated with red ring

3.2 Sea level rise scenarios for the city of Pärnu.

Within the SEAREG project the results of RCAO SLR scenarios were deduced for Pärnu case by Klein (2004). The outputs of RCAO scenarios and post-glacial uplift estimation are related to the Nordic Height System (NH60) based on the Amsterdam level. On the other hand, in Estonia the Baltic Height System, (BHS) is used for height data which corresponds to Kronstadt level. After detailed investigation of differences between two elevation systems Klein calculated values for SLR scenarios in BHS, presented in table 3.1.

Due to the fact that the RCAO-based projections show large uncertainties related to extreme surge events, the definition of 100-year flood has been applied for assessment of storm impact. According to Klein (2004) the level of 100-year flood Pärnu is 1.96 metres over the mean sea level. This estimation was based on sea level value of the Pärnu gauge for the years 1923-2003, i.e. the same frequency and height of storms surges as today is assumed.

SLR scenarios:	Low Case	Ensemble Average	High Case
SLR, m	0.09	0.56	1.08
SLR + storm surge, m	2.05	2.52	3.04

Table 3.1 Sea level values for different scenarios for the city of Pärnu Source: Klein, 2004

The examples of severe flood events were observed during the last century. On 17th of November, 1923 the highest see level (1.83 metres), up to this date, was measured. On 18th of October, 1967 were registered strong storm winds, its direction and general high water level of the Baltic Sea rose to an extreme sea level of 2.53 metres. In September, 1978 the storms caused again 1.83 metres water level rise. (Roosare and Järvet, 2001). Then, on 9th of January the sea water level in Pärnu city rose above 2.95 metres – the highest level ever recorded. The significant exceed of flood level in 2005 over 100-year flood value can be explained by the fact that sea level rise observed in 1967 was an extraordinary high point, considerably higher than statistical population of Pärnu gauge and was not taking under consideration. Abundant water levels were also observed in the following years 1924, 1931, 1932, 1940, 1943, 1961, and 1993().

Local digital elevation model (DEM) was the basis for transformation of sea level and surge values, to impact maps and evaluate spatial extend of inundation and flooding. For this purpose we used the DEM with spatial resolution 10 metres from the MOLAND database (Demicheli et al., 2003, see also Chap. 4). The use of impact maps is twofold: (1) to allocate properties, infrastructures and natural eco-systems endangered by sea level change; and (2) to produce quantitative assessment in terms of territory affected. The overall estimation of areas affected by SLR and storm floods about the city of Pärnu is presented in table 3.2. The impact maps represent one of the main input to risk and vulnerability assessment, which is a subject of Chap. 4.

SLR scenarios:	Low Case	Ensemble Average	High Case
Inundation (SLR), ha	380	570	776
Flooding (SLR + storm surge), ha	1057	1245	1524

Table 3.2 Area affected by SLR and storm floods according to different SLR scenarios.

4 Modeling urban dynamics for Pärnu city (Estonia)

This section concentrates on analysis of urban development of the city of Pärnu (Estonia), in order to answer the question: will current trends and policies lead to increase of exposure to natural hazards in the future?

4.1 Significance of the test site

Pärnu is located on the coast of Pärnu Bay, at the confluence of Pärnu and Audru Rivers – two the largest Estonian river systems. The considerably low elevation (around 10 metres above sea-level) makes Pärnu city extremely vulnerable to flood events. The historical centre, spas and hotels, the harbour – all are located in the area of direct impact of storm inundation. The sand-beaches and green-belt of parks are important recreation features and tourist attractions of the city. Coastal erosion and landward intrusion of marine water affect both beaches and lowland coastal ecosystems of two Nature 2000 sites.

Pärnu is an administrative centre of Pärnu County, a health resort and also a seaport of regional importance. The city is home for approximately 44,000 people[4] (2004). Two-thirds of the County's population reside in Pärnu city and its hinterlands. During the period from the mid-1980s until 2000, different social and economical processes formed the face of the city. The collapse of the communist regime, economical and social difficulties at the first years of Estonian State independence, liberalisation of economy and the subsequent tourist boom, lead to controversial trends in city population and land use dynamics. The economic decline and population migration flows during the immediate post-Soviet period led to a considerable decrease in city population, from 53,000 in 1987 to 50,000 in 2000 - a process which is still slowly continuing nowadays. The demand for new residential and industrial capacity was at a very low level. The signs of gradual improvement can be seen only since the mid-1990s, with a general revitalising of Estonian economy and tourism.

