Hydrological forecast system for Lake Mälaren

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Lake Mälaren is Sweden's third largest lake and perhaps the most important, by means of infrastructure. It is the drinking-water supply for almost two million people, including Stockholm city. The lake is also important for shipping and it's ecological and recreational values should not be forgotten.

In order to control the water level, Lake Mälaren is a regulated lake by law since 1941. The regulation has an impact on boat traffic, infrastructure and salt intrusion, as well as the ecology. The regulation is made by managing eight different floodgates and culverts at four different sites. The site Söderström, also known as Slussen, is currently subject to extensive reconstruction plans.

In order to provide better overview of the hydrology of Mälaren, a real-time forecasting tool was developed at SMHI. The tool, presented here, will be used as a support in the regulation of Mälaren, at present, during the reconstruction of Slussen and in the future.

KEY WORDS: Hydrological modelling, forecast system, regulations

Introduction

Along the shores of Lake Mälaren there are both cities and important infrastructure located close to the water. A flood event would have major consequences including on vital public services. The Swedish Civil Contingencies Agency (MSB) has concluded that even at water levels of a half meter above the mean water level of Lake Mälaren, essential public services are being threatened. That is, for example, non-delivery of electricity, drinking water, sewerage and heating. Reducing the current risk of flood is thus very important. It is also important to consider what climate change could mean in terms of sea-level rise and changes in runoff in the tributaries around Lake Mälaren.

In December the year 2000 it became evident that the discharge capacity of Lake Mälaren was inadequate, resulting in a critical flood situation. Already in the 1990's it was evident that the outlet structure, the Stockholm landmark Slussen, has to be replaced due to aging since its completion in 1935. The vulnerability of Lake Mälaren and its shore-lines, including parts of central Stockholm, was highlighted in 2007 by the Swedish Commission on Climate and Vulnerability.

On behalf of the city of Stockholm, SMHI has since 2007 been deeply involved in the hydrological, hydraulic, oceanographic, meteorological, statistical and climate calculations that are central in the reconsideration of the outlet structure and the whole regulation scheme of Lake Mälaren (Andréason et al, 2011). The objective to propose a new regulation scheme for Lake Mälaren was carried out in close co-operation with regional authorities and other interests.

In order to provide better overview of the hydrology of Mälaren, a real-time forecasting tool was developed at SMHI. The tool, presented here, will be used as a support in the regulation of Mälaren, at present, during the reconstruction of Slussen and in the future.

Material and methods

To accomplish set-up and implementation of the real-time hydrological forecasting tool for Lake Mälaren the following activities were carried out:

- Establishment of 6 new automatic water level stations
- Set-up and calibration of two hydrological models
- Set up of model describing the function of the gates and culverts needed to forecast lake water level and discharge through each of Mälaren´s eight outflow channels
- Automatisation of simulations of water level and river discharge including short and long term forecasts
- Set-up and presentation of forecasts and observations in a web-based interface
- On the job training with training of professional staff

The forecast system is implemented into SMHIs system for real-time hydrological production and runs automatically once per day to generate the latest forecasts. The system uses inputs, consisting of water level observations from Mälaren and sea level observations from Skeppsholmen. The sea level observations are needed since the discharge capacity varies depending on the actual difference between the lake and sea water level. On average, this difference is only 0.7 m. Two hydrological models and one oceanographic models developed and operationally used at SMHI, calculate the forecasted inflow to Mälaren and the sea water level over a forecast period of nine days (short term forecast). The oceanographic model HIROMB is further described by Funkquist, L. and Eckhard, K, 2007. In addition, historical observations are used to calculate also a long term forecast for the forthcoming three months. A model describing the function of the gates and culverts calculates the forecasted lake water level and discharge through each of Mälaren's eight outflow channels. The calculations are based on the last recorded lake water level and sea water level, as well as, the forecasted inflow and sea water level. An overview of the forecasting system is shown in *Figure 1*.

