04 - INNOVATIVE DECISION SUPPORT SYSTEMS FOR WATER MANAGEMENT: EXAMPLES FROM THE NETHERLANDS

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Abstract

Regional and local water authorities in The Netherlands, such as water boards and municipalities, are confronted with increasing periods with extreme weather conditions (drought and excessive rainfall), caused by climatic changes. At the same time, available space for water systems is decreasing, because of urbanisation and more capital intensive land use. Therefore a large number of Dutch water boards and municipalities operate decision support systems (DSS) for day-to-day water management and optimal operation of control structures; operational flood forecasting and warning; and analysis and evaluation of extreme weather situations. A DSS supports water managers, decision makers and crisis teams during periods of meteorological extremes, by offering them accurate information and analysis tools for evaluating strategies to prevent flooding or negative effects resulting from severe drought. These systems are based on hydrometric telemetry networks, highly detailed hydrologic and hydrodynamic models and fed with high-frequency and high-quality meteorological information such as calibrated precipitation radar data, actual information from satellite imagery and numerical weather forecasts.

Two commonly used systems in the Netherlands are the HydroNET system and the Delft-FEWS system. The HydroNET system automatically collects hydrological and meteorological measurements from regional and local telemetry networks and the national weather institute KNMI. HydroNET validates, corrects and combines the data for optimal data quality; it also calibrates precipitation radar data using ground meteorological station data. In a real-time, forecasting mode the DSS will twice a day (or once per hour in extreme conditions) calculate water levels, discharges and flow velocities using statistical models or combined hydrologic-hydrodynamic models. The HydroNET online data (web)services provide the required customized meteorological inputs, such as measured water levels or calibrated radar precipitation per hydrological response unit, either to the model engine directly or to the Delft-FEWS modeling shell. The results are presented in GIS maps (ArcGIS or web GIS) enriched with time series graphs, email reports and internet/intranet websites. Some systems automatically sends warnings when water level thresholds are exceeded, using SMS text messages and email reports. During crisis situations water managers can make additional computations with alternative flood control strategies, such as the deliberate inundation of retention areas to protect more vulnerable areas.

Setting up a DSS for water management requires profound knowledge and integration of hydrology, modeling, ICT and software development. The experience gained with the development, operation and maintenance of decision support systems for water management in The Netherlands are valuable for water managers internationally. This paper presents the innovative aspects of Dutch decision support systems and presents

critical success factors for implementation of a DSS for operational and strategic water management.

1. Introduction

About 25% of The Netherlands is below sea level and is artificially drained by pumping stations. These areas are among the most densely populated parts of the world. Urbanisation and increasing cost-intensive land use has led to a decrease in space for water. Climatic changes are expected to result in more extreme weather conditions for Dutch water managers, such as prolonged periods of drought or excessive rainfall. All these factors have led to a high demands from the public, when it comes to water safety and availability.

There are several national, regional and local authorities involved in Dutch water management. At all levels DSS are used to manage water systems effectively under current and future conditions. The National body Rijkswaterstaat is in charge of the national rivers (such as the Rhine and Meuse) and the flood defences at the coastline. Rijkswaterstaat operates several DSS systems, for example at the Maeslant storm surge barrier. This DSS controls the closure of the barrier and hence the closure of the port of Rotterdam, Europe’s biggest and busiest port. Next to Rijkswaterstaat there are 26 water boards in charge of the regional water system. The water boards are responsible for water safety, operation and maintenance of dikes and control structures (weirs, sluices, pumping stations), drought prevention, water quality and sewage treatment. They levy their own taxes and are independent from other government bodies. At local level municipalities are in charge of their sewage system networks and the operation of sewage control structures.

This article focuses on DSS for operational and strategic water management at water boards and local authorities. We present a range of used techniques and types of decision support for water management: from systems with a focus on provision of high-quality hydrometeorological information suitable to decision makers, to systems for real-time operational flood forecasting, warning and flood management.

2. DSS at Dutch water boards and municipalities

DSS are used at Dutch water boards for several purposes:

- Optimisation of day-to-day water management in terms of operation costs, capacity and energy usage. For example: running pumping stations at night time leads to lower costs for energy because of reduced electricity tariffs at night time. Discharging water at sluices near the coast during low tide at day time relieves water board staff from night shifts. However, these optimizations can be done only when possible (without increasing risks of flooding) so this requires accurate measurements of precipitation and water levels, combined with reliable forecasts of precipitation and resulting water levels;
- Flood forecasting and preparation. To prepare for heavy rainfall and high water, water boards prepare their water systems by lowering water levels to increase storage capacity of the water system by additional pumping or lowering weir crest levels;
- Flood warning to the general public and the preparation of emergency response services;

- Flood management. Water boards can have several management strategies or flood control measures for their water system, to reduce the extent of flooding or socio-economical damage resulting from floods. Examples are the upstream storage of water by increasing weir crest levels, issuing pumping stops in agricultural areas to protect urban areas, or the deliberate flooding of retention areas. Timing of these measures is critical: using them too early means they may have no effect and can not be used anymore, too late means unnecessary flooding and damage;
- Drought prevention and water distribution in summer to minimize damage to agricultural crops and minimize the negative effects of salinisation of ground water and surface water to valuable nature;
- Strategic analysis of the effect of climate scenario's on water systems.

