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## ClimOpt

### Ottimizzazione della gestione dei rischi climatici

Programma: Interreg IV A Italia-Svizzera

#### ● Feasibility FEWS Suedtirool – Analysis of a migration from ARFFS to Delft FEWS

AUTONOME  
PROVINZ  
BOZEN  
SÜDTIROL



PROVINCIA  
AUTONOMA  
DI BOLZANO  
ALTO ADIGE



KANTON  
GRAUBÜNDEN  
AMT FÜR WALD  
UND NATURGEFAHREN



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**Le opportunità non hanno confini.**



## Summary

This document presents a feasibility analysis for a migration from the Alto Adige River Forecasting System to Delft-FEWS by reusing existing hydrological and hydraulic modelling tools and data acquisition.

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## 1 Introduction

### 1.1 Background and Institutional issues

The Hydrographic Service of the Autonomous Province of Bolzano is responsible for issuing flood warnings for various local river basins, mainly the Adige and Isarco rivers and their tributaries.

Forecasting is part of “Centri Funzionali” a typical institutional framework set up in Italy during the last decade. A “Centro Funzionale” is a structure led by the Chief of the “Ripartizione Protezione Civile”. The specialized agencies for Forestry, Hydraulic works and Geology are subordinated to the “Ripartizione Protezione Civile”. The Hydrographic Service, which includes the Meteorological Service, the Hydrographic Service and the Avalanche Monitoring & Warning Service are part of the “Centro Funzionale”.

In case of imminent flood risk it is the duty of the Hydrographic Service to predict water levels and discharges with the longest possible lead time to support the “Centro Funzionale” in the issuing of timely warnings with a lead time between 6-12 hours.

The forecasts should enable the duty officers to provide information directly to the appropriate local civil protection departments in the areas at risk.

The present report examines the feasibility of a flood forecasting system for the Province of Bolzano using existing forecasting models and the Deltares data-model integration platform Delft-FEWS. The present feasibility study has been commissioned with the aim to upgrade and modernize existing forecasting capabilities to facilitate service, expansion and support in decades to come, while retaining core components.

### 1.2 Feasibility study overview

The present study commences with an analysis of the current forecasting system in use at the Hydrographic Service of the Province of Bolzano, Italy, the so called “Adige River Flood Forecasting System” (ARFFS). It continues with examining its components and the possibility of using parts of this existing operational system for inclusion into the Delft-FEWS flood forecasting platform. The report is concluded with an critical analysis and cost estimate of converting ARFFS into a FEWS-based system.

The present report is structured into the following components:

- 1) Introduction to the forecasting practices of the Hydrographic Service using ARFFS.
- 2) Analysis of the existing forecasting system ARFFS.
- 3) Description of the features and specifications and capabilities of Delft-FEWS.



- 4) Analysis of the necessary steps to include parts of ARFFS into Delft-FEWS.
- 5) A preliminary cost estimate for the implementation of a Delft-FEWS based forecasting system for the Province of Bolzano, including Support and Maintenance (S&M) services.

The results of this report will be presented during a Workshop to be held at the Hydro meteorological Service of the Province of Bolzano on September 23<sup>th</sup> 2013.

## 2 The Alto Adige River Flood Forecasting System (ARFFS)

### 2.1 Geography

The forecasting region under the management of the Hydrographic Service of the Province of Bolzano covers an area of 7400 km<sup>2</sup> and concerns the entire surface of the Province of Bolzano, northern Italy. The principal river systems are i) the headwaters of the Adige river originating in the upper Vinschgau valley, the western-most part of the provincial territory, ii) the Isarco river originating in proximity of the Brenner pass, and iii) the Rienza river, which originates in the Eastern part of the Province. The Rienza joins the Isarco within the city of Bressanone, while the Isarco meets the Adige in correspondence of Bolzano. The rivers originate at relatively high altitudes in alpine territory and receive a series of tributaries from smaller valleys and areas along their course.

The Adige River between Merano and the southern-most point of the Province (town of Salorno) flows between levees and is to a large part suspended above the surrounding valley surface.

The overall runoff regime of the headwaters is snow and glacier dominated due to presence of glaciers along the highest mountain areas and above 3000 m of altitude. The runoff in the rivers is lowest during winter months and reaches a peak during the main snow melt period between Mai and July. Figure 2.1 provides an overview of the annual hydrological regime in the Province of Bolzano.

