3. Improved Tools for Water Management

3.1. Major Goals

The main objective for improving tools for water management is to assess how both present and future climate variability impacts on the water resources in the Baltic Sea basin, and how to quantify and possibly reduce the associated risks caused by climate extremes.

- To develop further and apply coupled atmospheric-hydrological models for improved assessment of the availability of water resources in today's and future climate
- To develop, validate, and apply different modelling systems in selected river basins to assess the impact of climate variability and change on the hydrological regime including the occurrence and severity of extreme events
- To assess future risk of water shortage and extreme events by explicitly taking account of the societal use of groundwater and surface water resources, as well as man-made changes of land use
- To develop further flood forecasting models

3.2. How to achieve these Goals

Both well-established operational and experimental science-driven hydrological models will be applied in the Baltic Sea basin including semi-distributed models, water balance models and distributed, process-oriented models. Basin-wide modelling as well as catchment specific studies should be carried out. Results from such modelling will be closely analysed and compared to each other, and discussed in relation to the performance of regional climate modelling schemes. Coupling of atmospheric and hydrological models at regional and even smaller scales should be aimed for in an effort to develop more precise and reliable forecasting tools. It is expected that higher spatial resolution of atmospheric models and a better coupling with the surface including the effects of subscale landscape structures will improve quantitative precipitation forecast (section 1.4.4), the latter being the corner stone of flood forecasting systems. Moreover, hydrological models should play a role for the validation of climate models, thus exploiting their predictive power for the state of the soil and runoff characteristics. Finally, hydrological models shall be used as a tool for the creation of water resources scenarios.

A focus on both surface water and groundwater resources is needed to address societal needs for water management, as is hydrological modelling over a range of scales. This will impact on the analysis, design and optimisation of various uses, such as water supply, groundwater recharge, irrigation, storm sewers, river regulation, levees, spillways, bridges, and other infrastructure. Water management is not limited solely to issues of quantity, but water quality and nutrient transport play an important role in the usability of water and its ecological impacts on the Baltic Sea.

The Baltic Sea basin includes many lake-rich areas that are both an integral part of the hydrological cycle and an important resource to local communities. Lakes can provide water supply and be a source of groundwater recharge to local aquifers. Many of the larger lakes are regulated for purposes of hydropower production and/or navigation. Changes in either water quantity or quality can have substantial impact on users and local ecosystems.

Phase I of BALTEX identified four specific river basins (Torne, Daugava, Vistula, and Odra) for detailed hydrological studies and intercomparison, however, not all of these studies were completely fulfilled. In Phase II, detailed subbasin-scale studies should also be a priority, and more emphasis should be given to their implementation. The decision of where such studies are carried out should be based on 1) type of application, 2) availability of data, 3) and specific climate issues. Examples of two basins that were studied in more detail during Phase I and would be likely candidates for further study in Phase II are the Torne River Basin in the north and the Odra River Basin in the south.

With the above general considerations in mind, specifics on how to achieve the four major aims within this objective follow.

3.2.1. Development and Validation of Coupled Hydrological-Atmospheric Models

- *To develop further and apply coupled atmospheric-hydrological models for improved assessment of the availability of water resources in today's and future climate*

Although considerable progress has been made in coupled hydrological-atmospheric modelling, further work is required. Some groups have focused on improving the representation of hydrology directly as an integral part of their atmospheric model, while others have linked existing or modified hydrological models to atmospheric models. Both approaches need further work and efforts are needed to assess how applicable these approaches are to water resources management. A relevant question which remains is "how usable are the hydrological outputs from atmospheric models and at what scales." Thus, efforts towards improving precipitation forecasts concerning quantity and timing should be strengthened (Chapter 1.4.4). This necessitates enhanced research of the physics of precipitation process including the role of aerosol and the initiation of precipitation, and the implementation of the findings into atmospheric models. A better representation of hydrology and soil moisture and their subscale variability leads to a more realistic representation of near surface processes in atmospheric modelling, which will also feedback into improving quantitative precipitation forecasts due to the role of the atmospheric boundary layer in precipitation initiation. On the other hand, the typically larger-scale atmospheric modules of the coupled systems must provide downscaling techniques in order to serve the hydrological counterpart at the right scale. Thus, scaling considerations are a major issue for both subsystems when coupling both regimes. A particularly valuable use for improved coupling between hydrological models and atmospheric models would be forecasting of floods. Work to investigate the quality of forecasts - both atmospheric and hydrological - with higher resolution numerical weather prediction (NWP) models should be pursued.

