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FUTURE SEA LEVEL CHANGE:
A TRANSBOUNDARY PROBLEM IN THE BALTIC SEA REGION?
— SEAREG CASE STUDY AREA GDAŃSK

Michael STAUDT[1], Zbigniew KORDALSKI[2]

Abstract. The Interreg IIIB project Sea Level Change Affecting the Spatial Development of the Baltic Sea Region (SEAREG) addresses socio-economic and environmental aspects of the sea level rise in the Baltic Sea region (BSR). A rise of the sea level might lead to major flooding events, having severe impacts on the spatial development of cities and regions of the BSR. Ocean models and land uplift or land subsidence rates are factors that must be taken into account in addressing flood prone areas. One of the projects case study areas was city of Gdańsk. The Gdańsk region is a subject to land subsidence of 1–2 mm/year. The low lying areas on the coastal terrace and on the Vistula Delta plain contain the most important aquifers for public water supply. For the Gdańsk region, the project’s sea level rise scenarios vary from 0.03 m (low case), 0.48 m (ensemble average), up to 0.97 m (high case). In the course of an impact and vulnerability assessment, the impact zones are superimposed with existing land use data. These flood-prone areas should be protected in the future and countermeasures have to be taken to mitigate danger of future flooding.

Key words: sea level rise, climate change, climate modelling, water supply, GIS, spatial planning, Gdańsk region, Baltic Sea.

Abstrakt. Projekt „Sea Level Change Affecting the Spatial Development of the Baltic Sea Region” SEAREG, unijnego programu Interreg IIIB porusza społeczno-ekonomiczne i środowiskowe skutki zmian klimatu w regionie Morza Bałtyckiego (BSR), w szczególności związane z podnoszeniem się poziomu morza oraz zmianami odpływu z sieci rzecznej. Te dwa czynniki mogą prowadzić do wystąpienia katastrofalnych w skutkach powodzi, wpływających bezpośrednio na zagospodarowanie przestrzenne miast, jak również na zrównoważony rozwój całego regionu Morza Bałtyckiego. Jednym z miejsc objętych szczegółowym rozpoznaniem w ramach projektu był Gdańsk. W obrębie miasta na nisko położonych obszarach tarasu nadmorskiego i Żuław Wiślanych zlokalizowane są ujęcia wód podziemnych, ważne dla zaopatrzenia w wodę do picia i na potrzeby gospodarcze. Dla Gdańska strefy zagrożone powodzią i podtopieniami zostały wyznaczone przy pomocy oprogramowania GIS, z wykorzystaniem wysoko-rozdzielczych regionalnych modeli oceanograficznych, modeli powierzchni terenu i planów zagospodarowania przestrzennego. Opracowano 3 scenariusze, według których poziom morza w ciągu następnych 100 lat wzrośnie w rejonie Gdańska odpowiednio o 0,03, 0,48 i 0,97m.

Słowa kluczowe: podnoszenie się poziomu morza, zmiany klimatu, modelowanie klimatu, zaopatrzenie w wodę, GIS, planowanie przestrzenne, region gdański, Morze Bałtyckie.

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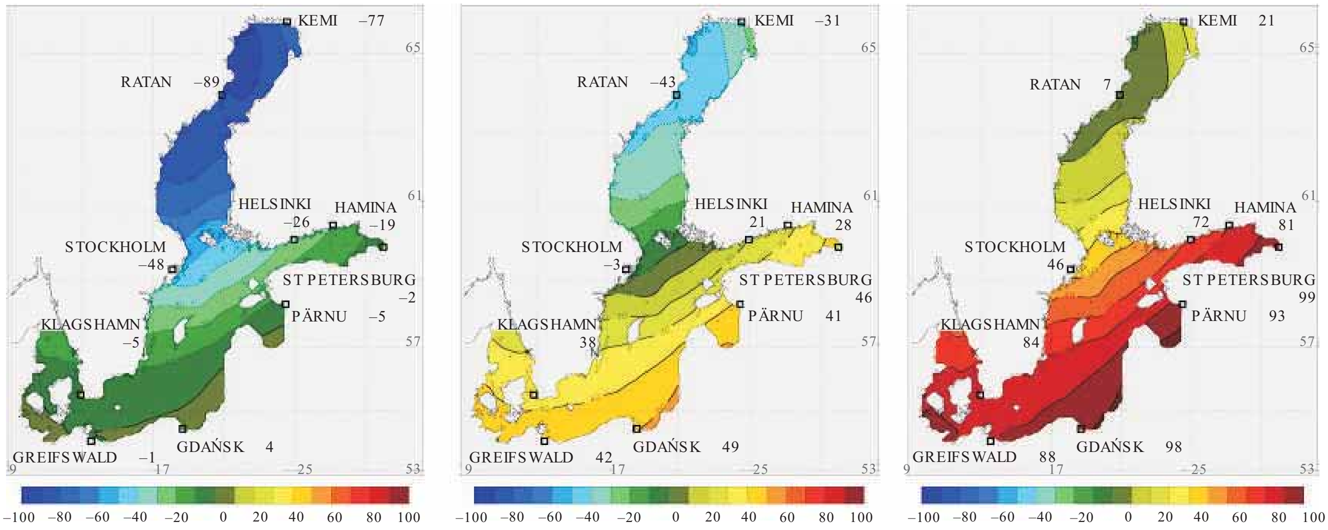
[1] Geological Survey of Finland (GTK), Land Use and Environment, Betonimiehenkuja 4, P.O. Box 96, FIN — 02151 Espoo, Finland; e-mail: michael.staudt@gsf.fi
[2] Polish Geological Institute, Marine Geology Branch, Kościerska 5, 80-328 Gdańsk, Poland; e-mail: zbigniew.kordalski@pgi.gov.pl