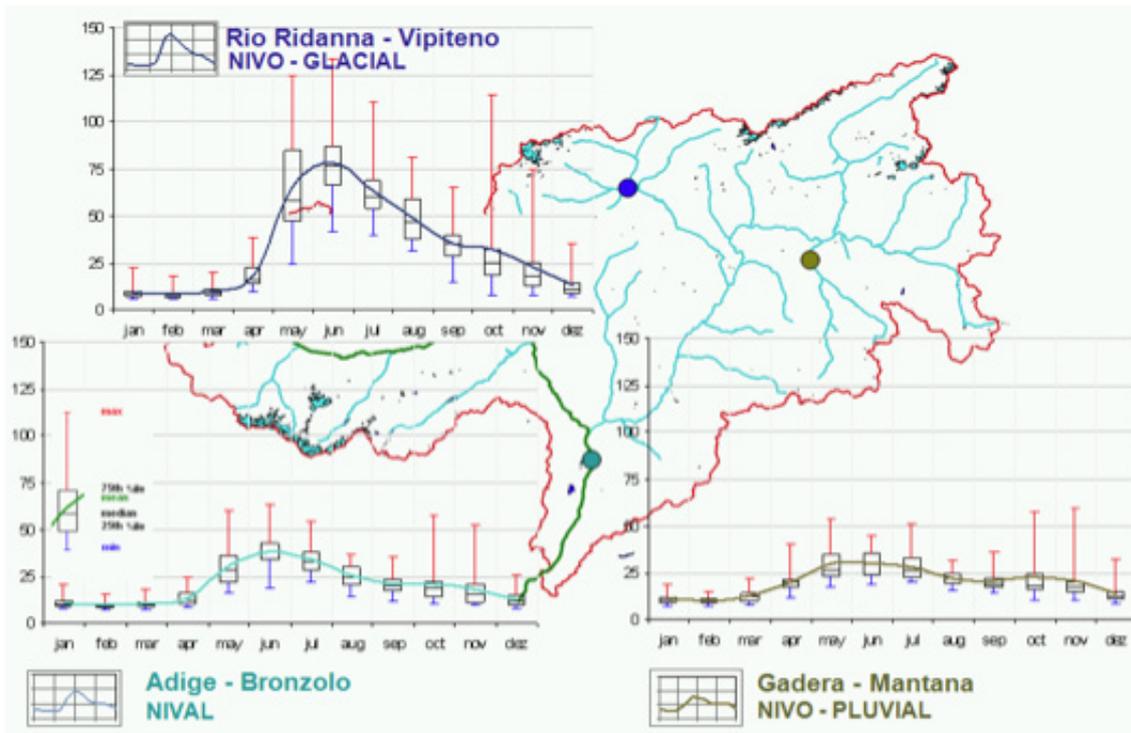


Figure 2.1 Flow regime in the principal river system in the Province of Bolzano

Since the post-war period a series of reservoirs have been constructed along the main river and their tributaries, some of which are located high up in the mountainous headwater catchments. The reservoirs play a fundamental role for hydropower generation and flow regulation. The hydropower dams have also the potential to mitigate floods. In case of inaccurate operations flood-related damage can eventuate. An example occurred during the 1987 extreme precipitation event in the Martello valley, during which the base outlet of the reservoir has been opened, causing a major local flash flood and significant damages in the valley.

The Hydrographic Service of the Province maintains a dense monitoring network, including water level recording stations, precipitation gauges, snow depth measurement devices and temperature gauges. The data are recorded by instruments from different manufacturers and transferred to the data processing unit at the Hydrographic Service in Bolzano in real-time. The entire province is also covered by a C-band weather radar, which is situated on the Monte Macaion at 1850 metres of elevation, and has an activity radius of about 120 km.

The Hydrographic Service in Bolzano has also access to numerical weather model output such as the ALMO model from the Meteo Swiss. The service has also access to ECMWF weather forecasting products and to the GFS global model.



In cooperation with the Civil Protection Service, the Hydrographic Service provides water level and discharge forecasts at a series of forecasting locations. The forecasts are aimed at protecting the population and economic infrastructure in the principal cities and urban centres along the main rivers from flooding, and to plan interventions of the civil protection service ahead of time.

## 2.2 ARFFS structure

The following section describes the basic features of the current forecasting system ARFFS, which consists of three basic components: 1) hydrological model with pre- and post-processing facilities, 2) system data base and 3) graphical user interface.