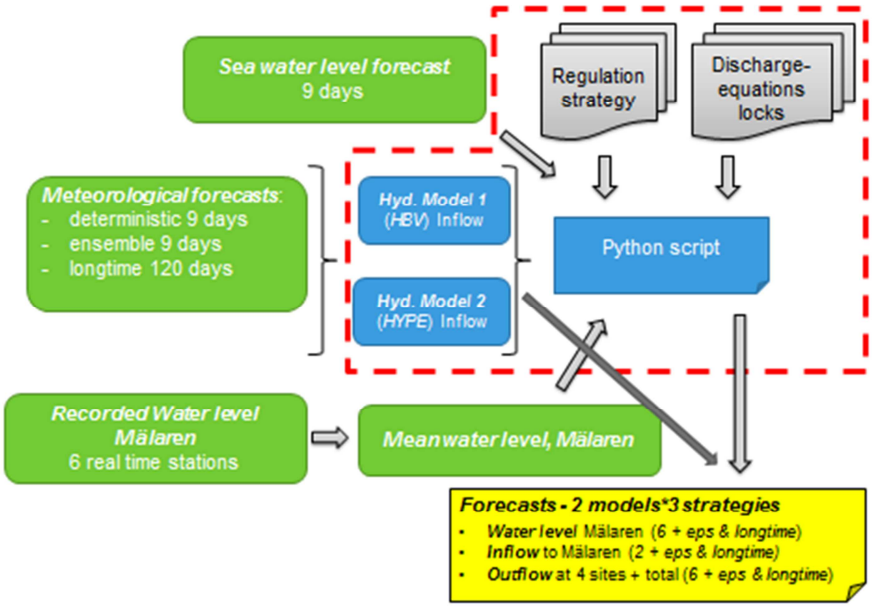


Figure 1 – Overview of the hydrological forecasting system for Lake Mälaren.

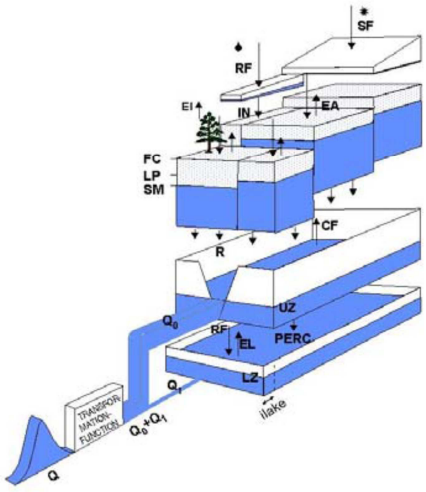
Establishment of automatic water level stations

In support and validation of the forecasting system, six automatic water level stations have been established. Station locations have been chosen to best determine the current average level in Lake Mälaren. The water level is measured both with a water bubble sensor from OTT and Keller pressure sensor accuracy of 0.5 cm. Data is collected via SMHI system AirViro (www.smhi.se/airviro) for long-term storage at SMHI.

Hydrological models

SMHI has experience from developing and using hydrological models since the early 1970s. Two hydrological models (HBV and HYPE), developed and operationally used at SMHI, has been set-up and calibrated for the catchment of Lake Mälaren. SMHI is using the HBV- and HYPE-models with a daily time step for numerous operational purposes such as hydrological forecasting and warnings, as well as for research and development projects focusing on water quality. The two models, HBV (Bergström, S. 1995, Lindström et al., 1997) and the HYPE (Lindström et al., 2010) are briefly described below.

The HBV was originally developed by SMHI in the early 70´s to assist hydropower operations. The aim was to create a conceptual hydrological model with reasonable demands on computer facilities and calibration data. The Hydrological Predictions for the Environment (HYPE) model is a dynamic, semi-distributed, process-based, integrated catchment model. It uses well-known hydrological and nutrient transport concepts and can be applied for both small and large scale assessments of water resources and status. The models can be seen as box models consisting of different storage elements. The different boxes represent snow storage, soil moisture storage, etc. *Figure 2* and *Figure 3* shows a schematic description of the HBV model and the Hype model. The models are used for river catchments divided into sub catchments that are linked through river routing routines. Main input data are precipitation,temperature and potential evapotranspiration.



RF = rainfall
SF = snow
IN = infiltration
EA = actual evapotranspiration
EI = evaporation from interception
FC = maximum soil moisture storage
LP = limit for potential evaporation
SM = soil moisture
R = recharge
CF = capillary flux
UZ/LZ = storage in upper/lower response box
PERC = percolation

Q0/Q1 = runoff components

Figure 2 - Schematic presentation of the HBV Model.