Coupled modelling should be accomplished at the 10-20 km scale with the present state-of-the-art atmospheric models and conceptual-type hydrological models. When aiming at a model resolution of 1 km, a further development of coupled model systems based on non-hydrostatic atmospheric models and distributed process-oriented hydrological models should be carried out. In such an effort the hydrological model should replace the traditional land surface scheme in the atmospheric component. Detailed analyses of the two-way coupled system should be performed, and the advantages and limitations of such model complexes need to be determined. In particular the ability to model and forecast extreme meteorological and hydrological events should be analysed.

3.2.2. Development and Validation of Hydrological Models for BALTEX Selected River Basins

- *To develop, validate, and apply different modelling systems in selected river basins to assess the impact of climate variability and change on the hydrological regime including the occurrence and severity of extreme events*

During BALTEX Phase I, large-scale hydrological models providing reasonable estimates of total river flow to the Baltic Sea were developed. The total inflow into the sea allows us to make generalised statements on the hydrology of large, regional drainage basins, but it does not provide the details necessary to analyse individual river systems and local drainage basins. More detailed models representing finer basin scales can provide more useful information for water managers on how extremes in both the present climate and the future climate will impact on specific river basins. Representation of groundwater at such scales is a component that is presently lacking and should be addressed. A better representation of the physical processes and exchanges of lakes is also needed. In addition to providing more detailed information for water managers, the model development part under this objective will play an integral role for analysing hydrological outputs from atmospheric models and contribute to the development of coupled models as detailed in the first aim of this objective, see section 3.2.1 above.

3.2.3. Studies of Climate Change Impacts on Water Resources Availability and Extreme Events

- *To assess future risk of water shortage and extreme events by explicitly taking account of the societal use of groundwater and surface water resources, as well as man-made changes of land use*

The hydrological modelling developed to meet the first two aims should be used together with outputs from the analysis of climate variability and climate projections (see Chapter 2). Driving hydrological models with both retrospective and future climate scenarios provides detailed information for water resource managers on how hydrological regimes respond to changing conditions. More details on projected effects of past, present and future climate variability, as well as man-made changes of land use, will greatly enhance the knowledge base of water managers. This will allow them to make risk assessments on the performance of their respective systems under variable climate conditions. A number of uncertainties associated with both the scenarios and modelling techniques exists, and attempts to account for them must be pursued in this work. This will partially be addressed by using many different scenarios.

3.2.4. Improvement of Flood Forecasting

- *To develop further flood forecasting models*

Real-time flood forecasting is a specific area where society is expected to have a direct benefit from improvements in soil moisture assessment, weather forecasting and remote sensing techniques. In association with improvements of coupled hydrological-atmospheric models (see section 3.2.1), improvements in data assimilation techniques and the use of new data, *e.g.* radar and satellite observations of rain and clouds, should be pursued. Driving hydrological models with ensemble forecasts from NWP models is already being tested. This will need further development of both the theoretical basis and practical implementations. Inputs from now-casting methods *e.g.* based on satellite and radar observations have also been used on a limited basis and should be further developed and tested in hydrological models. Downscaling of the output of weather forecast models to the usually much smaller scales of the hydrological counterparts is an important issue, especially in relation to precipitation. Questions to be answered include, for example “can new methods for estimating precipitation from radar help to give better hydrological forecasts”, and “what is the benefit in initialising hydrological modelling with remotely-sensed soil moisture and snow water content estimates”.