## 2.3 Data pre-processing processing

The ARFFS forecasting system is equipped with a series of pre-processing facilities, which perform all necessary data elaboration. The principal functionalities include spatial and temporal interpolation of precipitation, gap filling, quality control and extrapolation of series if needed.

The incorporated snow accumulation and melt module requires complex spatial interpolation of the temperature based on altitude zones, which is also performed by the data pre-processor.

The hydro-meteorological data required for the operation of the system are observed real-time precipitation and temperature, as well as weather forecasts by the Meteo Swiss ALMO model. The ALMO data need to be disaggregated and spatially averaged/interpolated over the river basins defined in the hydrological model.

## 2.4 The hydrological model

The hydrological model at the core of the ARFFS system (Hydrological Forecasting Model - HFM) is a conceptual hydrological simulation tool (Norbiato et al. 2008, 2009) based on the Variable Infiltration Capacity (VIC) model concept (Todini, 1996), which has been applied in a spatially-distributed fashion to the territory of the Province of Bolzano. The model is programmed in the FORTRAN 90 programming language.



The model contains a soil storage entity and a surface storage entity. The subsurface storage entity works according to the variable infiltration capacity principle. With increasing saturation of the subsurface, the infiltration capacity diminishes and the discharge towards the surface increases. The outflow of the subsurface and the surface storages contribute to the channel flow in the stream channel network. In the network the flood wave is routed via the Muskin-gum method.

Figure 2.2 shows the basic scheme of the ARFFS hydrological model, including the groundwater and the surface storage.

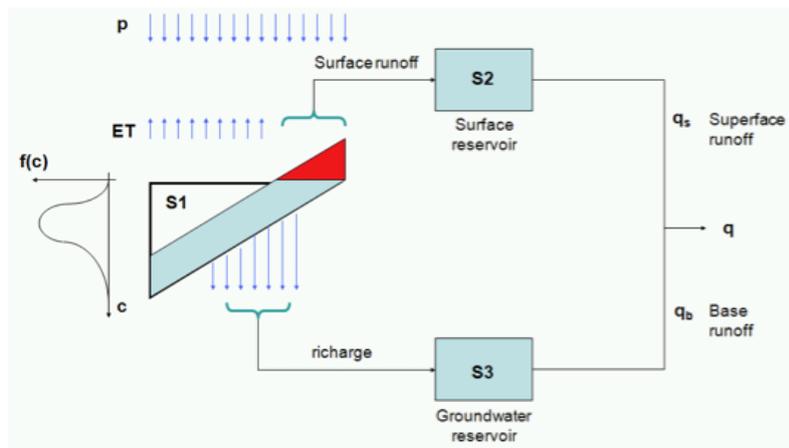


Figure 2.2 Scheme of the hydrological model in ARFFS

The hydrological model is also equipped with a snow module based on the radiation energy balance. If the temperature of the snow surface, which is calculated via the energy balance, remains below a threshold temperature level, precipitation is accumulated as snow; if the threshold is exceeded, precipitation is falling as liquid and is thus transformed directly into runoff.

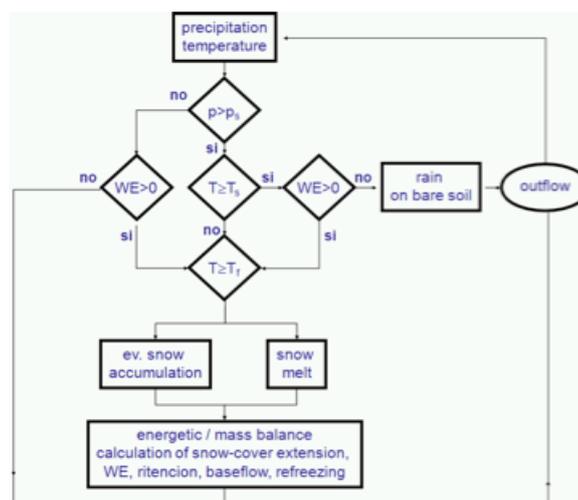


Figure 2.3 Snow computation module



Solution of the energy balance in combination with the mass balance allows calculating snow cover extension, base flow generation through melting of the snow pack, and potential refreezing. Figure 2.3 shows a schematic view of the snow accounting module.