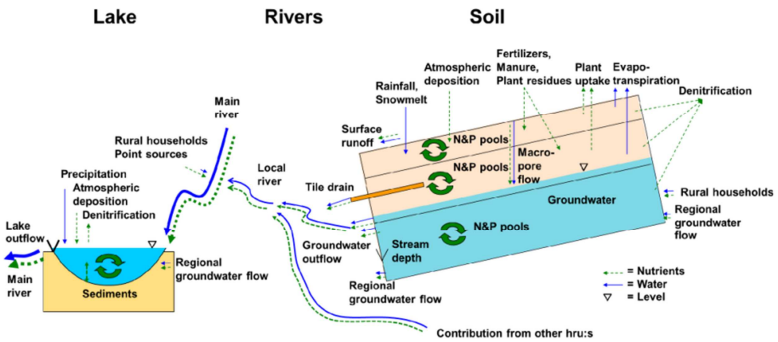


Figure 3 - The structure of a HYPE-model sub-basin, showing hydrological as well as water quality processes simulated by the model, complemented by simple structure of river reach and lake processes.

Operation of Mälaren gates and culverts

The regulation of Lake Mälaren is made by managing eight different floodgates and culverts located at four different sites *Figure 4*. A model describing the function of the gates and culverts, forecasted lake water level and discharge through each of Mälaren´s eight outflow channels was set up. The calculations are made using an iterating script, which compares the current water level to a regulation strategy, to determine the status of each of the eight channels. Alongside the forecast results given by today's legislation of regulation, the system also calculates forecasts, using two alternative regulation strategies that could be used during the reconstruction of Slussen.

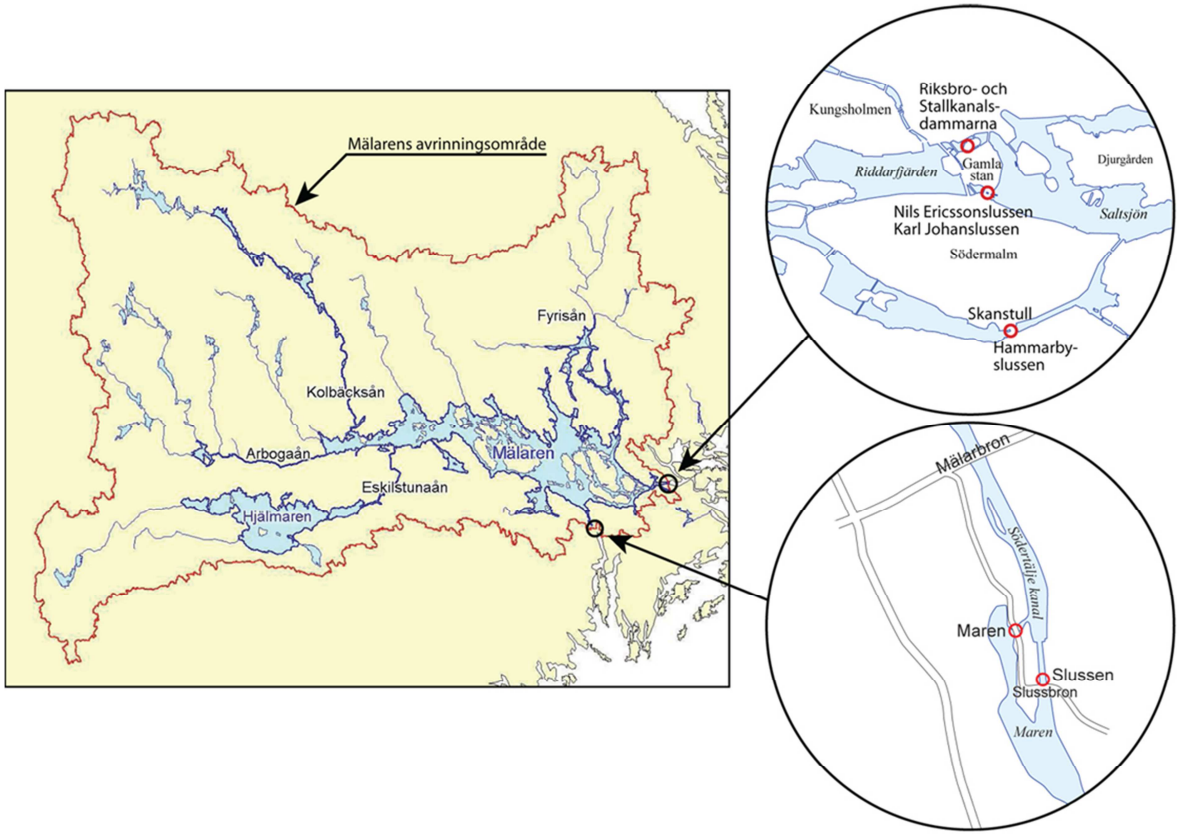


Figure 4 – Catchment of Lake Mälaren and location of outlet floodgates and culverts.