At municipalities DSS are used for:
- Issuing short term flood warnings to general public and the preparation of emergency response services;
- Flood calamity management;
- Handling of flood damage claims of civilians and companies after flooding;
- Analysis of sewer networks, such as the evaluation of the operation of sewage storage tanks or pumping stations;
- Detection of clogging of sewage networks.

In both cases (water boards and municipalities) some general requirements apply to any DSS used for operational and strategic water management. The DSS needs to produce reliable results, be available 24/7 to its users, continuously online and up-to-date with data on hydrology and meteorology. It needs to produce results timely and quickly so lead time is sufficient to enable the water manager to respond. Finally the DSS needs to be user friendly and communicative: especially during crisis situations where water managers are under stress and available time for decision making is limited.

3. Essential: accurate and reliable precipitation information

The most important input for Dutch DSS systems is detailed and reliable precipitation information, both measurement and forecasts. Fluvial and pluvial flooding are the most dominant flooding types encountered in the Netherlands. The last tidal flood in occurred in 1953; however, fluvial flooding occurs once every few years and pluvial flooding occurs several times a year somewhere in the Netherlands. The majority of fluvial floods in the regional water systems, which are managed by Dutch water boards, have been induced by heavy rainfall events. In urban areas pluvial flooding is the dominant flooding type, because urban water systems are responding quickly to local heavy rainfall and space for storing water excess is limited.

Traditionally rain gauges are used for measuring precipitation. However, proper placement of rain gauges proves to be both challenging and costly, especially for organisations not specialised in meteorology such as water boards and municipalities. In The Netherlands Royal Dutch Meteorological Institute (KNMI) operates a dense network of daily rain gauges (approx. 325) and sub-hourly weather stations (30) which measure precipitation. These data are available to water managers at very low cost. For use in hydrology however, an even denser network of rain gauges is required to fully capture the spatial variation in precipitation. On average for urban water management one rain gauge per e.g. 4 km^2 (proposed approach in the Netherlands) would be necessary and this presents enormous investments to municipalities.

From the mid 1970s onwards the availability of weather radars provides an opportunity to measure almost real-time rainfall intensities over a wide area at high spatial resolution. The KNMI also operates two of these weather radars, which generate several meteorological data products, of which one is the precipitation per 5 minute interval, on a 1 x 1 kilometer grid. However, there are some issues regarding the use of weather radar data, which need to be addressed before the high resolution spatial radar precipitation data can be used in a DSS for water management:

- The quality of uncorrected rainfall intensities from weather radar data alone is usually not good enough for hydrological water system analysis, because precipitation intensities are usually underestimated, depending on the weather conditions or the distance of an area from the radar.
- The radar data formats are not easy to use for water managers and the timing of delivery and the completeness of the radar data varies, due to variations in the process chain of the radar data.

The issue of data quality is overcome by combining radar data and rain gauge data. The location of precipitation can be well identified by weather radars and the precipitation quantities by rain gauges. The combination of radar and rain gauges yields optimal results. In The Netherlands the correction of radar data by rain gauges is executed using two methods. The first method is a mean-field bias (MFB) correction as described in Holleman (2007). This method calculates the mean difference between the 30 automatic KNMI rain gauges and the corresponding radar pixels. This mean difference is applied to each radar pixel within the radar image. The second method includes several corrections such as a bias correction, a distance correction and finally a spatial correction (Holleman, 2003).

Figure 1 and Figure 2 show the result of the correction process. In these figures precipitation measured at a radar pixel above a rain gauge is plotted against the precipitation measured at the rain gauge. The rain gauge data is independent: the rain gauges are not used in the correction process.

