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Adaptation to floods and droughts in the Baltic Sea basin under climate change

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There has been an increasing body of evidence regarding the ongoing climate change at variety of scales. Since the climate and freshwater systems are closely inter-connected, a climate change induces changes in the freshwater systems. Even if presented climate change impacts on water resources in the Baltic region are not as strong as in other areas, and some of them are advantageous, adaptation would be needed to avoid adverse impacts and to enhance beneficial effects. Adaptation strategies in the Baltic Sea region are currently at the stage of research or policy investigations. When considering adaptation, one addresses projected impacts — in much of the Baltic Sea basin, precipitation and river runoff would increase in winter, but they may decrease in summer in the south (according to some, but not all, models). There are projections of more intense summer precipitation in the Baltic region, but also more frequent summer droughts are likely. The present paper also discusses the adaptation notions and concepts, mitigation *vs*. adaptation, and the uncertainties.

Introduction

The climate and freshwater systems are closely inter-connected, so that any change in one of these systems induces a change in the other. All hydrological processes are affected by climate change, including the variables of primary importance in water management, such as river discharges; water levels in rivers, lakes, and groundwater; and soil moisture, which are controlled by the climatic variables, notably precipitation, evaporation (dependent on temperature, radiation, humidity, and wind speed), snowmelt and glacier melt.

Climate change impacts on freshwater resources

There has been an increasing body of evidence of the ongoing warming at the global, European, and sub-European (national, regional, local) scales. A discernible global warming has been observed, with higher rate in the last decades. Most of the observed increase in the global mean air temperature since the mid-20th century is very likely due to the rising anthropogenic greenhouse gas concentrations. The updated 100-year linear trend (1906–2005) shows a 0.74 °C global mean temperature increase, while the linear warming trend over the last 50 years (0.65 °C) is nearly twice stronger than that for the last 100 years (IPCC 2007). Twelve of the last thirteen years belong to the top thirteen globally warmest years on record, i.e. since 1850 (Kundzewicz *et al*. 2008a). An extraordinary anomaly of mean air temperature of 12 consecutive months, from July 2006 to June 2007 was detected at three spatial scales (local, national, and hemispheric; cf. Kundzewicz *et al*. 2007a, 2008a). At all these scales, the pre-2007 records were exceeded by wide margins. The future warming is projected to be ubiquitous, and faster — with global temperature rise from 1980–1999 to 2090–2099 projected to be in the range 1.1–6.4 °C, depending on scenarios of the socio-economic development and on the mitigation policy, shaping the greenhouse gas emissions (IPCC 2007).

Observed anthropogenic climate change and its impacts have been unprecedented in human history. However, we are already committed to inevitable further warming (ca. 0.5 °C) due to past emissions and corresponding water-related impacts, even under the unrealistic assumption of an instantaneous freeze of greenhouse gas concentrations at the present level (Wigley 2005). Three principal classes of water-related problems — having too little water, too much water, or polluted water — are projected to be exacerbated by climate change.

According to model-based projections, the drought problems are likely to be more severe (cf. Kundzewicz *et al*. 2007b, 2008b). Alcamo *et al*. (2007) found that, globally, area of increasing water stress, defined as the ratio of water withdrawal to long-term average annual water resources, in excess of 0.4, will largely (approximately two- to four-fold) exceed the area of decreasing water stress until the 2050s, while the quantitative projections strongly depend on the scenario and climate model.

Long-term trends in precipitation have also been observed in many regions of the globe and further, stronger, changes in precipitation are expected. Spatially-distributed projected changes in precipitation directly impact river runoff, the variable of most importance in water management. By the mid-21st century, annual average river runoff is projected to increase by 10%–40% at high latitudes and to decrease by 10%–30% over some dry regions at mid-latitudes. Projections for Europe are consistent with this general formulation. Mean annual precipitation and river flow are likely to decrease over southern Europe and much of central Europe and to increase in the north, including parts of the Baltic Sea region (Kundzewicz *et al*. 2007b, 2008b). Projections of increased mean annual precipitation and river flow in much of Scandinavia translate into an increase in hydropower potential (Bergström *et al*. 2006).