Web-based interface

Forecasts and observations, automatically produced by SMHI real-time hydrological production, can be presented in a web-based interface which visualizes the results as graphs and numbers connected to geographical points on a map. Mälaren profile has originally been set-up in an interface called WebHyPro. Currently a new interface, HYFO (www.smhi.se/2.153/professionella-tjanster/energi/hyfo-beslutsunderlag-vid-planering-av-vattenresurser-1.2486), is under development at SMHI and Mälaren profile is being set up in this new interface. The interfaces allows for presentation of observations, forecasts and post- processed data into various forms. Format for visualization of results from the hydrological forecasting system for Mälaren has been decided on in close collaboration with the end-user in order to assure usability of the system as supporting tool in decision-making.

Results and discussion

As described in previous sections the set-up and implementation of a hydrological forecasting system for Lake Mälaren includes a range of activities, all aiming at providing trustful information and to give a better overview of the hydrology of Lake Mälaren. Forecasts and observations for Lake Mälaren are now automatically produced by SMHI real-time hydrological production and further vizualised in the web-based interface HYFO providing easy access of the results to end-users. The main results presented in HYFO are summarised below.

- Observations, short and long-term forecast of water level in Lake Mälaren for three different regulation schemes.
- Observations and short term forecast of water level in the Salt sea
- Observations of water level at 6 new automatic water level stations in Lake Mälaren
- Simulated short and long-term forecasted inflow to Lake Mälaren
- Simulated short term forecasted inflow to Lake Mälaren from main tributaries
- Simulated short and long-term forecasted outflow from Lake Mälaren (four sites and three different regulation schemes)

In addition to above, observations and forecasts of temperature and precipitation at a number of meteorological stations in the Mälaren region can be accessed and vizualised through the interface. There is also a possibility to have an overview of hydrological modelling results (precipitation, runoff, temperature, snow etc) from a general calibration made with the HYPE-model for all subcatchments in Sweden. Some examples from the interface are shown in *Figure 5*, *Figure 6*, *Figure 7* and *Figure 8*