## 2.5 Hydrodynamic routing

Full hydrodynamic routing in the model is performed only along the Adige River downstream of Merano until Salorno, the south-most location of the Province. For this purpose the “*UNET One-Dimensional unsteady flow model through a full network of open channels*” (US Army Corps of Engineers, 2001) is utilised. The model solves the Saint-Venant Equations and can perform full dynamic routing. Along the modelled branches the model utilises the geometry of actual cross section profiles.

In the remaining part of the rivers the routing is performed using the Muskingum routing method, which is solidly integrated in the hydrological modelling system.

## 2.6 The PantaRhei data base

The flood forecasting system is connected to an internal central system data base PantaRhei, which forms the operational data storage unit of ARFFS. The data base is of type Oracle. The PantaRhei data base is connected to the general data base of the Hydrographic Service, in which the real-time data read by the instruments and transmitted by the telemetry network are stored. This general data base of the Hydrographic Service uses WISKY technology.

The PantaRhei data base stores the following information:

- hydro-meteorological data series.
- modeling system parameters.
- data quality management parameters and information.
- definition of geometry (topology, hydraulic geometry).
- the information on the sequence of modules that need to be triggered to perform a hydrological simulation run.
- simulation results.

Figure 2.4 shows a schema explaining the interconnection in-between the WISKY data base and PantaRhei within ARFFS.

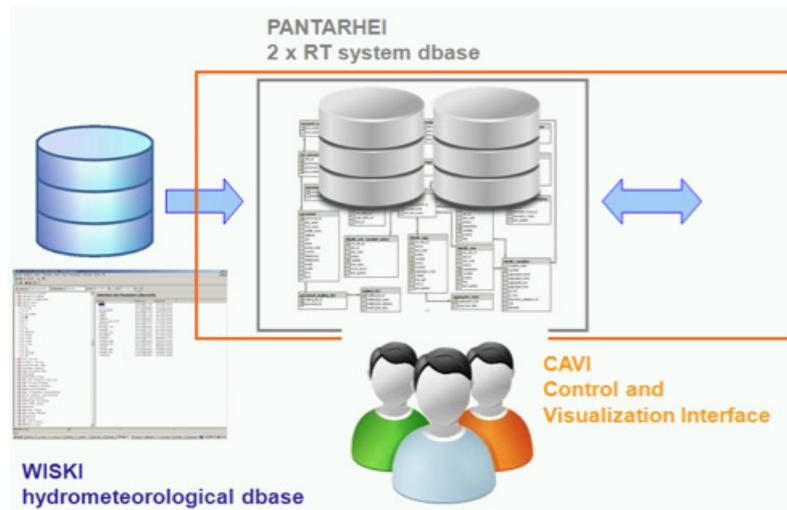


Figure 2.4 Connection between the data base of the Hydrographic Service and the PantaRhei data base

## 2.7 Graphical User Interface

The hydrological modelling system and the data base system can be controlled via a graphical user interface (GUI). The GUI provides the following functionalities:

- data import from external sources (WISKI and river cross section data); data quality management.
- control of model simulations. The simulations are performed in “simulation” and “forecast” mode.
- report generation.
- meteorological scenario and reservoir state selection for real-time simulation.
- visualization and monitoring of the internal state of the system.

The GUI is programmed in the Pascal programming language.

## 2.8 Output post-processing

All model results such as simulated and forecasted series of discharges and water levels are stored in the PantaRhei data base. The plotting facilities in ARFFS access PantaRhei and extract the data to perform customized plotting and report generation in ARFFS.



## 2.9 General Characteristics

The ARFFS system constitutes an advanced forecasting system, which has been developed to include the functionalities commonly present in state-of-the-art systems. However, one of the principal design features of ARFFS consists in the fact that the simulation models are not loosely connected with other system components, such as the PantaRhei data base or the graphical user interface. Instead hydrological model output is directly written to the data base PantaRhei, without using intermediate I/O file systems.

While this feature has no impact on the operation and the performance of the forecasting system, it reduces the flexibility in servicing the system on the long term, as it ties the user to the data base system and graphical user interface, which is solidly interconnected with the modelling system.

This architecture does not allow for an easy substitution of simulation modules during the life cycle of the system and requires specialized support interventions if changes to the system need to be made.



### 3 Delft FEWS System Features

The present chapter describes the system features and capabilities of the Delft-FEWS flood forecasting system. The system has been initially developed between 1999-2003 as a prototype research tool during the 5<sup>th</sup> Framework Programme (FP5) R&D project EFFS (European Flood Forecasting System) sponsored by the European Commission.