Pärnu is a health resort of international stature, with a more than 100-year history. This status is also proved nowadays by its membership in the European Spas Association (since 2000), and the European Blue Flag that has been flying at the beach of Pärnu since 2001 (WHO Healthy city). Pärnu is also a member of the European Federation of Conference Towns (EFCT). Therefore, this tertiary sector is a core of the city economy, and provides jobs for 68% of the active population. The primary and the secondary sectors correspond to 2% and 30% of employees[5]. The main industrial activities are timber- and furniture-production, and textile-manufacturing. The unemployment rates, compared to the indicators of

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[4] http://www.parnu.ee

[5] http://www.parnu.ee/fileadmin/user_upload/pdf/linn_arvudes_est_2004.pdf

the whole of Estonia, are substantially low. The port of Pärnu which is located in the mouth of the Pärnu River serves for the export of timber, horticultural peat and flax.

4.2 Modelling the future - MOLAND model applications

To facilitate the forecast of urban land use dynamics, we propose the use of future urban scenarios by means of a cellular automata (CA)-based spatial model, named MOLAND -Monitoring Land Use/Cover Dynamics (Barredo et al., 2003, 2004, Lavalle et al., 2004). The model consists of "cells" which represent continuous space and can evolve from one "state" to another according to "transitional rules". The model operates at two levels. At the micro- level, the CA-based model determines the fate of individual cells based on the type of the activities in their neighbourhood. Unlike conventional CA, this model is defined with large neighbourhoods and more cell states representing socio-economic land uses and natural land cover (Barredo et al., 2003). At the macro- level, various additional factors such as overall land use demand, effects of the transportation network as well as legislative, environmental and institutional characteristics (e.g. environmental protection, zoning) constrain the behaviour of the CA-model. This approach allowed us to integrate '"physical", environmental as well as institutional aspect of territorial development.

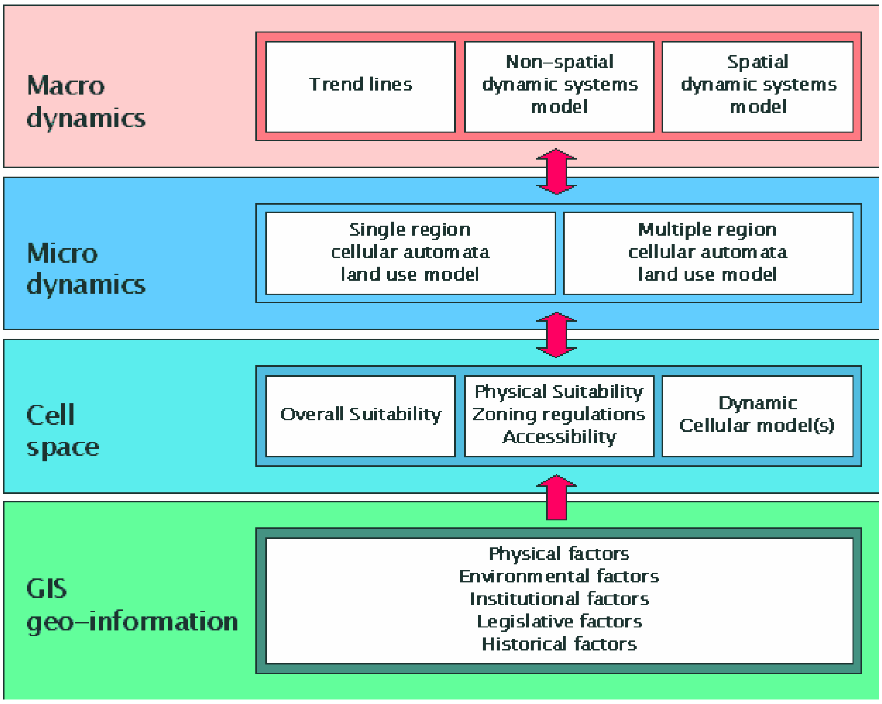

Figure 4.2 Scheme showing the role of cellular automata land-use model as core elements in linking socio-economic and environmental models operating at different geographical scales in MOLAND model. Source: Lavalle et al., 2004