The seasonal distribution of river runoff is also projected to change. Precipitation and river runoff would generally increase in winter, but in much of the Baltic Sea Basin (e.g. in the southern regions) it may decrease in summer (according to some, but not all, models). In many areas, the proportion of snow to rain in winter precipitation would decrease and there would be a reduction in accumulation of water stored in the form of snow. The winter–spring runoff peaks are expected to occur earlier (cf. Vehviläinen & Huttunen 1997).

Despite projections of more intense summer precipitation in the Baltic Region, also more frequent summer droughts are likely. There have been recurring and prolonged dry spells in recent summers in Scandinavia (e.g., exceptional severe drought of 2002/2003 in Finland) — possible harbingers of future droughts, with adverse consequences to a number of sectors, but in particular to agriculture. Then, conflicts between different sectors or different water requirements could grow, e.g. using water for cooling in power plants may further increase water temperature and have an effect on the living conditions of aquatic ecosystems (EEA 2007). In rural areas, the need to irrigate would increase, and the current conflicts of interest between agriculture and natural aquatic environments could be exacerbated.

Intensity of rainfall events is projected to increase even in some regions where the mean annual precipitation is likely to decrease (Christensen and Christensen 2003). The increased risks of floods could threaten the infrastructure, but they could also have a quality dimension. Higher intensity of precipitation and runoff may increase soil erosion and leakage of nutrients and pollutants, adversely affecting water quality, biodiversity, and human health. The expected decrease in summer flow, combined with increased temperature in lakes of southern and southeastern Sweden may have negative consequences for both the supply and quality of drinking water. But also where the runoff is projected to increase, risk of water quality problems can grow (flushing of contaminants and toxins e.g. from industrial sites and landfills by intense precipitation or floods; overhelming of wastewater treatment plants). Regional warming leads to an increase in water temperature and change in the ice regime. The Baltic Sea could be increasingly affected by eutrophication (algal bloom) and pollution. Along low-lying coasts, the intrusion of salt water may affect the quality of groundwater. With a rising sea level, saltwater intrusion may lead to broader-scale limitations of water-extraction possibilities.

In such countries as Denmark, an increased demand for water could be expected in urban areas (e.g. for cooling and watering of green areas) and the existing problems of over-use of groundwater resources close to urban areas could be exacerbated.

According to the material compiled nationally (cf., EEA 2007), the impacts of climate change in Estonia are relatively small compared with those in other countries of Europe. The rise in temperature and precipitation are expected to have positive rather than negative effect on the Estonian economy. The results of analysis of water supply and demand indicate no major effect of climate change on water use in Estonia. The groundwater resources can guarantee a sufficient supply of good quality domestic water in all regions of the country.

In larger Baltic countries, such as Sweden, considerable regional differences are projected. Country-average runoff is projected to increase by 5%–24% towards the end of the 21st century depending on the scenario chosen, with greatest increase in the mountainous northwestern regions, and decrease in the south-east. In much of Sweden the spring flow will occur earlier than recently and be lower. In southern Sweden, the summer runoff will decrease substantially, exacerbating streamflow-drought risk, while higher average autumn and winter runoff is projected, with likely consequences to an increased risk of flooding (EEA 2007).

Uncertainty

Precipitation, the principal input signal to freshwater systems is not simulated with adequate credibility in present climate models. Projected precipitation changes are model- and scenario-specific, and loaded with high uncertainty, which is (in relative terms) much stronger than for temperature projections. Hence, quantitative projections of changes in river flows at the river basin scale, relevant to water management, remain largely uncertain (Varis *et al.* 2004, Milly *et al.* 2005, Nohara *et al.* 2006) and these uncertainties have to be taken into account in the planning process (e.g., of flood protection infrastructure of long lifetime) and when assessing future vulnerability. For most of Scandinavia, climate models are consistent in projecting future precipitation increase, but over large areas of the Baltic Region there is much uncertainty in projections, so that even the sign of precipitation and runoff changes is inconsistent across the current generation of models (Milly *et al.* 2005, Nohara *et al.* 2006, IPCC 2007). There are robust, model-supported, findings on some variables and regions, but less so elsewhere.