The system has been subsequently implemented as a fully operational forecasting platform in different contracts for the UK Environment Agency to serve as a model and data integration platform within the UK national forecasting system as well as for the Dutch Ministry of Transport and Waterways for flood forecasting on the River Rhine. In the latter case the system is shared between The Netherlands, Germany and Switzerland.

Delft FEWS is currently at the core of different national and regional forecasting systems for national and international river basins in Europe (Germany, Austria, Italy, Spain, Switzerland, Portugal), the USA as well as in Asia (Mekong river Commission, Singapore) and Australia. In Italy Delft-FEWS is used as a forecasting platform for the River Po by the Agenzia Interregionale per il Fiume Po (AIPO). The following sections provide an overview of the key elements and features of the system.

#### 3.1 Functional System Features

##### 3.1.1 Main user-interface

Delft-FEWS uses a map as the main user-interface. The map is built up of several GIS-layers (e.g. rivers, catchments, cities, roads). The measurement stations, forecast locations and catchments can be indicated on the map. Different filters can be defined for showing different type of locations and parameters. An example of the main user-interface of Delft-FEWS is presented in Figure 3.1.

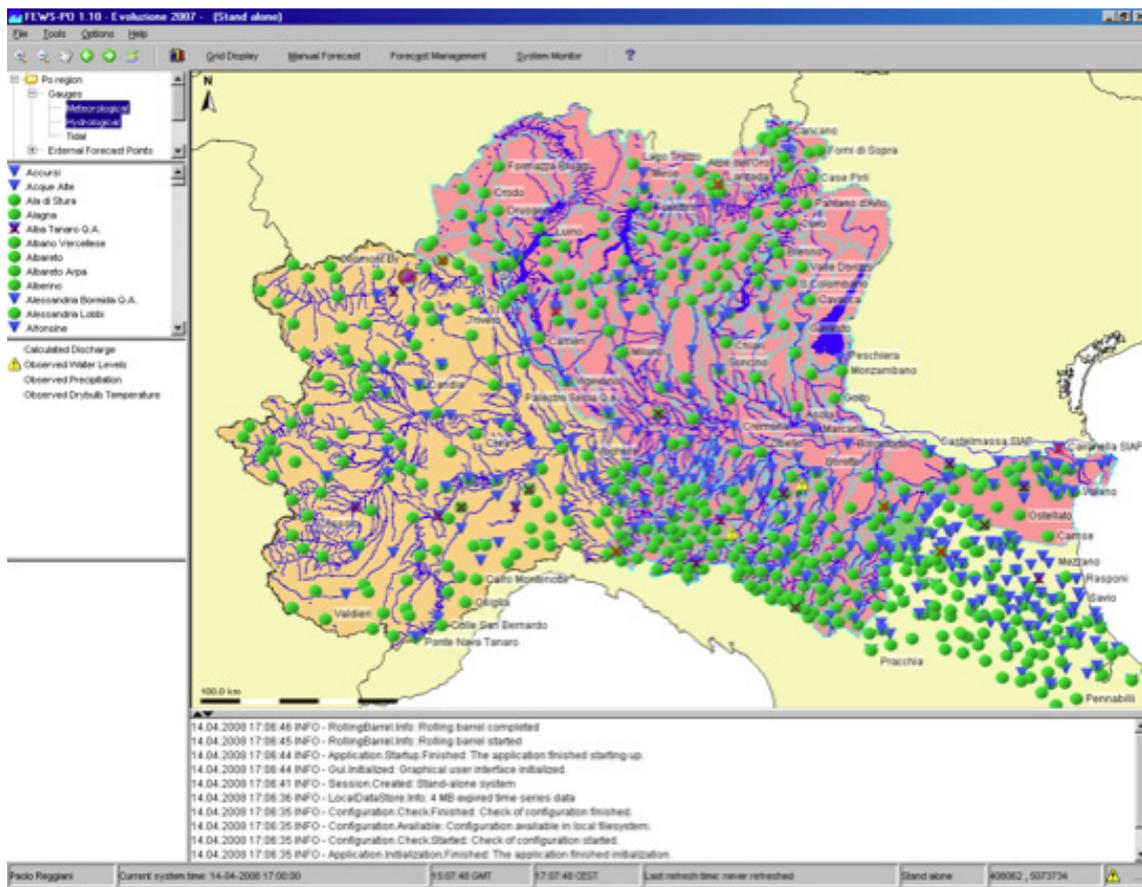


Figure 3.1 Example of Delft-FEWS map-based user-interface for the Po river system