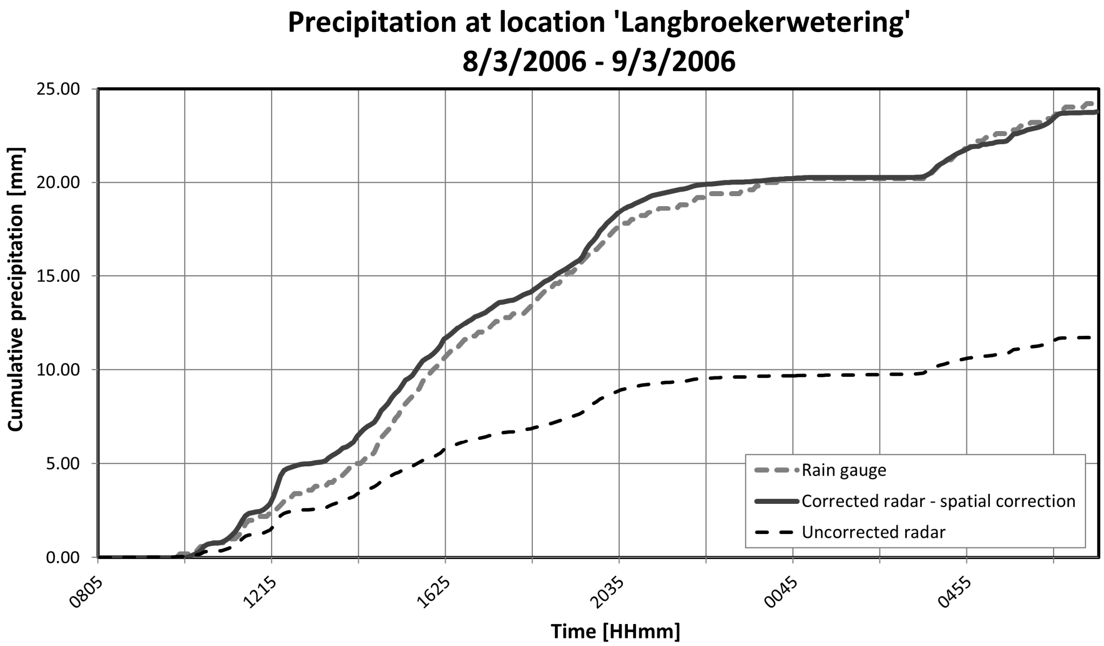

Figure 1. Uncorrected radar data, (independent) rain gauge data and corrected radar data on a five minute basis for a 24 hour rain event.

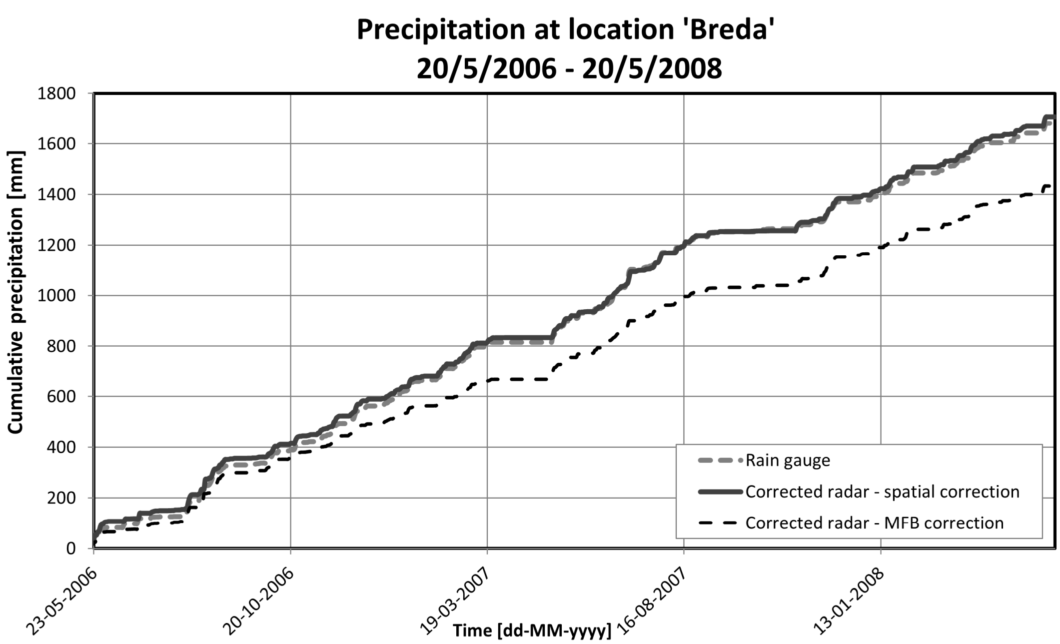

Figure 2. Cumulative precipitation at an independent rain gauge and at the corrected radar pixel above the rain gauge. Correction of radar data was done using a quick MFB correction and a full spatial correction.

The correction methods have been tested and verified at several locations situated in different parts of in The Netherlands and for several rain events.