There are many sources of uncertainty in future projections, starting from impossibility to foresee the future human behaviour (population change, social and economic development, climate mitigation policy, controlling intensity of greenhouse effect via the future greenhouse gas emission and carbon sequestration). Uncertainties are also introduced by the transfer functions: from greenhouse gas emissions/sequestration to atmospheric concentration of greenhouse gases, further to climate change (including feedbacks) and to climate change impacts. Every transfer function in the above system bears large uncertainty, so that amplification of uncertainty can be observed, throughout the logical chain from emissions to impacts. Already the climate model uncertainty (converting greenhouse gas concentrations into climatic variables, such as temperature and precipitation) is large. There is a large difference between results obtained by using different scenarios and different models. Intra-model uncertainty (for the same model and different socio-economic and emission scenarios) can be lower than the inter-model uncertainty (for the same scenario and different models).

Uncertainty in practical water-related projections is also due to a spatial and temporal scale mismatch between coarse-resolution climate models and the smaller-grid scale of a drainage basin, for which the much finer information is necessary and where adaptation is undertaken. Further, time scale of interest (e.g., for heavy precipitation resulting in flash flood, the dynamics of flood routing is in the temporal scale of minutes to hours) differs from the available climate model results (typically given at daily/monthly intervals). Scale mismatch renders disaggregation necessary and this is another source of uncertainty. Uncertainty in findings about future climate change impacts refers particularly to extreme events. Part of uncertainty is due to hydrological models and deficiencies of available observation records for model validation.

Uncertainties of climate change projections increase with the length of the future time horizon. In the near-term (e.g. 2020s), climate model uncertainties play the dominant role, while over longer time horizons, uncertainties due to the selection of emission scenarios become increasingly significant.

Adaptation: notions and concepts in water management perspective

A working definition of adaptation may read: adjustment in natural or human systems in response to actual or expected changes (stimuli and their effects), which moderates harm or exploits beneficial opportunities (after IPCC, modified). Taxonomy of adaptation distinguishes several classification categories, such as: anticipatory (proactive; adaptation to projected changes) or reactive (adaptation to past or ongoing changes), autonomous (spontaneous) or planned, private or public.

Capacity to adapt to climate change impacts varies across regions, societies and income groups. The differences reflect a number of factors, such as wealth, housing quality and location, level of education, mobility, etc. However, enhancing adaptive capacity, i.e. increasing system's coping capacity and coping range (cf. Kundzewicz 2007b), is ubiquitously needed. Adaptation policy stakeholders (persons or organisations that have a legitimate interest in a project or policy, or would be affected by a particular action or policy) are manifold, from central via regional to local authorities, individuals and communities affected, planning bodies, NGOs, researchers and the media. Participatory decision making is indispensable in the adaptation process. Supra-national bodies (such as the European Union) and national governments are expected to create enabling and enhancing environment.

There exist limits to adaptation, therein physical limits (e.g., when rivers dry up completely, hence adverse effects cannot be avoided); economic limits (affordability; or cost–benefit/cost–efficiency concerns); socio-political limits (e.g., constructing water storage reservoirs may not be acceptable due to the detrimental effects to the environment and the need for resettlement); or institutional limits (e.g. inadequate capacity of water management agencies) (cf. Arnell and Delaney 2006). Barriers to adaptation to floods via relocation can be physical, e.g. lack of land for relocation, or social — unwillingness of people to relocate.

Water management decisions have always been made on the basis of uncertain information. Yet, climate changes challenge the existing water management practices by adding uncertainties and novel risks that are often outside the range of experience. Adaptation, both reactive and anticipative makes use of a feedback mechanism, implementing modifications (and possibly correcting past mistakes) in response to new knowledge and information (from monitoring and research to modelling studies producing scenarios).

Water resources systems are designed and operated on the basis of the stationarity assumption: the past is the key to the future (Fiering and Matalas 1990, Kundzewicz *et al*. 2007b, 2008b). However, "the stationarity is dead" (Milly *et al*. 2008), hence the existing design procedures cannot be optimal: systems can be under- or over-designed resulting in either inadequate performance or excessive costs (e.g., with a large safety margin).

Unfortunately, the existing climate projections for the future are loaded with high uncertainty. Despite the recent progress in evaluating uncertainties (e.g., via ensembles-based studies), quantitative projections of changes in river runoff remain largely uncertain (Kundzewicz *et al*. 2007b, 2008b). Hence the question may arise — adapting to what?