Delft-FEWS is an open system which allows the use of different models for different catchments and/or rivers. The models can range from regression or correlation type of models, to rainfall-runoff models and 1D-hydrodynamic models. It is also possible to use a correlation type of model for one (sub)basin and use a rainfall-runoff model and a 1D-hydrodynamic river model for another basin. Delft-FEWS communicates with the external modules through an open XML based published interface<sup>1</sup>. The output produced by the models in this published interface format is imported in Delft-FEWS and can be analysed in the user-interface. The user can thus analyse in detail e.g. the output of the catchment models which is the input for the river routing models.

The Delft-FEWS user-interface allows the user to view the data for both measurement stations and forecast locations. For measurement locations, the available data can be shown up to the current system time or up to the time the last forecast run was made. Delft-FEWS allows to make several forecast runs, with different rainfall predictions. Each of these forecasts is stored and can be viewed later on by opening it again. For locations which are both measurement stations and forecast points, both types of data can be shown into one graph. See also Figure 3.4.

<sup>1</sup> The XML- interface is published on the web-site of NFFS and the web-site of Delft-FEWS.

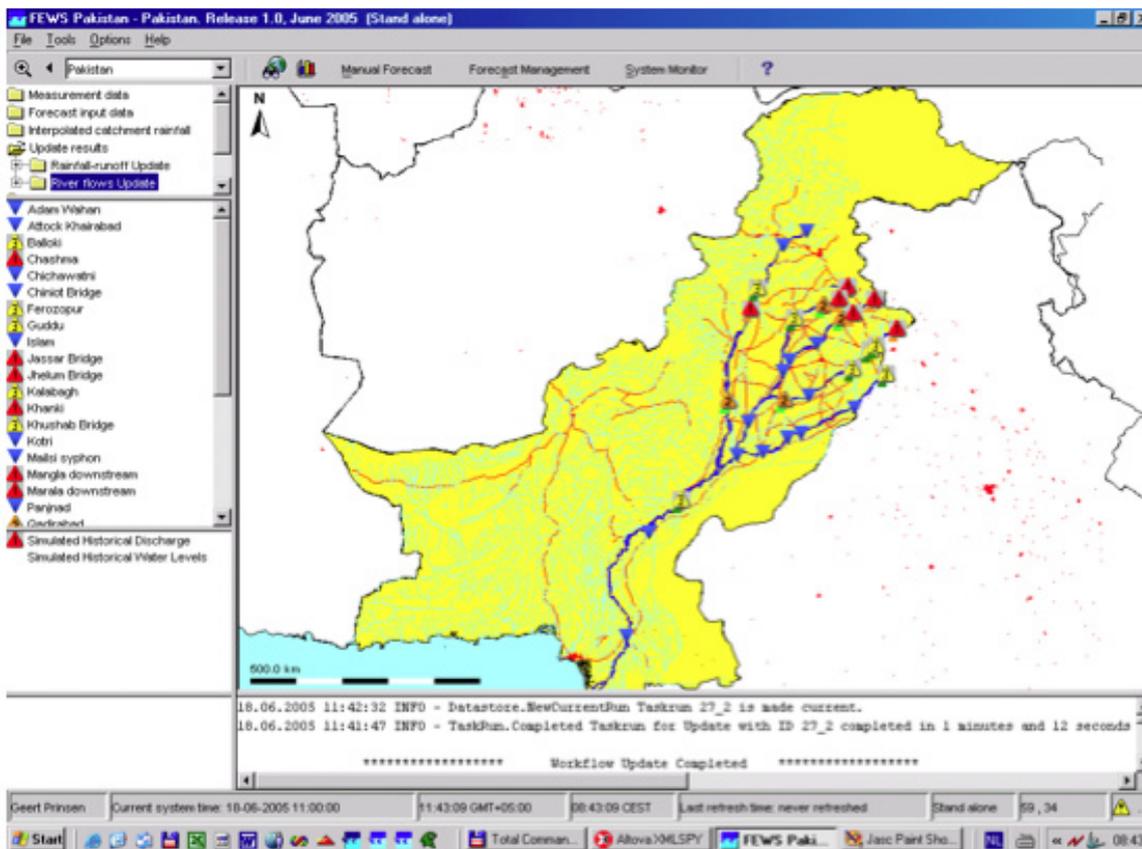


Figure 3.2 Example of the use of different warning level icons (taken from FEWS-Pakistan)

The Delft-FEWS user-interface indicates for a given forecast locations whether threshold levels are exceeded in the current forecast by using different icons. It is possible to distinguish different threshold levels (e.g. low flood, medium flood and high flood levels) and use different corresponding icons on the map display, as shown in Figure 3.2. The threshold levels are shown in the graphs as well, as shown in Figure 3.5.