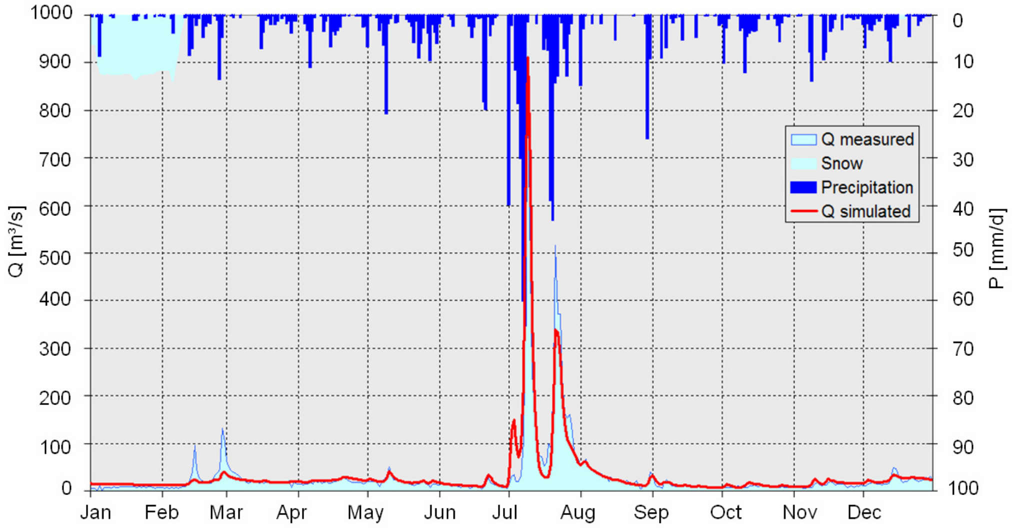

Fig. 3.1 Precipitation P (measured) and runoff Q (measured and simulated) in 1997 at Otmuchow, Nysa Klodzka reservoir, Poland). Runoff was modeled by the Precipitation-Runoff model for the whole Odra basin (SEROS), validation period was 1995-1999. Peaks show the extreme flooding events in July 1997 (by courtesy of Theo Mengelkamp, GKSS).

3.3. Involvement of Stakeholders

Within water management, the potential stakeholders range from international and national agencies to individual landowners. Their involvement will vary according to the type and scale of projects initiated. Examples are dam owners/operators, national rescue services, municipal water suppliers, farmers, newly established EU water district authorities, national environmental agencies *etc*. In some cases, the stakeholders may even provide potential funding sources for research projects. Stakeholders should help define the types of studies to be performed, provide additional inputs for researchers where possible and make active use of delivered results to improve performance of management tools.

3.4. Potential Activities

As pointed out above, potential activities cover a range of applications, model scales, data needs and coupling to meteorological models. A few specific examples are listed below.

3.4.1. High Resolution Hydrological Modelling

For investigating the impact of present day climate and climate change on distributed runoff and other hydrological variables, high resolution hydrological modelling is needed. It could be accomplished by 1) conducting (or adapting) compatible nationwide hydrological studies in all Baltic countries using basin-based hydrological models with sub-basin resolutions of 200-500 km^2, or 2) using macro scale hydrological models that cover the Baltic Sea basin with horizontal grid resolutions approaching 0.2 to 0.1 degrees. This would provide comprehensive, detailed mapping of runoff, groundwater recharge and other hydrological variables, as well as a platform to perform a wide range of hydrological modelling activities.

3.4.2. Improvement of Parameter Estimates for Distributed Hydrological Models

Within distributed hydrological modelling, it has proven difficult to link model parameter values to measurable basin characteristics. Prediction in Ungauged Basins (PUB), an International Association of Hydrological Sciences (IAHS) decade initiative, aims at improving our ability to estimate hydrological characteristics in basins where river discharge measurements are unavailable. This would be carried out by performing regional hydrological model applications and calibrations to estimate runoff characteristics and model parameters. Trials to relate runoff characteristics and parameter values to land use and soil type classes would then be conducted. A suite of different hydrological models could be used to test the robustness of the results. This should be closely associated with the work described above for high resolution hydrological modelling.

3.4.3. Coupling Hydrological Models to Regional Climate Models

Emphasising improvement in the hydrological components of regional climate models (RCMs), existing hydrological models for large catchments should be coupled to RCMs. Various coupling procedures should be tested and the performance of the models compared. The feasibility of common coupling procedures and common routing systems shall be investigated and optimum coupling procedures defined for a range of system applications. For validation, means and variability of present-day climate simulations from the coupled models at different scales should be compared to meteorological and hydrological observations. Of particular importance is the ability to model extreme hydrological and meteorological events. Thus, detailed frequency studies of modelled as well as observed time series should be performed and compared. New satellite techniques (*e.g.* the Gravity Recovery and Climate Experiment "GRACE") should be used for validation.

3.4.4. Analysis of the Consequences of Climate Change for Hydrology and Water Resources Management

Detailed basin and aquifer oriented studies of the consequences of projected climate change impacts on hydrology and water resources management need to be carried out. The appropriate modelling tools could either be forced hydrological models or regional coupled model systems. Assessing general trends in groundwater recharge and runoff, as well as future variability including extreme events are the primary foci. Different aspects of water management will be considered, including groundwater abstraction to water supply and irrigation, storage in reservoirs for hydropower and water supply, adequacy of reservoir spillways, protection of lowlands by levees, lakes and rivers as recipients for treated waste water, drainage by storm sewers, and others. Reliable estimates of, among others, the load of nutrients to lakes and costal areas are important for the water quality studies described in Chapter 4. Basin and aquifer studies at different scales are needed, and linkages to stakeholders would be particularly important in this project.