Uncertainty in climate impact projections has implications for adaptation practices. Adaptation procedures need to be developed, which do not rely on precise projections of changes in river discharge, groundwater, etc. Water managers can no longer have confidence in an individual scenario or projection for the future, because it is difficult to evaluate its credibility. Multi-model probabilistic approaches are preferable to using the output of only one climate model, when assessing uncertainty in the climate change impacts. The large range for different model-based climate scenarios (cf. ENSEMBLES Project of the EU) suggests that adaptive planning should not be based on only one or a few scenarios, since there is no guarantee that the range of simulations represents the full possible range. Further, based on the studies done so far, it is difficult to assess water-related consequences of climate policies and emission pathways, with high credibility and accuracy (Kundzewicz *et al*. 2007b).

There are a range of adaptation measures reviewed in EEA (2007). One can try to prevent the adverse effects of climate change by structural and technological means (e.g. hard engineering solutions and implementation of improved design standards), or by legislative, regulatory and institutional means (integrated management; revision of guidance notes for planners and design standards). One can avoid or reduce risk by relocation or other avoidance strategy, improvement in forecasting systems, contingency and disaster plans. One can share loss (insurance-type strategies) and be prepared to take residual risk. Research (reducing uncertainties), education, and awareness raising are essential pre-requisites for adaptation.

From the sustainable development perspective (EEA 2007), the adaptation in the water sector should reduce the vulnerabilities of people and societies to shifts in hydro-meteorological trends, increased climate variability, and extreme events, and should protect and restore ecosystems that provide critical land and water resources and services. Further, it should close the gap between water supply and demand, by enhancing demand-reducing actions.

Planning horizons and life times for some adaptation options (e.g., dams, forests) are up to many decades, during which information is expected to change. There is an opportunity cost of failure to act early *vs*. value of delay (narrower range of uncertainty) and a controversy whether to adapt now to the existing uncertain projections or to wait for better information and adapt then. Early adaptation is effective, provided that projections of future climate change are sufficiently accurate, while delayed adaptation may lead to greater subsequent costs. A precautionarity principle should offer guidance. However, it is expected (CEC 2007a) that if no early policy response is taken, the EU and its Member States may be forced into reactive un-planned adaptation, as a response to increasingly frequent, and costly, climate extremes and crises, which may threaten Europe's social and economic systems and its security. For impacts where confidence in the projections is high, adaptation should start early. Early action could bring competitive advantages for European companies that are in the forefront of adaptation strategies and technologies, globally.

There exist "no-regret" strategies: do things that make sense anyway. It is always good to save energy, water, and raw materials. Improved incorporation of current climate variability into water-related management would render societies better prepared to future climate change. However, even if adaptation to climate change impacts typically entails significant expenditures, cost estimates are limited and speculative. Even less is known about the benefits of adaptation, in terms of damages avoided. This area constitutes a clear research need (Kundzewicz *et al*. 2007b).

Mitigation *vs.* adaptation

Both mitigation of (causes of) climate change and adaptation to (effects of) climate change are needed to avert or reduce adverse impacts. Mitigation aims to curb greenhouse gas emissions (by energy savings and transition to a global low-carbon economy) and to expand the potential for sequestration of carbon dioxide. Severe climate change impacts can only be prevented by early, dramatic cuts of greenhouse gas emissions. The EU goes for a very ambitious objective of keeping global average temperature increase below 2 °C as compared with the pre-industrial levels. For higher warming, the risk of "dangerous" (wording of the UN Framework Convention on Climate Change) climate change and adaptation costs would increase significantly. At the Council meeting in spring of 2007, the EU heads of states and governments unanimously agreed to reduce EU greenhouse gas emissions by 2020 by at least 20% as compared with the 1990 levels (by 30% in case of a global and comprehensive agreement). They also called for a global reduction of up to 50% by 2050 (CEC 2007a).

Mitigation acts on a global level (where local activities are integrated) over larger time scales due to the inertia of the climate system, slowing the rate of climate change and thus delaying the timing and magnitude of impacts. Adaptation can reduce vulnerability to changes in climate at the local level, but enabling environment is needed on all scales (sub-national, national, European Union). Mitigation can be interpreted as a kind of (constrained) "source-control" solution, while adaptation is an "end-of-pipe" approach. The benefits of mitigation will not be realized until several decades later, thus adaptation is needed to address near-future impacts. However, without mitigation, the increasing magnitude of climate change would render the adaptation to impacts very difficult, if at all possible. If the mitigation is not effective and temperatures are allowed to rise strongly, the costs of adaptation measures are likely to soar and indeed their relative effectiveness would then diminish.