The model requires as input digital maps of actual and historical land use, accessibility maps derived from the transportation network, and maps of inherent suitability for different land use states. Optionally, if available, zoning status (i.e. legal constraints) and socio-economic (e.g. population, income, production, employment) variables are used to adjust fully the model. The area of Pärnu city was mapped in 2002 according to MOLAND methodology, in framework of the project "Creation of the territorial and environmental data sets of the Harjumaa County and Via-Baltica transport corridor" (Demicheli et al., 2003). The data-sets correspond to reference (2000) and historical (1986) dates. For modelling purposes, the area of Pärnu city and its surroundings was extracted from the land use / cover data set. The area delimitation does not follow the administrative boundaries, but defines a buffer around the continuously built-up core area. This approach widens the analysis from administrative cities to "functional urban areas" (Kasanko et al., in press) and provides the possibility to model city expansion. Therefore, the total area under study is 71.9 sq km.

Two steps of modelling process are required: (1) Calibration of the model by means of finding appropriate values for each cell's transitional rules, and (2) Simulation of future development throughout the scenario-period.

The Pärnu model was calibrated using historical (1986) and reference (2000) land use / cover data sets, accompanied by transport network layers. The model consists of: 9 "active" urban classes (states) which participate in urban sprawl; 9 "vacant" land uses, representing areas where expansion takes place, such as agricultural and natural land; and 7 "fixed" classes where development is restricted. Among the active urban classes there are five classes for different types of residential areas, including so-called "block houses" – the class which is an important category for cities with a communist-regime background. The other four classes are industrial, commercial, and services areas, and transport units.

The model was calibrated for the period of 14 years using the historical data set. Land areas demanded for each active urban class were derived from the change statistics between the historical and reference data-sets, and incorporated into the model from the outset. Also, the calibration was adjusted according to different trends in land demanded at different stages of calibration period. The resulting maps of the calibrated model were compared with the actual land use from reference data set. They were tested by using accuracy analyses - firstly by statistical and then by spatial metrics (Engelen, 2003).

4.3 Land use scenarios

Two scenarios for developing the city of Pärnu were tested which cover the period time of 2000-2025: (1) the business-as-usual scenario and (2) the 'optimistic' scenario.

The **business-as-usual scenario** (figure 4.2, A) assumes that the demographic and socio-economic trends of the last 5 years of the calibration period remain the same. The population continues to decline, however, steady demand for detached family houses leads to slight increase of the residential land use. Development of residential areas continues on the city edges and during simulation period it will not exceed 2 %. The economy grows slowly mainly because of the tourism and services. Industry continues to go down at initial 5 years and stabilise at the end of simulation period. In the inner city, industrial land use is gradually substituted by commerce; as a result the whole area of industrial land use shrinks. The appearance of new urban clusters apart of core area is limited.

The 'optimistic' scenario (figure 4.2, B) is partly based on visions of Pärnu City Council planning authorities. The city of Pärnu is an example of good practice in planning. The Pärnu Local Agenda 21 and Pärnu General Development Plan for period of 2001-2025 are compiled and available for public on city's web site[6]. Both documents proclaim more sustainable and balanced development and multifunctional use of urban space. According to one of the possible -optimistic- prognosis described in the mentioned documents the city's population can increase up to 55 600 in 2025. The demands for residential land are also calculated and published – 9 ha for multi-storey and 54 ha for detached family houses – which its represent 6% of the whole residential area in the year 2000. The banks of the Pärnu River are planned to be converted into more attractive residential and leisure areas instead of industrial use. Also a new residential development is designed along the Pärnu River. The mentioned demographic changes are coupled in our scenario with more dynamic economic growth. The economy of region has its advantages besides general revitalising of the country economy after entering EU and starting to benefit from EU Cohesion and Structural Funds. So that the tourism, services and commerce are favourable sectors, but the industry recovers and grows slightly. Table 4.1 summarises main features of both scenarios.