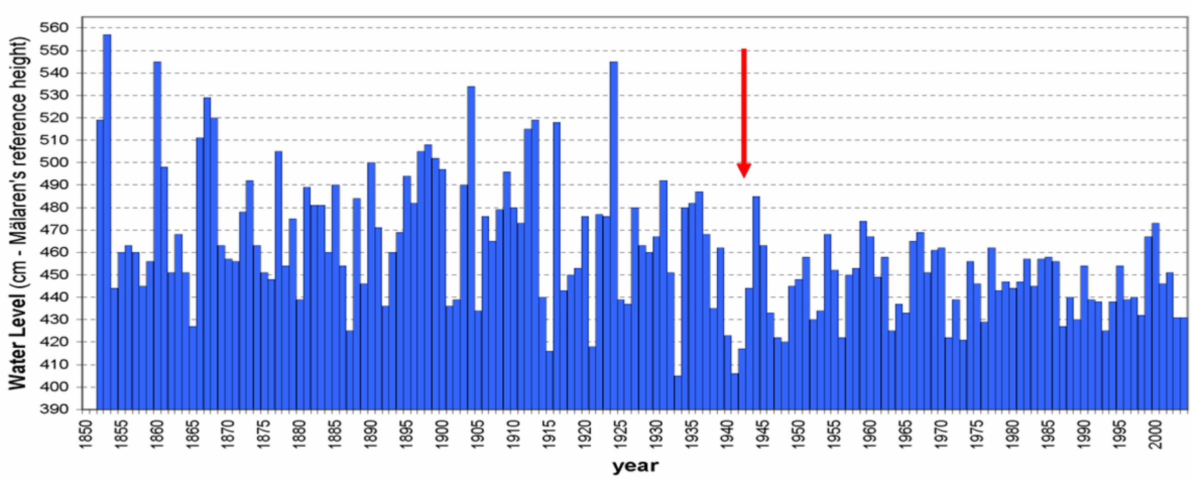

Fig. 3.2 Water level of Lake Mälaren (Sweden) since 1850. River regulation started in 1943 (red arrow) and resulted in a significant decrease of extreme flooding events (by courtesy of Phil Graham, SMHI).

3.4.5. Hydrological Modelling with Radar-derived Precipitation Applications

Radar data have the potential to become an important input for real-time flood forecasting. So far, radar data have been of limited use in hydrological models due to quality problems and insufficient adaptation of the hydrological models to radar information. This is continuously being improved on both sides, and the BALTEX Radar Data Centre now has several years of archived radar data for development use (see Chapter 8). Hydrological models should be driven with radar-derived precipitation for selected catchments. These should then be evaluated on the basis of both long-term and flooding events, and compared to results using other sources of precipitation forcing.

3.5. Specific Data Needs

High quality, long record precipitation and temperature datasets of good spatial coverage are essential for good performance in hydrological modelling. Accurate precipitation datasets are particularly important and alternative data sources like re-analysed data that lead to better estimates of Baltic Sea basin-wide precipitation and evapotranspiration. Data from microwave sensors of the GPM/EGPM mission (European Contribution to the Global Precipitation Mission) should be explored, whenever possible. In this context, the application of standardised corrections to measured precipitation should be given particular attention. Also, disaggregating of precipitation data based on Radar measurements should be pursued. BALTEX scientists will cooperate with and contribute to COST action 731 ("Propagation of Uncertainty in Advanced Meteo-Hydrological Forecast Systems") in order to address issues associated with the quality and uncertainty of meteorological observations from remote sensing and other potentially valuable instrumentation.

River discharge is important for calibration and evaluation of model results. Most of the river discharge records in the BALTEX Hydrological Data Centre are currently monthly. For specific basins selected for more detailed study, daily river discharge observations shall be obtained from the national hydro-met agencies.

Estimates of evapotranspiration in both hydrological and atmospheric modelling are particularly susceptible to uncertainty. National agencies and other relevant data holders will be contacted in order to collect relevant datasets, *e.g.* remotely sensed temperature and soil moisture content of the land surface layer, that help to improve both calculation and validation of evapotranspiration, into BALTEX Data Centres.