Globally, an optimal (e.g. cost-effective) mix of mitigation and adaptation may exist and hence scientific efforts (e.g. EU FP6 Project "Adaptation and Mitigation Strategies" (ADAM)) are devoted to study the problem. We have to avoid the unmanageable and to manage the unavoidable.

Mitigation of climate change and adaptation to climate change and its impacts are sometimes in conflict. Some water management adaptation measures, such as desalination, pumping deeper groundwater, or water treatment, are energy-intensive and their implementation increases the atmospheric carbon dioxide concentration, which drives the greenhouse effect and warming. Afforestation and bio-fuel production in drier environments serve mitigation (carbon sequestration) but not necessarily adaptation (massive evapotranspiration of scarce water). Enhancing water storage, and — in particular — small retention, is advantageous for both adaptation (storing water when abundant and releasing when scarce, hence, weakening hydrological extremes) and for mitigation (small hydro-power without fossil fuel burning). Yet, construction of large reservoirs typically involves serious environmental and social concerns.

Climate mitigation and adaptation policy should not be seen in isolation, but rather mainstreaming should be sought, based on integration of general adaptation strategies (not only adaptation to climate change), which become part of national or regional strategies and policies of sustainable development.

Adaptation in the Baltic Sea region

The ongoing climate change has already impacted, and is projected to impact, the Baltic Sea region. Hence, adaptation is necessary to optimally benefit of positive effects and to reduce threats.

European Union (EU) background

As compared with other regions of the globe, Europe in general and the Baltic Sea region in particular, have high adaptation potential in socio-economic terms due to strong economic conditions, high GDP, stable growth, well-trained population with capacity to migrate (not only within one country but also within the super-national organism of the EU, consisting of 27 countries), and well developed political, institutional, and technological support systems (Kundzewicz and Parry 2001). However, adaptation is generally low for natural systems. Also, equity issues come about, since more marginal and less wealthy areas (and groups of people within an area) are less able to adapt.

Most countries sharing the Baltic Sea basin (except for Russian Federation, Belarus, Ukraine, and Norway) are members of the European Union (EU), and hence obey to the common EU legislation.

Subsidiarity principle, guiding the EU policy, means that the member states have to react flexibly to the specific challenges in their countries. Adaptation is basically local. However, the EU plays a coordinative role when dealing with transboundary issues and sectoral policies. It provides co-funding of a range of projects (including infrastructure). Use of structural and cohesion funds serves improvement of water supplies, e.g. in the rural communities (of climate change relevance). The EU supports research, information exchange, awareness-raising and education. In brief, it creates enhancing environment.

An important legal act of the EU, which sets out a framework for actions in the field of water policy, is the Water Framework Directive (WFD), which entered into force in December 2000. The key objective of the Directive is: to achieve a "good water status" for all waters of the EU by 2015. The Directive is universal and does not explicitly mention climate change. However, climate change must be considered in order to fulfil the main objective. As specified in WFD, through integrated water resources management it will be possible to address climate change impacts, including adverse water quality effects (e.g. in result of sea-level rise, heavy precipitation, and water temperature increase).

As indicated in the EU Green Paper on adaptation (CEC 2007a), the four-pronged approach to policy options is envisaged. The early action in the EU should integrate adaptation when implementing and modifying existing and forthcoming legislation and policies; integrate adaptation into existing Community funding programmes; and develop new policy responses. Further, adaptation should be integrated into EU external actions, reflecting the growing concern about climate change impacts and resulting adaptation needs in third countries. Dialogue and partnerships on adaptation must be established with developing countries, neighbouring and industrialised countries. Vigorous efforts should be made to reduce uncertainty by expanding the knowledge base through integrated climate research. Finally, European society, business and public sector should be involved in the preparation of coordinated and comprehensive adaptation strategies.

Principal adaptation measures in the Baltic Region

In the sequel, adaptation measures are examined, related to ongoing and projected water problems in the Baltic Sea region. Since the principal water-related problems are floods and droughts, they are the focus of the present paper. Many adaptation options address water-related problems potentially exacerbated by climate change, in particular the increasing variability of water resources, i. e. increase in the frequency of occurrence of the state of having too much water (floods) and having too little water (droughts). These hydrological extremes do not only have water quantity dimension, but they also exacerbate water quality. During floods the sewage treatment plant are not operating properly so that the sewage may contaminate the water bodies. Moreover, intense precipitation and surface runoff may flush agricultural chemicals (e.g. pesticides) to rivers, resulting in massive fish kills. Even if the slogan says that "dilution is not a solution to pollution", during streamflow-droughts, there is simply too little water for diluting the effluents.