	Business-us-usual	**Optimistic**
Demographic developments		
Population	decreases	increases
Number of households	slightly increases	grows considerably
Economic developments		
Industry	declines	stabilises and grows
Commerce	slightly increases and stabilises	increases
Tourism & services	increases	grows fast

Table 4.1 Driving forces for land use development. Comparison of "Business-as –usual" and "Optimistic" scenarios

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[6] http://www.parnu.ee

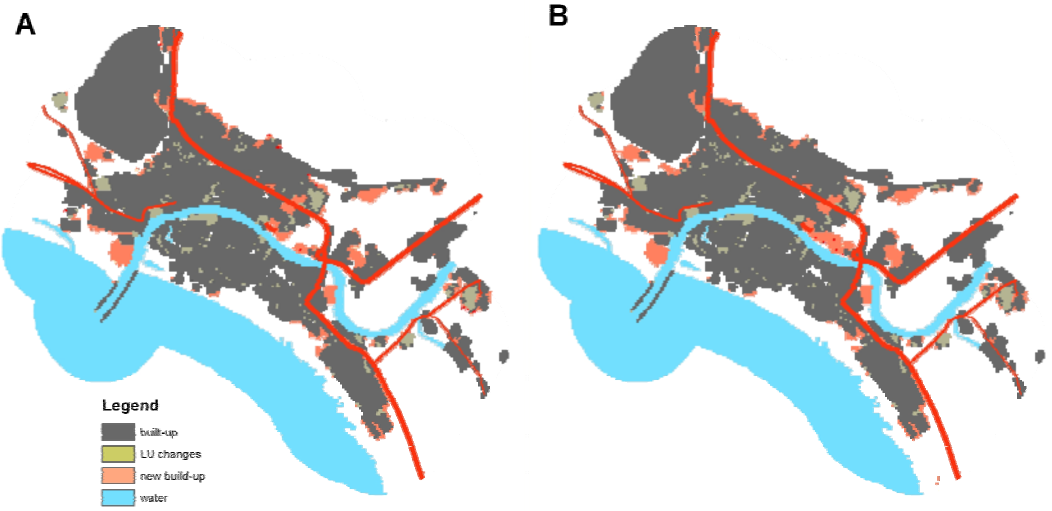

Figure 4.2. Scenarios of urban land use development for Pärnu city: A-business-as-usual scenario and B-“optimistic” scenario.

Both scenarios show (figure 4.2) that the demand for the new development will not lead to considerable urban sprawl, and then the expansion outside old cores will be moderated and come along with the densification of urban space by developing of barren and abandoned land on city’s edges

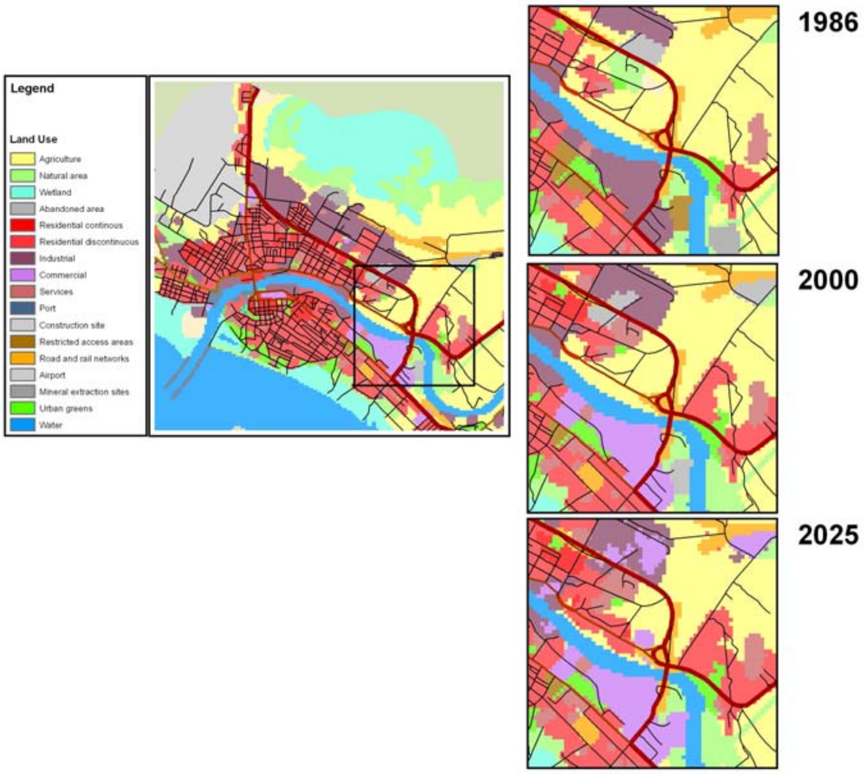

Figure 4.3. An example of new development of residential and commerce land use on city outskirts