The correction methods described above have been applied in the HydroNET system. HydroNET is a software toolbox with a spatial hydrometeorological database for water managers, to enable the use of high-resolution meteorological information in water management such as radar data. It is developed by HydroLogic and currently used by over 70 Dutch municipalities and by more than 50% of all Dutch water boards. HydroNET automatically and continuously collects, validates, corrects and stores hydrometeorological data and makes is available to users at water authorities via user friendly interfaces (Figure 3 and Figure 4).

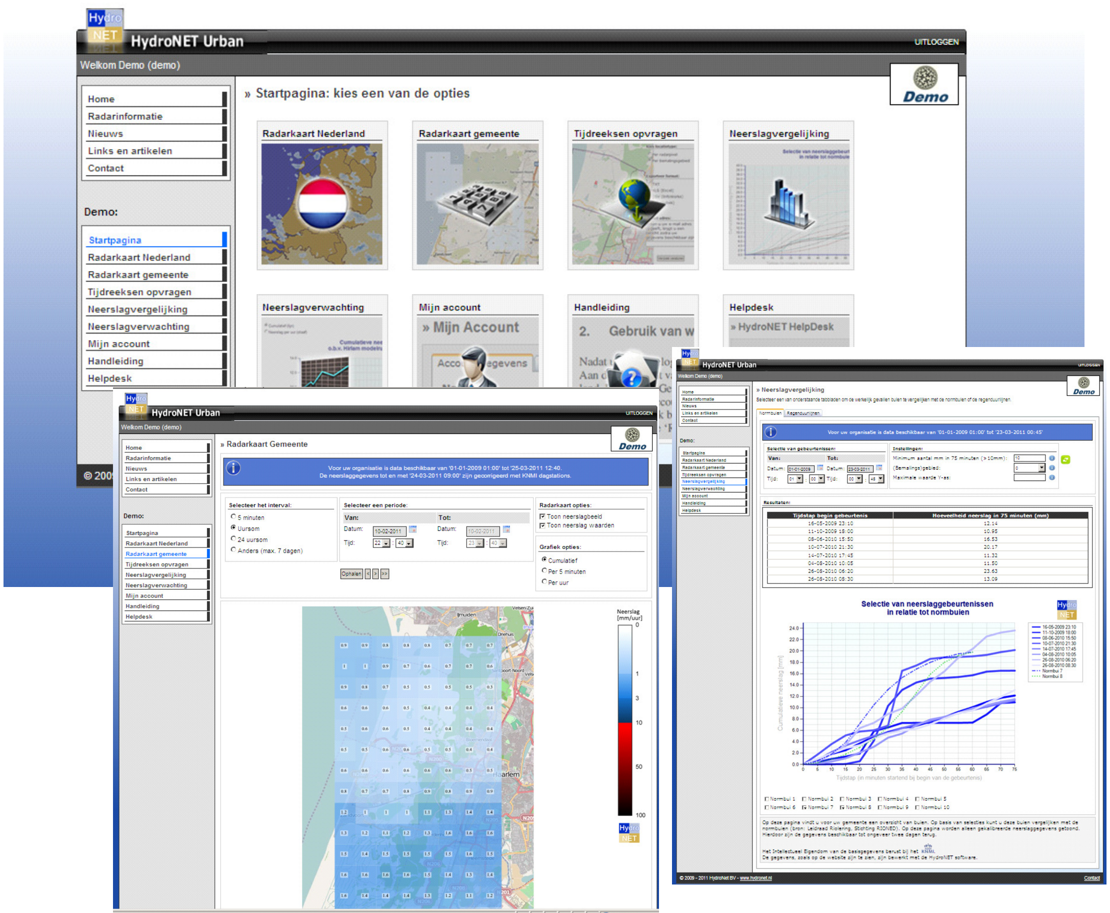

Figure 3. Example of the HydroNET web portal functionality for urban water managers, to work with high-resolution spatial precipitation data from radar. HydroNET automatically produces precipitation sums per pixel or per sewage network compartment. It also produces downloadable time series data files for input in sewage network models and statistics on precipitation events, such as return period.