INTRODUCTION

Scientists try to model the future climate to predict what kind of environmental changes might occur. Currently it is understood that the earth's climate is warming up and the sea levels are rising. The question is, at what speed and to what extent the climate will get warmer. Climate modellers try, therefore, to inform on the trends in the climate change and assist in delineating areas that could be affected by sea level rise and/or flood patterns in 100 years time.

Within the SEAREG project, the Swedish Meteorological and Hydrological Institute (SMHI) utilised two emission scenarios (A2 and B2) by IPCC to calculate a regional climate model called the RCAO model (Rossby Centre Atmosphere Ocean model). The RCAO model has been applied to calculate future sea level changes for the Baltic Sea using two global general circulation models (GCM) to represent the recent climate (time slice 1961–1990). These two control simulations were used as a basis for producing four future scenarios based on two different emission scenarios called A2 and B2 that predicted a time slice 2071 to 2100 (Meier *et al*., 2004). The A2 scenario assumed larger and continuously increasing emissions of the major anthropogenic greenhouse gases. The B2 scenario predicted a slower increase of these emissions. In the B2 scenario, air temperature rise amounted to 2.4 and 2.6°C, and in the A2 — 3.3 and 3.4°C, respectively, depending on the global general circulation model used (Church *et al*., 2001).

To calculate the mean sea level rise up to the year 2100, both the land uplift (Ekman,1996) and the mean sea level rise were converted to represent the situation relative to the geoid. Ekman (1994), and Ekman and Mäkinen (1994) presented a unified height system (NH60) designed for comparisons between geodesy and oceanography for the Baltic Sea area. The land uplift is summed up with the three sea level rise scenarios to gain the resulting overview maps of the sea surface height (SSH) in the Baltic Sea Region after 100 years (Fig. 1). The project does not imply that the ensemble average scenario ("a medium case") is the best estimate, i.e. three scenarios were selected to illustrate the range of uncertainty.



"Low case (+4 cm)" "Ensemble average (+49 cm)" "High case (+98 cm)"

Fig. 1. Winter mean SSH relative to the annual mean SSH for 1961–1990 (after Meier *et al*., 2004, modified)

ASSESSMENT OF MODELLED SEA LEVEL RISE IMPACTS IN THE CITY OF GDAŃSK

Gdańsk is the largest city of northern Poland, situated on the southern coast of the Baltic Sea, in the Gulf of Gdańsk. It is located in a conurbation together with the cities of Sopot and Gdynia as well as suburban communities, which together form a metropolitan area called the Threecity (Trójmiasto), with a population of over one million people. Gdańsk has a population of 460,000 (2002) and is the capital of the Pomeranian province, and one of the major centres of economic and administrative life in Poland.

Having the deepest and never freezing port on the Baltic Sea, it is the largest reloading centre on the Polish and Southern Baltic coasts. The main industries are located in the harbour area and along the Martwa Vistula river shores, which are highly vulnerable to sea level rise and river flooding. There are future construction plans, such as new reloading terminals as well as housing development plans for the Martwa Vistula Island and near the shoreline. Currently, 880 ha of urban and industrial areas in the city lie below 1 m above sea level (m a.s.l.), 1,020 ha of them lie between 1.0 and 2.5 m a.s.l.