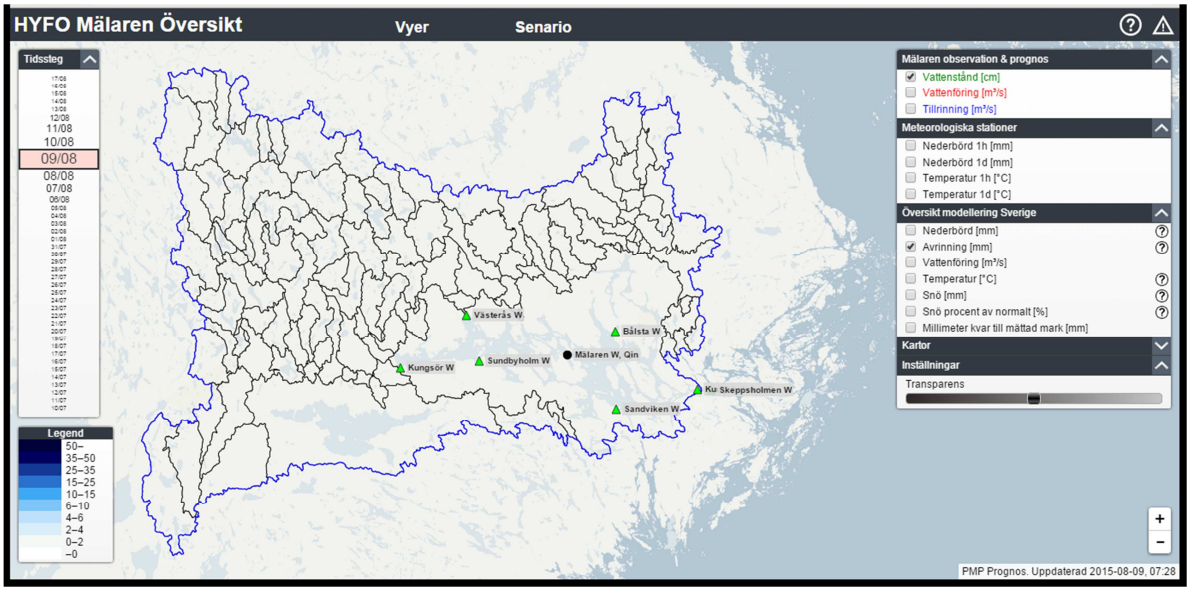


Figure 5 – Overview of Lake Mälaren.

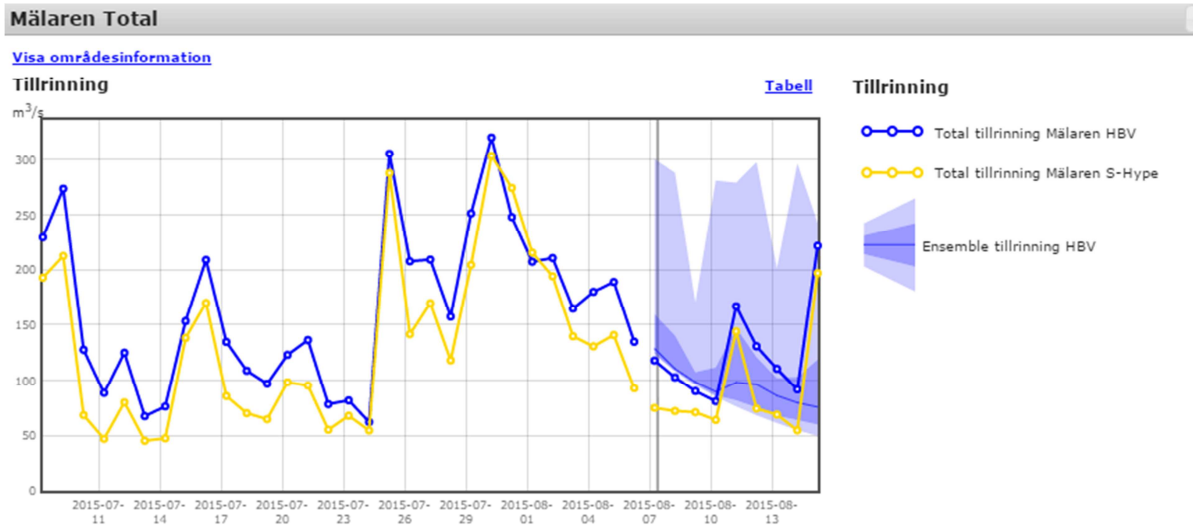


Figure 6 – Graph showing simulated total inflow to Lake Mälaren (Blue line - HBV model, yellow line – HYPE, graded blue - forecast ensemble 50 members for HBV)