### 3.1.2 Model controls

The Delft-FEWS user-interface allows the user to review catchment model input data, run the catchment model(s) on user command, and view the output as shown in various figures in this section.

Forecast runs with the catchment models can be made on command by the user or as part of a regular forecasting schedule. The models can be configured to run either individually or in one pre-programmed workflow. Each workflow can be started manually by the user or using the scheduler. The scheduler can be configured to run a workflow at any user-defined fixed time interval, e.g. daily, every 3 hours or every half hour. This is illustrated in Figure 3.3.

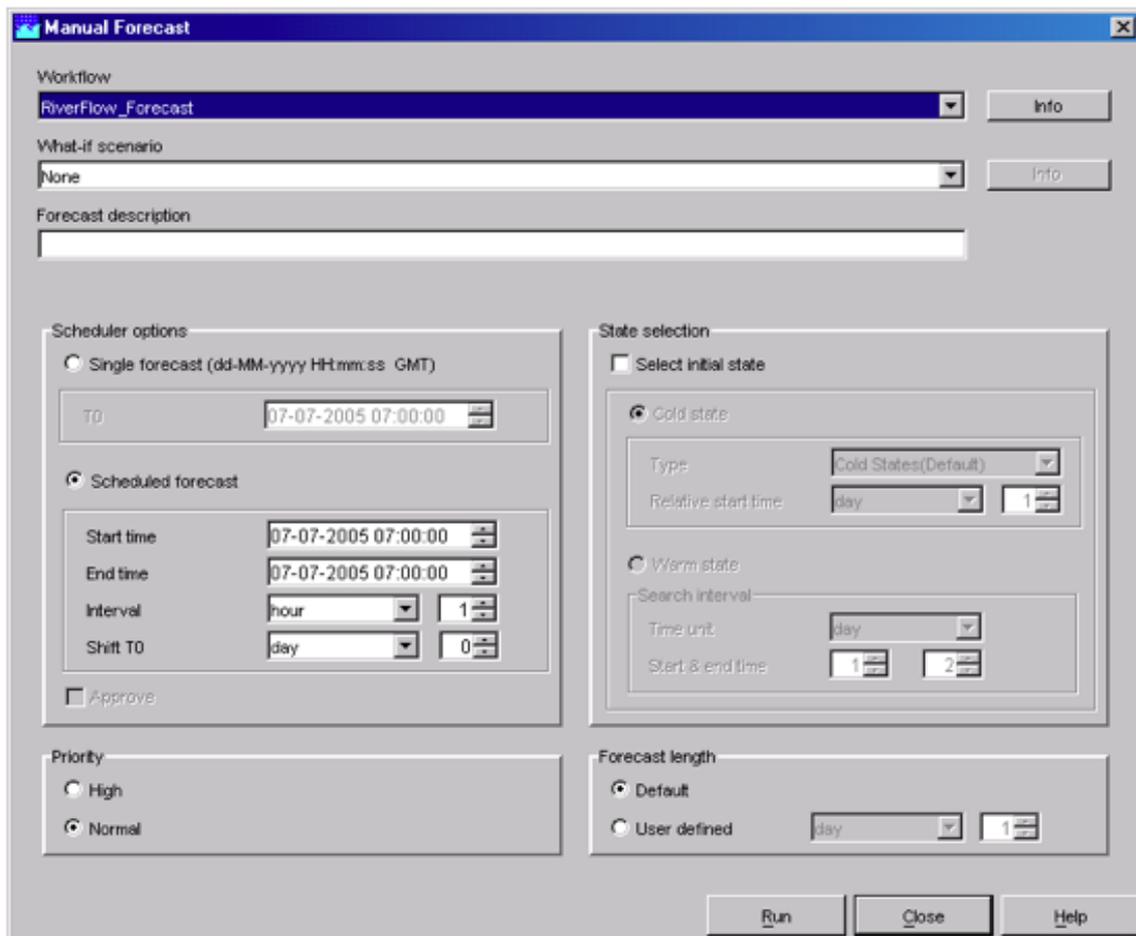


Figure 3.3 Example of scheduler options and state selection

Delft-FEWS default runs with the current time as system time (time zero). However, it is possible for the user to change the system time. This allows hindcasting, for instance analysing how Delft-FEWS would have performed during a particular historical flood period when better rainfall forecasts would have been available. It is also possible to make several forecast runs with different rainfall predictions, and compare the forecast runs among each other and with the actual observations.