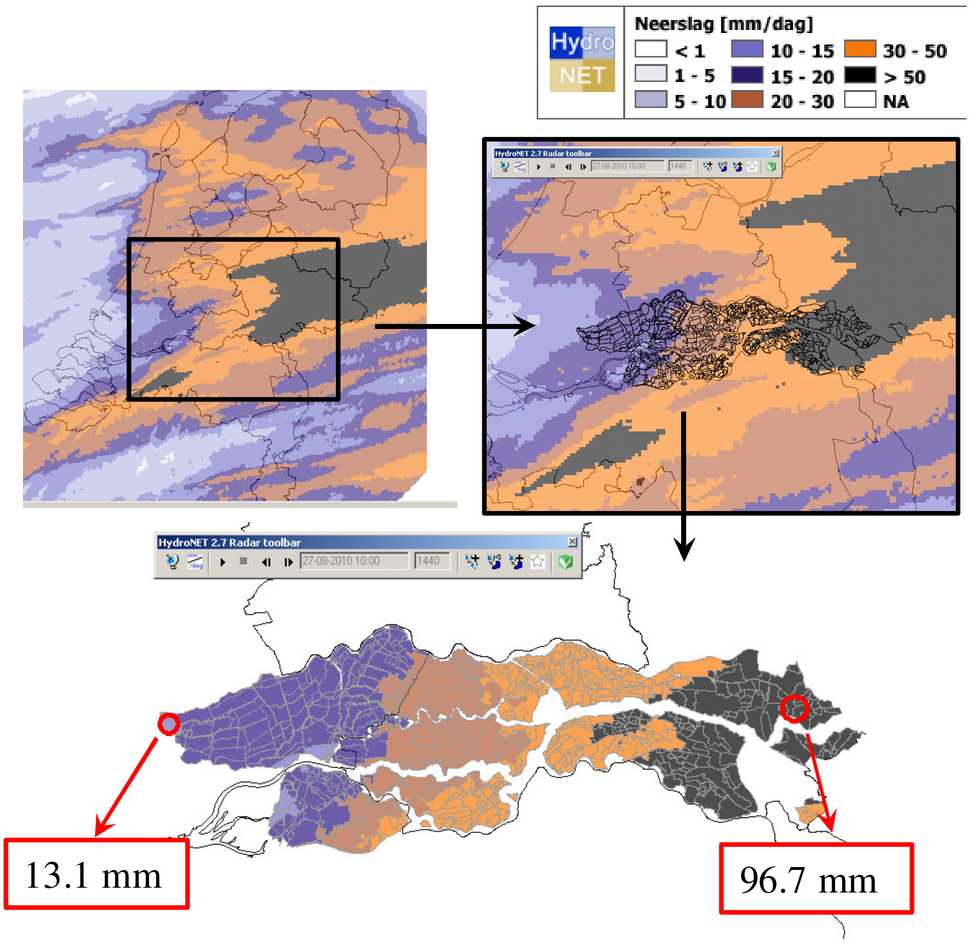

Figure 4. ArcGIS based processing of radar data using the HydroNET ArcGIS toolbar for working with radar data. Users can generate precipitation per polygon (for example: catchments, hydrological response units) and produce detailed time series files of precipitation for better calibration of hydrological models.

Highly detailed and accurate measured precipitation is essential for decision making in water management. For operational flood forecasting and warning also precipitation forecasts are required. The KNMI makes available two numerical weather models to water managers in the Netherlands, which contain forecasted precipitation:

- Hirlam (High Resolution Limited Area Model) for 48 hours in advance, in grids of 7x11 kilometer with a time step of 1 hour.
- EPS (Ensemble Prediction System) of the ECMWF which provides forecasts in ensemble (52 model runs) for 10 days in advance, for several locations in The Netherlands with a time step of 6 hours.

In HydroNET measured precipitation can be extended with forecasted precipitation based on these numerical weather models. The Hirlam model is used to gain insight into short term forecasted precipitation on a local scale (for example: per catchment or hydrological response unit). The EPS model is used for medium and long term precipitation forecasts and also provides insight into the uncertainty of the forecast. This uncertainty is translated into a minimum, average and maximum precipitation scenario, to enable operational water managers to prepare for possible more extreme situations.