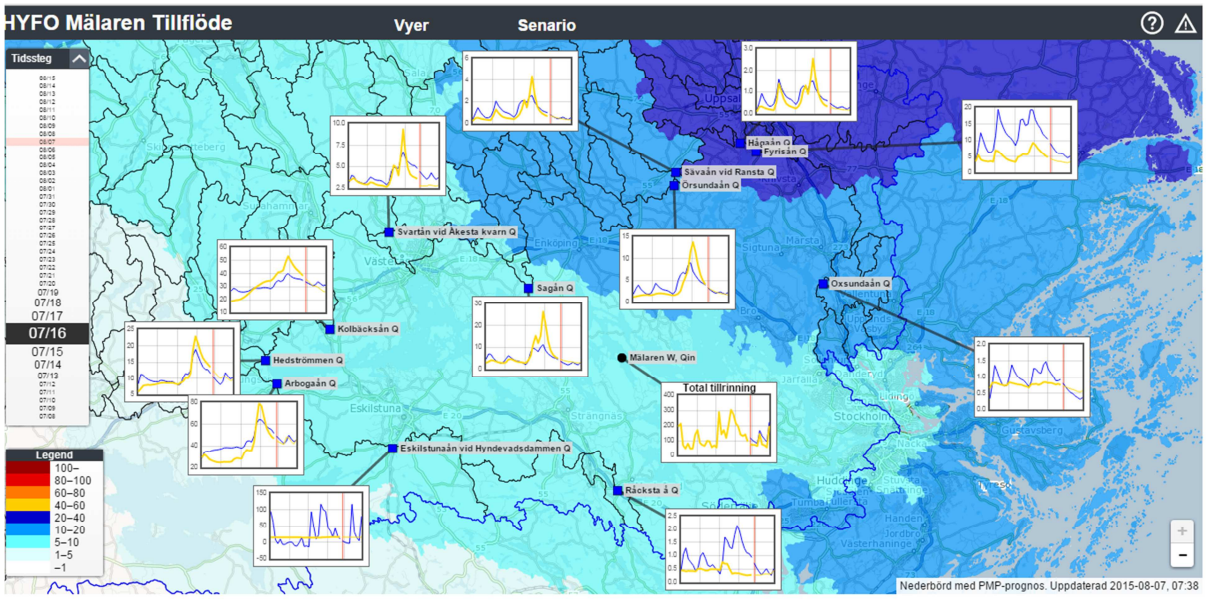


Figure 7 – Overview of inflow to Lake Mälaren from main tributaries

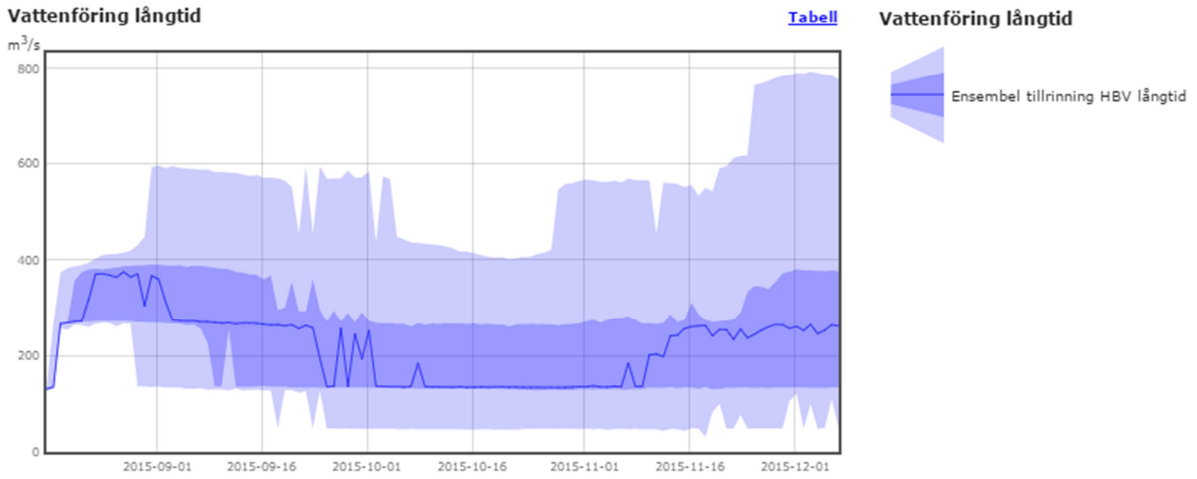


Figure 8 – Simulated long term forecast of total outflow from Lake Mälaren according to today's legislation

Conclusion

The project has successfully resulted in a complete hydrological forecasting system for the Lake Mälaren, now in operational use. The system is today an important tool providing hydrological information for the Lake Mälaren and its tributaries, minimizing the risk of infrastructural damages. The system is used as a supporting tool in the regulation of Mälaren already today and it will be further beneficial during the reconstruction of Slussen and in the future.

Acknowledgement

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www.smhi.se/airviro

www.smhi.se/2.153/professionella-tjanster/energi/hyfo-beslutsunderlag-vid-planering-av-vattenresurser-1.2486 (*Description of HYFO in Swedish*)

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The calculations are made using an iterating script, which compares the current water level to a regulation strategy, to determine the status of each of the eight channels. Alongside the forecast results given by today's legislation of regulation, the system also calculates forecasts, using two alternative regulation strategies. These will probably be used during the reconstruction of Slussen, as today's strategy, legislated in 1941, would then have to be neglected.

The forecast system is implemented into SMHIs system for real-time hydrological production and runs automatically once per day to generate the latest forecasts. The forecasts and observations are presented in a web-based interface, which visualizes the results as graphs and numbers connected to geographical points on a map.

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