LAND SUBSIDENCE, SEA LEVEL RISE, STORM SURGES AND FLOODS

The Gdańsk region experiences land subsidence of an average magnitude around 1–2mm/year (Wyrzykowski, 1985; Fig. 2). For the last 100 years, the average sea level in Gdańsk rose about 1.5 mm/year (Wróblewski, 1994). Beginning from the 1950s, this rate has risen to 5 mm/year (Fig. 3). There are serious flood hazards for the low lying parts of the city, especially when ice jams in the Vistula coincide with the spring high water stages (Fig. 4). Strong and long lasting northern winds 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, as occurred during many floods (Rotnicki, 1995). Another source of floods in the city originates from higher water runoff from the hills west of Gdańsk, after cloud bursts, as occurred during the last flood event in 2001. The magnitude of these flash floods rises also in combination with storm surges, and their occurrence will be more probable within a changing warmer climate.

A risen sea level will alter the magnitude of floods from the seashore, changing also the impact of simultaneous high water stages and floods from discharging rivers and creeks. For the greater Gdańsk area, the following sea level rise scenarios have been calculated: (1) low case — 0.03 m (2) ensemble average — 0.48 m, and (3) high case — 0.97 m. Climate change affects also wind and precipitation patterns. The frequency of dangerous storms increased in the Gulf of Gdańsk from 11 incidents in the 1960s–70s to 38 in the 1980s–90s (Wróblewski, 1994). In combination with a risen sea level, future storm surges might reach heights of up to 2.5 m a.s.l.

The flood hazard rises with accelerated sea level rise and an increased frequency of heavy storms. Within the large and important parts of the city, port facilities, urban districts, industrial areas, warehouses, transportation routes, the old town, drainage water systems, and sewage plants as well as groundwater recharge areas are vulnerable to accelerated sea level rise and endangered by flooding. Several waste sites, including illegal and reclaimed ones, as well as industrial sites are situated in locations below or just above 1 m a.s.l. Since the high case scenario estimates flood prone areas up to 0.97 m a.s.l., the dumped or stored contaminants in these sites pose a certain environmental risk. Water intrusion can lead to mobilisation of the contaminants into the shallow aquifers and, therefore, may be a threat for future drinking water supply. The low lying areas, endangered by flooding on the coastal terrace and on the Vistula Delta Plain, contain the most important groundwater water recharge areas for water supply of Gdańsk.