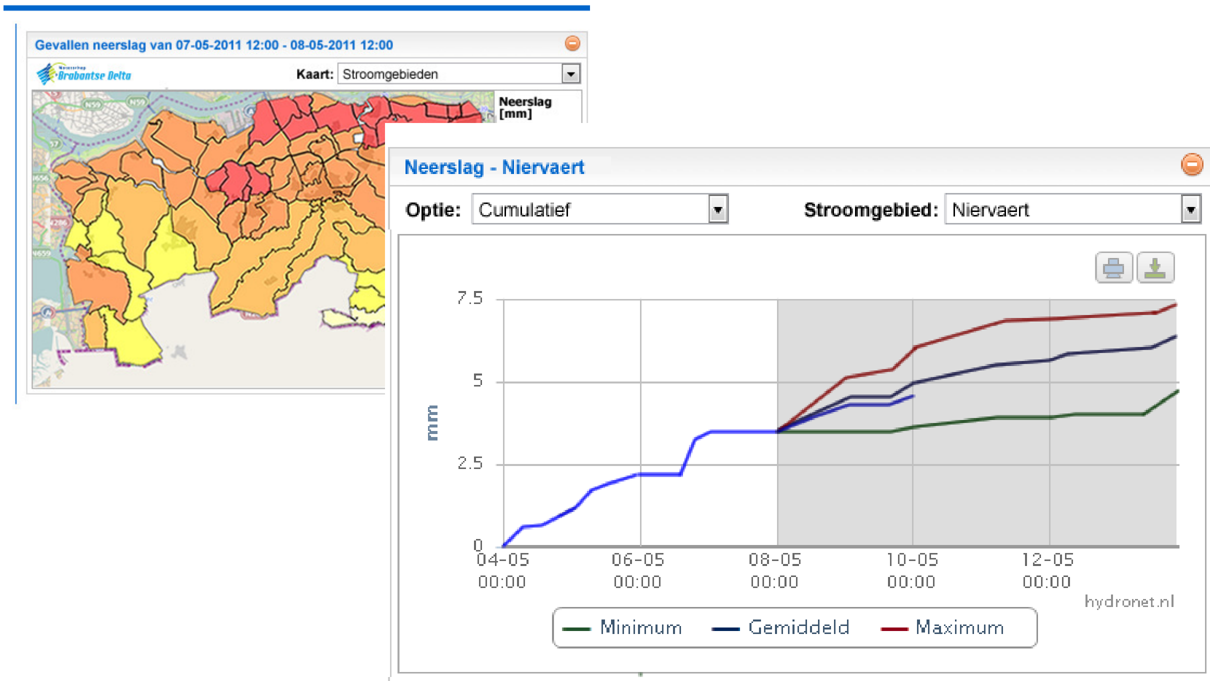

Figure 5. Web based dashboards for water board operational staff to gain insight into the spatial variation of the cumulative precipitation per catchment (top left). By clicking on a catchment a graph (bottom right) is displayed with the measured precipitation by corrected radar (blue line) extended with precipitation forecasts (grey background) from the Hirlam and EPS numerical weather models. The uncertainty in the precipitation forecasts is displayed using a minimum, average and maximum scenario.

The combination of measured and forecasted precipitation supports operational water managers at water boards in their daily tasks. HydroNET provides a user-customisable web portal where water managers can create their own dashboards to work with the hydrometeorological data. The web portal has a drag-and-drop based workspace (comparable to the iGoogle concept) where users can place their interactive tools for working with the hydrometeorological data. Pre-selections, settings and preferences are stored in a central database and re-used when the user logs in again. HydroNET also provides automatic alerts via SMS text messages or email reports, in case thresholds for measured or forecasted precipitation are exceeded.

4. Integration of telemetry, hydrologic and hydrodynamic models

All Dutch waterboards have telemetry networks available which produce high resolution, almost real-time water levels, discharges, flow velocities and other hydrological parameters. At several water boards DSS are running which collect and validate this data and use it to initialize hydrologic and hydrodynamic models. These models are in some cases highly detailed schematizations of the water system, with each water course and water control structure modeled as an individual object (see Figure 6).