Flood protection and preparedness

In response to a number of recent destructive inundations in Europe, such as the summer floods in 1997 and 2002, that hit several countries in the Baltic Sea basin, the EU Floods Directive (CEC 2007b) was adopted. The Directive states that the EU Member States shall, for each river basin district or the portion of an international river basin district lying within their territory, undertake:

— a preliminary flood risk assessment (a map of the river basin; description of past floods; description of flooding processes and their sensitivity to change; description of development plans; assessment of the likelihood

of future floods based on hydrological data, types of floods and the projected impact of climate change and land use trends; forecast of estimated consequences of future floods);
— preparation of flood maps and indicative flood damage maps, for areas which could be flooded with a high probability (return period of 10 years on average); with a medium probability (return period of 100 years), and with a low probability (extreme events);
— preparation and implementation of flood risk management plans, aimed at achieving the required levels of protection.

It is expected that implementation of the Directive — the most advanced legislation worldwide in the area of flood protection and flood preparedness — would considerably reduce the flood risk throughout the 27 EU member states.

There are several adaptation strategies in the area of coping with floods, which can be labelled as: protection (as far as technically possible and financially feasible, bearing in mind that the absolute protection does not exist — every dike is designed to withstand a N-year flood, e.g. 100-year flood, so it can be overtopped and/or breached/washed away, if a much higher flood occurs), accommodation (living with floods), or retreat (relocation from flood-risky to flood-safe areas) (cf. Kundzewicz and Schellnhuber 2004). This latter option aims to rectify maladaptation and floodplain development. Strategies for flood protection and management may modify flood waters and/or susceptibility to flood damage and impact of flooding.

The principal flood protection and flood preparedness measures in the Baltic Sea region are shown in Table 1.

In several Baltic Sea basin countries (e.g. Sweden, Finland), activities are underway to improve dam safety (e.g. via spillway dimensioning) and to re-design major dam discharges. Assessment of the technical and safety conditions of individual water structures and of the potential for further development is being done. Upgrade of structural defenses (e.g. expanding enclosure within embankments and improving the existing embankments around low-lying areas, increasing the height and strengthening of levees, enlarging reservoirs, etc.) and revision of the management regulations for water structures are being envisaged. Upgrade of drainage systems (in particular of urban drainage) for a future wetter climate is also found necessary. The need for costly defence and relocation measures, e.g., relocating industry and settlements from flood plains may be envisaged. A small-scale structural action is flood-proofing on the site, i.e. adapting existing building codes to ensure that long-term infrastructure will withstand future climate risks.

The notation of 100-year droughts or 100-year floods has to be revisited in the light of ongoing, and projected, climate change. The 100-year flood for a past control period is unlikely to be of the same amplitude as the 100-year flood in a future time horizon, which is of importance for large water infrastructure (e.g. dikes, dams and spillways). However, due to the difficulty in isolating the greenhouse signal in the observation records and the large uncertainty of projections for the future, no precise, quantitative information can be delivered. In parts of Germany, flood design values have been increased by a safety margin, based on climate change impact scenarios. The projections for 2050 include an increase of 40%–50% in small and medium flood dis-

Table 1. Principal flood protection and flood preparedness measures in the Baltic Sea region (source: EEA 2007 and own data). Asterisks in the secon and third columns indicate the subjective classification of a measure being either "implemented" or "planned/considered necessary".

Adaptation measure	Implemented	Planned/considered necessary
Technical flood protection (e.g. dikes, floodwalls, relief channels)	***	***
Natural storage of flood water	**	***
Restriction of settlement in risk areas	**	***
Standards for building development	*	***
Forecasting and information	***	***
Insurance schemes	*	**

charges and of around 15% in 'hundred-year' floods. A 'climate change factor' was introduced, which is to be taken into account in any new plans for flood control measures (EEA 2007).