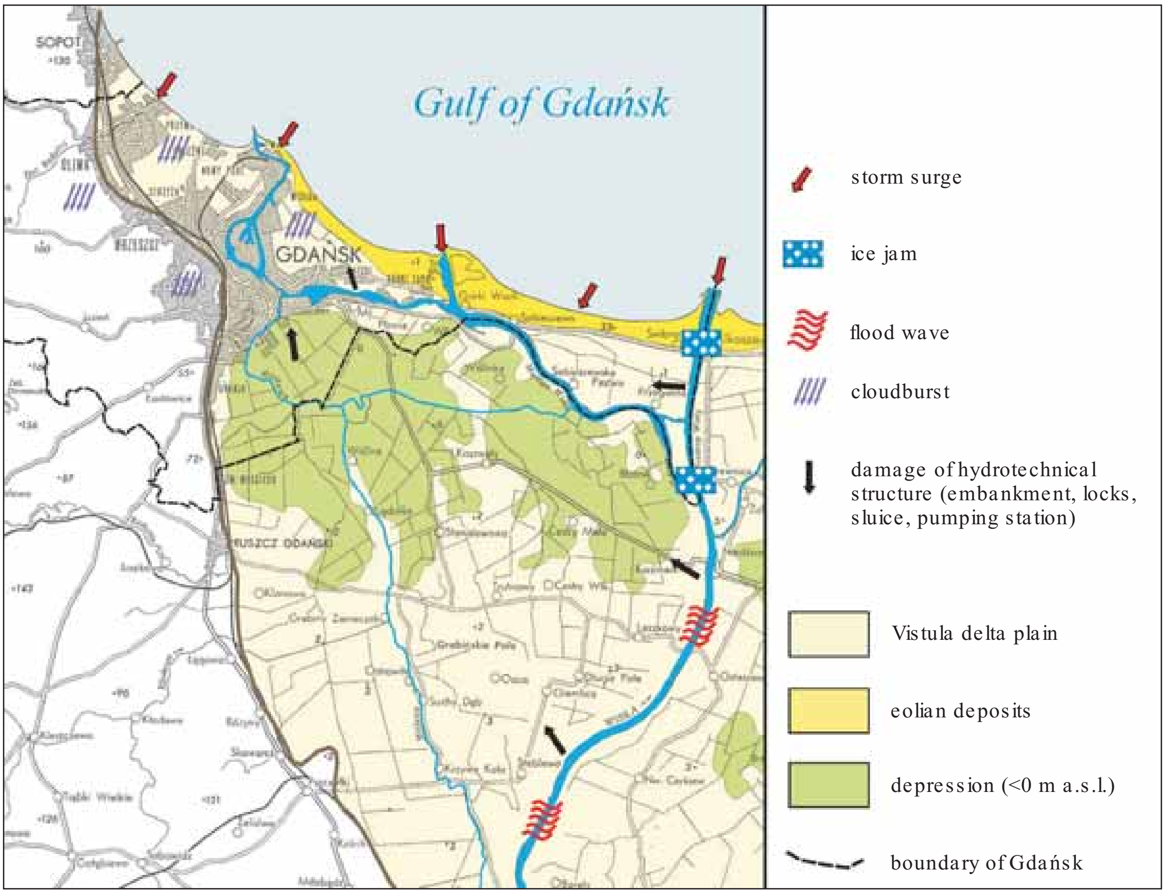


Fig. 2. Causes of flooding in the case study areas Gdańsk and Sopot (source: Polish Geological Institute, modified)

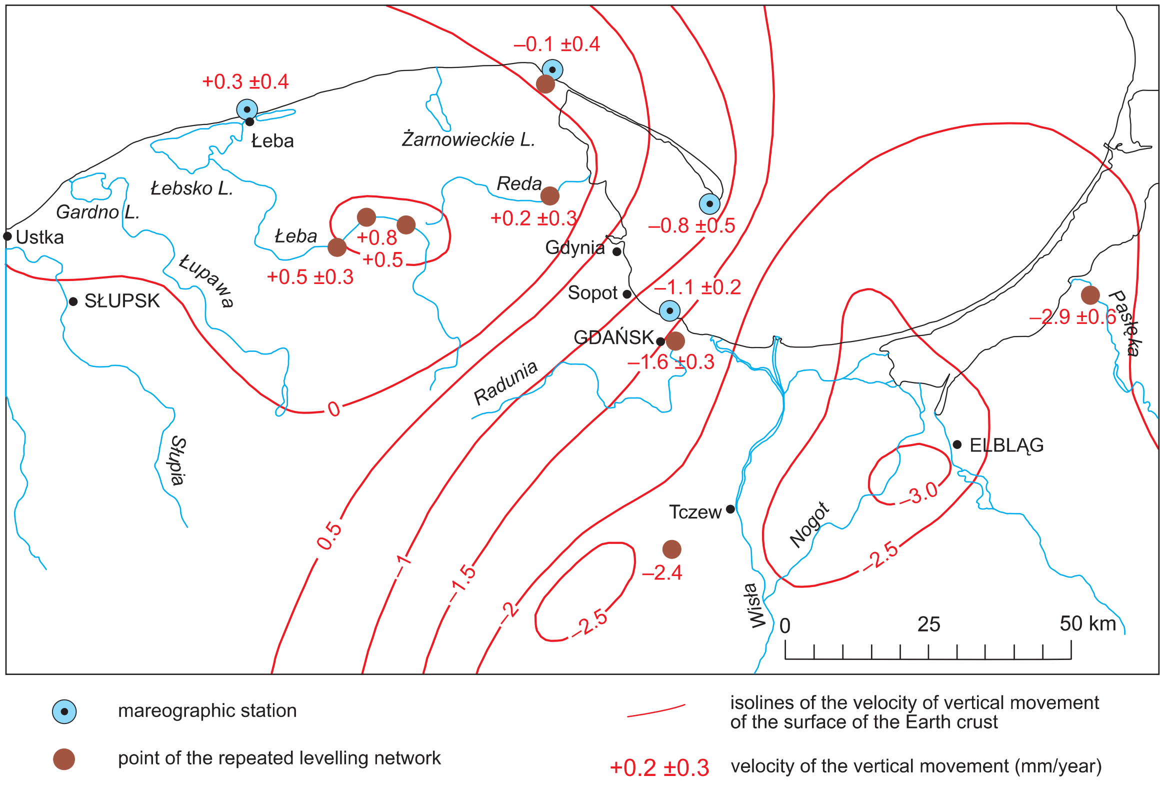


Fig. 3. Vertical movement of the earth surface in the Gulf of Gdańsk (after Wyrzykowski, 1985, modified)