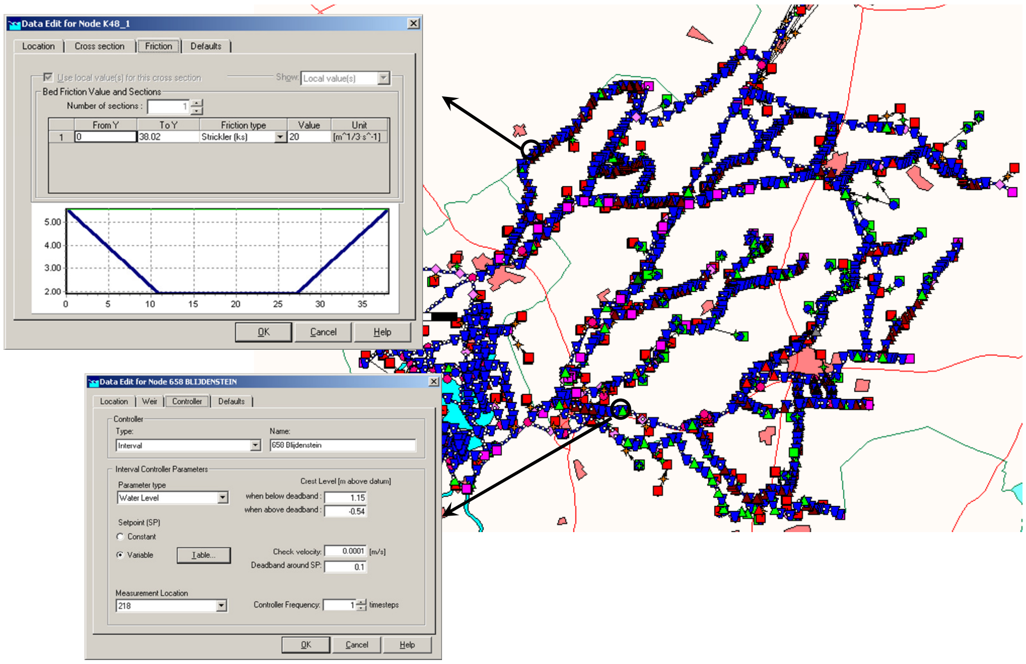

Figure 6. Detailed hydrodynamical model of the Reest en Wieden water board water system. This detailed model is used in the HydroNET DSS to produce accurate water level forecasts for the next 3-5 days. Water level forecasts are made using the telemetry data, radar precipitation data and numerical weather model forecasts.

After the initialization process, the models are accurately describing the current status of the water system. Twice a day (or once per hour in extreme conditions) model computations are made using the latest precipitation measurements and forecasts, as described in the previous paragraph, to produce forecasts of water levels, discharges and flow velocities. Typical forecast horizons are in the range of 2 to 5 days. The HydroNET online data (web)services provide customized meteorological inputs for the model calculations, such as calibrated radar precipitation per hydrological response unit. The model calculations are done using the Delft-FEWS modeling shell or the model engine directly. High performance calculation (HPC) techniques such as distributed computing and parallelisation are used to limit the required time for computations.

The results are presented in GIS maps (ArcGIS or web GIS) (Figure 7) enriched with time series graphs, email reports and internet/intranet websites. Some systems automatically send warnings when water level thresholds are exceeded, using SMS text messages and email reports. During crisis situations water managers at the water boards can make additional computations with alternative flood control strategies. They can select predefined scenarios for managing the flood event using communicative screens, or they can create custom scenarios by specifying certain measures to be taken. Examples of such measures are issuing a pumping stop or the deliberate inundation of retention areas to protect more vulnerable areas. After the water manager has defined the flood control strategy the model schematization is changed, to reflect the actions that are taken and the model computations are run again. Typically these calculations take 5 – 15 minutes in case of a highly detailed model, and multiple of these calculations can be run simultaneously.