Unfortunately, the urban green area is not an active function in this modelling case and it is difficult to be incorporated into the model. However, the strong wish of the authorities is to keep the town as much ‘green’ as possible. Aside from the edge development, another favourable direction of urban expiation is shown by ‘optimistic scenario’ (figure 4.2, B) establishing towards the new residential areas along the Pärnu river banks and appearance of associated service area cluster (figure 4.3). As well, the considerable land use dynamics counter on the functional changes of land use in the inner city is shown by both scenarios (figure 4.2). The substitution of industry by other activities, mainly commerce and services will continue in forthcoming decades.

4.4 Growing exposure to risk

The allocation of future urban land use in hazard-prone areas pointed out by impact analysis (Chap. 3) can be illustrated by simple geographical overlap (Figure 4.4). It is noticeable that extend of impact on build-up area is considerable because of the storm surges for all three scenarios from “Low” to “High” case. On the other hand, SLR will affect mostly the port area, beaches and coastal wetland.

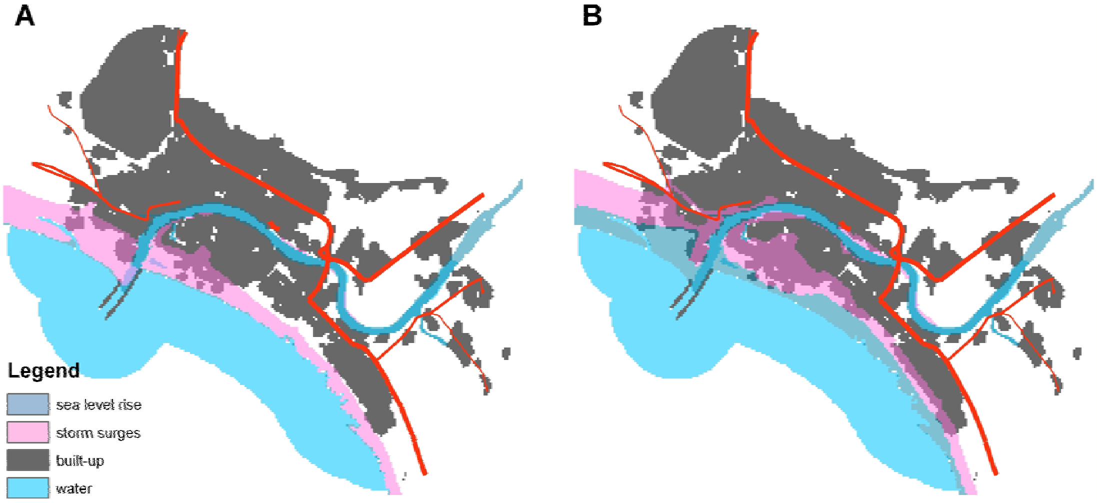

Figure 4.4. The extend of CC impact –SLR and storm surges– for Pärnu city from A- “Low case” to B– “High case” scenarios. Built-up area is presented for year 2025 according to “optimistic” urban growth scenario.

The increase of overall urban areas is likely to be under flood risk in the future and can vary from 20 up to 170% according to different CC scenarios (figure 4.5). The impact has its maximum in the city centre where the historical buildings, spa and conference facilities are located. The port area is also affected. The surge impact on administrative, social and communal buildings located in the centre would seriously increase the vulnerability and affect the cooping capacity of the city. The impact on built-up area is less along the river and sea shores. The main anxieties are sand beaches and city's greenbelt and parks, important for the recreation features and tourism attractions.