However, the Baltic region countries have been increasingly acknowledging the importance of not relying only on technical flood protection. One of the options is the watershed management ("to keep water where it falls" and to reduce surface runoff and erosion). Restoration of wetlands and flood-plain forests and re-connection of old river arms are being considered. There is a call (e.g. in Germany) to "give more space to the rivers", to designate flood areas, and to devise flood plain protection measures. Further, legal regulations are implemented/envisaged related to use of flood-plain areas, such as restrictions on new infrastructure and on handling substances dangerous to water (e.g. non-use of oil-fired heating systems). It is important to improve society's awareness of the flood risk.

Protection against droughts (*see* Table 2)

Adaptation options for drought, low flow, and water scarcity address either the water supply side (provide more water) or water demand side (curb demand so that less water is used). Traditionally, adaptation used to be more on the supply side, hence expansion of water supply system has been traditionally sought.

Supply side adaptations include enhancing storage via increasing storage capacity for surface water (construction of retention reservoirs and dams), and groundwater (aquifer recharge), rainwater harvesting and storage, conjunctive use of surface water and groundwater, water transfer, desalination of sea water, removing of invasive non-native vegetation, deep well pumping.

Seeking savings ("negaliters") rather than supplying extension ("megaliters") is increasingly emphasized e.g., via promotion of more effective water use (e.g. water saving technologies), improvement of the operation of existing water management systems, reduction of leaks and water losses through repair and reconstruction of pipeline systems. Demand-side adaptation options play an increasingly important role in the Baltic region countries. They are, among others, reduction of specific water consumption per capita using technical means, water demand management through metering, recycling water (e.g., re-use after treatment of waste water). There are policy instruments: legislative and regulatory, financial (levies) and market-based options that affect consumer behaviour e.g., water pricing, subsidies and taxes, charges and fines. Scarce water should be re-allocated to high-value uses. The public must be made familiar with impacts of climate change and sensible water-saving measures. The information policy should be connected with education for environmental awareness raising of consumers with respect to water resources. The existing systematic monitoring in basins, including smaller ones, should be strengthened in order to improve the identification of water reduction and consequent strategy decisions.

Improving efficiency of water use in irrigation (slogan "more crop per drop") is particularly important since irrigated agriculture is the main water user, in volumetric terms. Among meas-

Table 2. Principal drought, low-flow, and water-scarcity adaptation measures in the Baltic Sea region (source: EEA 2007 and own data). Asterisks in the second and third columns indicate the subjective classification of a measure being either "implemented" or "planned/considered necessary".

Adaptation measure	Implemented	Planned/considered necessary
Technical measures to increase supply (additional source, increased capacity)	**	***
Increasing efficiency of water use	*	***
Economic instruments	**	**
Restriction of water uses	*	**
Landscape planning to improve water balance	*	***
Forecasting, monitoring, information	*	***
Insurance schemes	*	**

ures are: changes of agrotechnical practices (to minimize the loss of soil moisture, use of crop rotation, shifting sowing dates) and introduction of new cultivars (drought-tolerant crops). Soil should be protected against erosion (e.g., as a consequence of surface runoff and flash floods) and negative effects caused by cultivation e.g., by reduction of fertilization with organic fertilizers, and change of the structure of agricultural crops. Soil moisture should be conserved e.g., through mulching. However, extending of irrigated agriculture may not be a feasible solution in all Baltic countries. For instance, Polish agriculture is mostly rain-fed and — due to scanty, and variable, precipitation and the dominating lowland character, hence scarcity of sites for water storage reservoirs — no sufficient water volumes would be available if massive agricultural irrigations become necessary.

Concluding remarks

Even if presented climate change impacts on water resources in the Baltic Region are not as strong as in other areas, and some of them are positive, adaptation would be needed to avoid adverse impacts and to enhance beneficial effects. Adaptation strategies in several Baltic Sea countries are currently at the stage of research or policy investigations. These include policy guidelines, planning strategies and consultation processes. The starting point for adaptation is that the detailed evaluation of the impacts of climate change, related risks, and the definition of adaptation measures are determined and then integrated into the planning and operation of different sectors and institutions.

In Finland, an adaptation strategy has been established, based on a set of scenarios for future climatic and economic conditions, whose objective is to reinforce and increase the capacity of society to adapt to climate change. Despite large uncertainties in impacts of climate change, countries of the Baltic Sea region intend to prepare for managing adaptation.

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