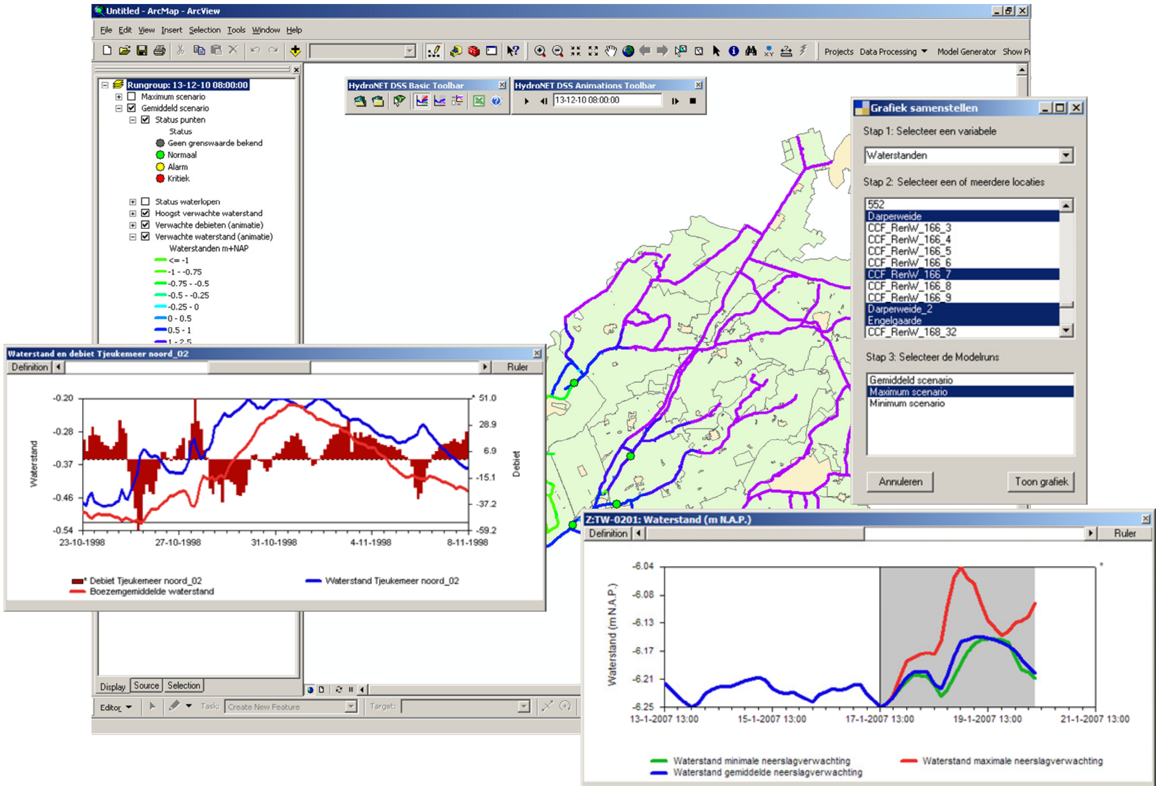

Figure 7. User interface of the HydroNET DSS system for water board Reest en Wieden. Forecasts are presented in a GIS environment where users can click on the map to display graphs with water level forecasts.

5. Maintenance and support

For Dutch water boards that use the HydroNET system at their office, HydroLogic maintains an online HydroNET helpdesk to assist the water board staff. The helpdesk can be contacted during office hours, but also offers 24-hour support in crisis situations (high water). Water board staff can contact the helpdesk with questions about interpreting the results, using the system, or to get advice on the current hydrological situation, weather conditions and weather forecasts. To deliver optimal support, the HydroNET helpdesk has an operational backup system of the water boards system running at the HydroLogic office. The HydroNET helpdesk also provides on-site training of water board staff in using hydrologic-hydrodynamic models, using meteorological forecasts in operational water management and using the system for flood forecasting and flood management.

6. Development and implementation of a DSS

Development of a DSS for water management requires profound knowledge of hydrology, modeling, information and communication technology (ICT) and software development. Successful implementation of the DSS also requires involvement of users in the process of defining functionalities, user interfaces and testing. At HydroLogic the DSDM Atern approach is followed for this purpose (www.dsdm.org). Part of the approach is early interactive sessions with users to define what they exactly expect from the DSS.

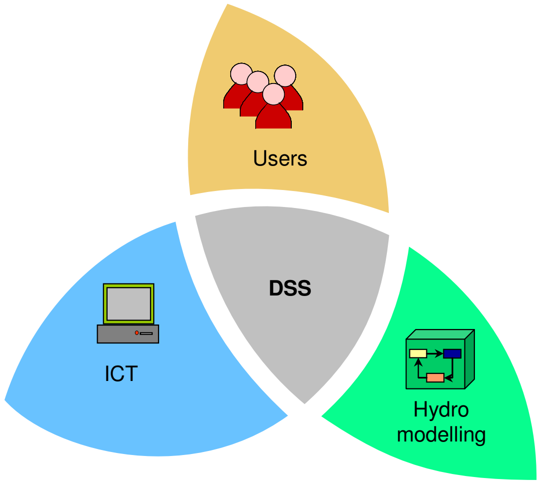

Figure 8. Successful implementation of a DSS requires integration of hydrology, modeling, ICT and close end user involvement (left). Co-creation with end users: brainstorming, sketches and content-wise discussions (right).

One of the most important recent developments in ICT for hydrology are the Software as a Service (SaaS) paradigm and the cloud computing concept. SaaS means that software that is fully running on servers operated and maintained by the developer, at their office or hosted at a dedicated datacenter. The software is offered to the client (and its users) via interactive web interfaces. Advantages of SaaS are various: no local installations of software and infrastructure at the client side is required; updates to the software can be implemented more quickly and for all clients and users simultaneously; all data is maintained and made available at a central place. Cloud computing present networks of servers which are connected to share loads of traffic and computations. The interesting feature of cloud is that it permits replication of services, using virtualisation technologies. This creates the possibility to have any number of servers available to the user on demand and increase the amount of computing power when needed, for example for uncertainty analysis. The latest HydroNET version has been developed as a SaaS solution and is currently migrated to a cloud environment, to ensure optimal performance and availability to its users at water boards and municipalities.

7. Conclusions

Dutch water boards and municipalities are using Decision Support Systems (DSS) for day-to-day water management, water management under extreme conditions (drought and floods) and for strategic analysis of their water systems. These DSS range from information systems to enable the use of high-resolution and accurate hydrometeorological information in water management with software tools, to operational flood forecasting and management systems which use detailed models. Key innovations of the Dutch DSS are the use of reliable and accurate corrected radar precipitation data, the integration of both detailed deterministic and ensemble numerical weather forecasts, web based personalisable dashboards for water managers, the use of highly detailed hydrologic and hydrodynamic models for operational flood forecasting and the use of advanced ICT techniques such as HPC, SaaS and cloud.

References

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