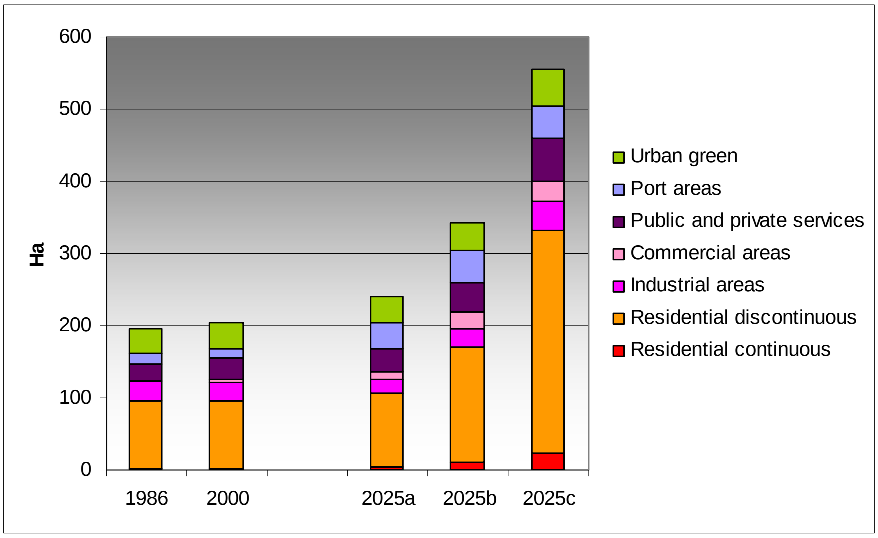

Figure 4.5 Urban land use classes in SLR and surge-prone area: historical (1986) and present (2000) situations and assessment for different hazard impact scenarios concerning "optimistic" urban growth scenario. 2025a corresponds to "Low case" scenario; 2025b - "Ensemble average" scenario and 2025c - "High case" scenario.

The effects on service and recreation areas show that tourism and service sectors will receive enormous direct and indirect impact from the storm flooding. Moreover, based on the "high case" scenario the amount of service areas affected can grow by 70% (figure 4.5). The considerable industrial and commercial areas are located in flood-prone area as well, but impact will mainly bear on the medium size industry lots being close to the port and shipyards. The large establishments along outer motorway bypass in the north part of the city will be not touched. SLR would not affect transport infrastructure, and even the "High case" scenario evaluates that the surge impact on main transport link will be low. Then, around 40 km of minor streets in the city centre will be affected by storm flooding.

It is worth to notice, that even now more than half of the built-up areas under flood risk belongs to the residential land use. It can be assumed that the number of properties and dwellings exposed to storm inundation will increase and can even triple due to the CC induced heaver storms (figure 4.5, 2025c).

Considerable changes in the land use in the inner city such as emerging of new commerce and service establishments, re-development and densification of urban space, will lead to increase of property values in endangered areas. On the other hand, the fact that Estonian low restricts construction development close to the coast will mitigate significantly SLR effects.

The natural and semi-natural coastal areas receive vast and devastating impact (table 4.2), which even in the medium case would lead to overall disappearance of sand beaches. Squeeze or loss of these areas will not be compensated by landward migration due to the fact that new coastline would be close to build-up area.

SLR scenarios:	Low Case	Ensemble Average	High Case
Sand beaches (Total stocks in 2000 - 15 ha)			
Affected by SLR, ha	7.8	14.5	15
Affected by SLR + storm surge, ha	14.5	14.5	15
Coastal wetland (Total stocks in 2000 - 405 ha)			
Affected by SLR, ha	26	193	338
Affected by SLR + storm surge, ha	361	370	370

Table 4.2 Area of sand beaches and wetlands affected by SLR inundation and winter storm surges

5 Vulnerability to sea level changes

Classical vulnerability assessment was not a part of this study. But in order to cover this issue, we are analysing recent extremely heavy storm which took place in Pärnu on 9th of January, 2005. Hereafter we review the facts and conclusions published on official City Council website and in the media.

5.1 Lessons learned from extreme events - January, 2005 flood

The most recent examples of extraordinary heavy storms in Pärnu are from winter 2005, when storms sweep across Northern Europe causing electricity blockages, floods, traffic accidents and even humans' deaths. At 9th of January the sea water level in Pärnu rose above 2.95 metres – the highest level ever recorded. Flooding water covered one-third of city centre, causing evacuation of many people, transport and sewage problems. The direct and indirect damage produced by flood events in January, 2005 is estimated up to 22.4 mil Euros (353 mil. Estonian Kroons)[7].