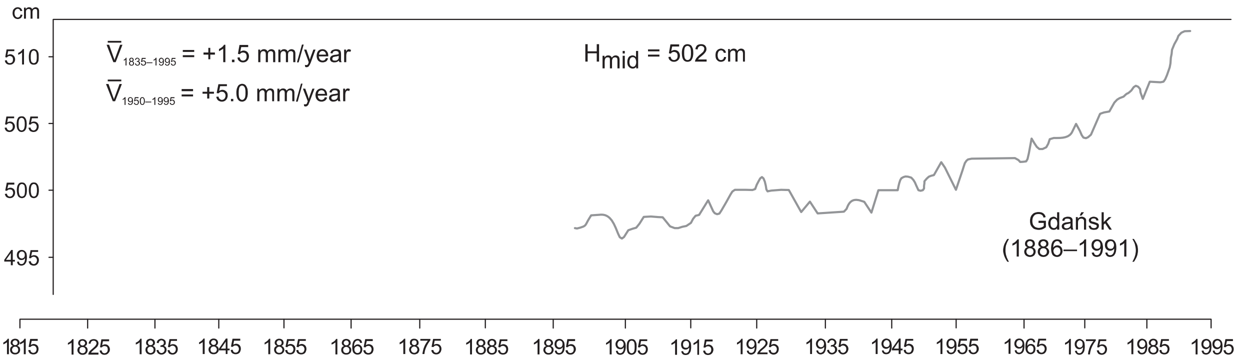


Fig. 4. Mean sea level rise measured at the Gdańsk–Nowy Port gauge (after Dziadziuszko, Jednorał, 1996, modified)

APPLICATION OF THE DECISION SUPPORT FRAME (DSF) IN THE POLISH CASE STUDY AREAS GDAŃSK AND SOPOT

A Decision Support Frame (DSF) is currently being 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: (1) Modelling and GIS applications, (2) Impact and Vulnerability Assessments, (3) Knowledge Base, and (4) Discussion Platform (Schmidt-Thomé, 2003, 2004).

Digital Elevation Models (DEMs) were produced by digitising topographic maps, coastline, and embankments in scale 1:10,000 for the case study areas Gdańsk and Sopot. The DEMs were processed with a grid resolution of 10×10 m with TOPOGRIDTOOL in the Arc/Info environment. Further-

Fig. 5. Flood prone areas in the area of the Nowy Port following the SEAREG sea level rise scenarios

Note the depression zone where industrial areas are located

more, all relevant data such as hydrogeological information, locations of dumpsites, soil contamination, land use, and infrastructure data were overlaid in the GIS. Five sea level rise scenario maps for Gdańsk and Sopot were produced and the hotspots were identified (Fig. 5). Following the DSF approach, these maps were discussed with local experts (spatial planners, scientists) and interviews were performed.

So far, the climate change and respective sea level rise are not topics for 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. The representatives showed great interest in the project's scenarios, especially because of questions on drinking water supply.

RESULTS

The evaluation of the impact matrix for the cities of Gdańsk and Sopot are presented in Table 1 and 2. The local experts were asked to fill out impact matrices that are 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 their expertise, with a classification consisting of the values: “no impact”, “low”, “medium” or “strong impact” (see Tables 1 and 2). The impact matrices are reflecting the local experts opinion of a possible future sea level rise affecting different sectors. As a further step, the vulnerability of the municipalities will be assessed.

The following points summarise the main outcomes of the Polish SEAREG case study area scenarios:

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

Table 1

Impact matrix for Gdańsk

Sea-level rise effects Gdańsk	Sector agriculture fishery forestry	Sector industry its waste	Sector services	Infra-structure	Housing	Open urban area incl parks, green fields, waste land...	Groundwater watersupply	Protected nature areas 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”, and “strong impact”, weighted values from six local planning and environment experts

Table 2

Impact matrix for Sopot weighted values from three local planning and environment experts

Sea-level rise effects Gdańsk	Sector agriculture fishery forestry	Sector industry its waste	Sector services	Infra-structure	Housing	Open urban area incl parks, green fields, waste land...	Groundwater watersupply	Protected nature areas 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

CONCLUSIONS

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. During the 2nd SEAREG Case Study Gdańsk meeting in October 2004, the first preliminary sea level rise maps were shown and the feedback from regional and municipal authorities was very positive. The topics of brackish water intrusion into the Quaternary coastal aquifers and the current and future situation of the water supply were deeply discussed. There are plans for future change of the water supply source towards the coastal aquifers which will make the water supply of the region even more vulnerable to sea level rise than it is presently. The city planners have now the DSF and the impact maps as a tool for future spatial planning. The topic of climate change is at this moment still underestimated by the cities situated along the Baltic coast, and the SEAREG project could help to arise their awareness through illustration of the future sea level rise problem. So far, the DSF is being applied in several cities in the Baltic Sea Region and it would be an interesting task to develop it further and apply it in other regions.

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