It is important to underline that winter storms and surges are not something new for Pärnu city. But the last event was comparable with the catastrophe of over 30 years ago, in 1967, when water level reached 2.53 metres. and since that disastrous event perception of danger trimmed down in the public and through authorities. The storm alert issued by Estonian Meteorological and Hydrological Institute (EMHI) – official authority responsible for sea level forecasting– was greatly underestimated and predicted water level at 1.70 metres. At the same time, another, more precise and warning forecast was issued by marine researches of Technical University of Tallinn. Despite of this fact, the city and rescue authorities continued to consider only one of the estimations.

Figure 4.6 Storm surge in Pärnu, 9th January, 2005. Source: http://www.parnu.ee/index.php?id=1065

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[7] http://www.parnu.ee/index.php?id=1065

As it was concluded by the mayor of the city, generally the rescue operations were well co-ordinated and due to the brave efforts of rescue services there were any death tolls. However, rapid unfold of events revealed some strategic gaps in crisis regulation plans. So that the evacuation has been started when water level exceeded the value of 1.50 metres and the access by vehicles to houses in some city areas was already impossible. As a result of underestimation of the sea level forecast and operational flood management, the teams were working in extremely difficult conditions and also some victims arrived to the hospitals with symptoms of hypothermia.

It is noticeable that sea level reported for this storm is comparable with the one projected by “High case” scenario. Hence the storm damage assessment of the 22.4 mil. Euro can give us a hint about the future risks regarded to trends discussed in Chapter 4.

The infrastructure recorded serious problems. Beside electrical blockage and transport difficulties, the city confronted problems regarding the water supply and sewage. Thus, some city districts are not connected to water supply and sewage systems, taking drinking water from private wells. The intrusion of sea water and contamination of sewage disclosed very vulnerable issue.

Households’ insurance losses are assessed approximately up to 9.5 mil Euro (150 mil Estonian Kroons[6]), but it was reported that the share of insured households is considerably low.

It was widely agreed in the media that January, 2005 storm was a grave lesson. Disastrous event showed that existing structural measures - approximately 1 metre high sea walls established to protect the centre of city - do not guaranty sufficient flood defence and would not be enough to cope with future floods. The awareness about warning trends should be raised among public and authorities. It should lead to appropriate flood defence and urban planning strategy in order minimize risk. This strategy should cover pre-flood activities such as improvement in alert system and preparedness, operational flood management as well as measures assuring citizens’ ability to cope with flood consequences.

Figure 4.7 Storm damage liquidation. Source: http://www.parnu.ee/index.php?id=1065

6 Final remarks

Within this approach we tried to demonstrate that integrated assessments of climate change effects can be conducted on local spatial scale. The assessment needs the combination of knowledge from diverse scientific disciplines, ranging from the natural and social sciences. The advantages of risk-based assessment of climate change effects are oblivious and allow planers and policy makers to use it as a powerful tool for risk management. The application of scenarios can address uncertainty of unfolded future, where range of alternative images can illustrate what would happen if one or other hypothesis is proved correctly.

The important component of approach is the temporal scale in CC impact assessment. Beside of using global and regional scenarios for CC and SLR, we introduced temporal baseline for impact and risk assessment. The application of CA-based spatial modelling tool allowed us to estimate what structural impact CC might have in regards to local development alternatives. It may be feasible for studies of local adaptation to estimate the feedback of mitigation policies over planning horizon of several decades.

Although the integration of CC and land use scenarios seems a very promising direction, some work is needed for linking both approaches. There are particular socio-economical “storylines” behind of the global GHGs emission scenarios and CC scenarios. There is may be a reason to ensure that the global and regional scenarios of changing social, economic, and technological conditions are consistent.

The relations between trends expressed by indicators and damages evaluated in monetary units are requiring further investigations. But it should be noticed, that such kind of relations can be very case-specific and vary greatly depending on local conditions.

A new challenge would be the development of land use dynamical model supplemented by SLR scenarios. It is feasible to include in the model trends of sea level changes as a factor of declining suitability for constructional development.

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