Delft-FEWS supports the storage of all model state files, i.e. the dynamic variables describing the internal state of the model.

Typical state files for 1D-hydrodynamic models include water levels and discharges at all calculation points; typical state files for rainfall-runoff models contain data on (soil) moisture content. When starting a model forecast run, Delft-FEWS will provide the model with an appropriate state file generated by a previous model run, if available. This is defined as a so-called *warm state*. As a fall-back, so-called cold state files with some default initial states of the model can be used.



The communication of Delft-FEWS with the models uses the XML-based Published Interface (PI). First Delft-FEWS exports the available data in Delft-FEWS (typically time series data and state files) in the form of pre-defined self-explanatory XML file(s).

The XML files are converted to model input files using a specific model *pre-adapter*. After this, the model is run and produces its output in a native format. A model *post-adapter* converts the output of relevant locations and parameters to an XML file which is imported in Delft-FEWS.

This working procedure implies that before each model is run, the necessary up-to-date input information will be provided by Delft-FEWS through the pre-adapter interface. A model will never be using “old” input datasets.

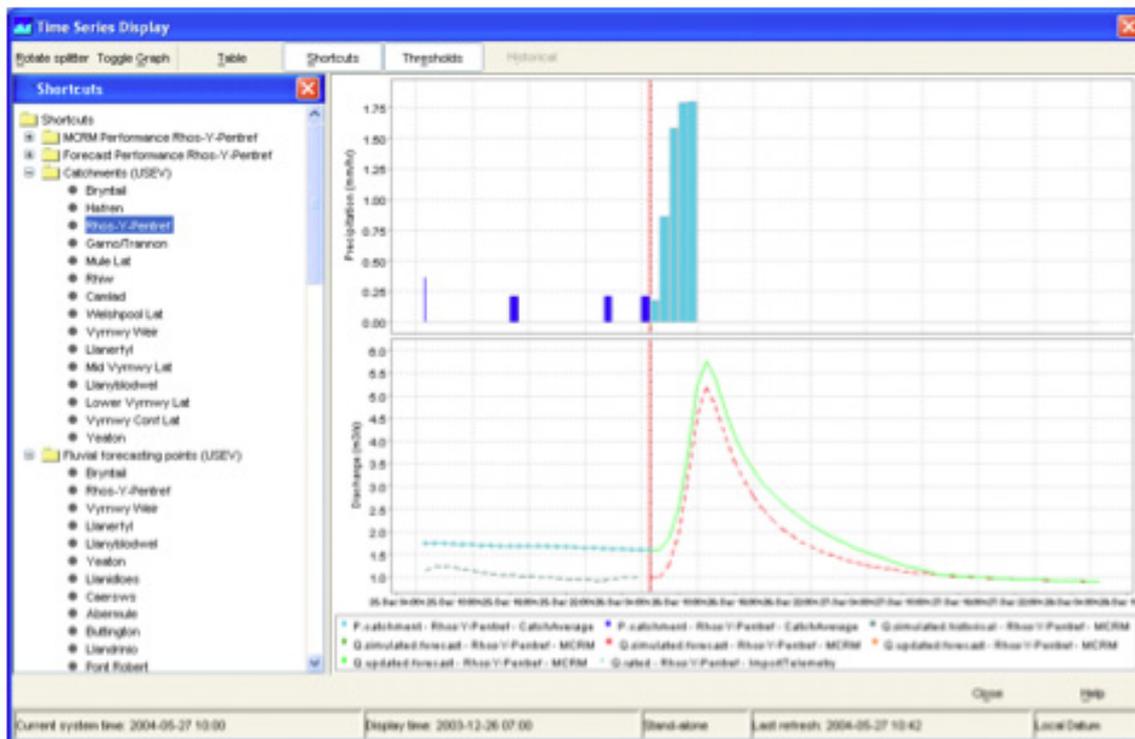


Figure 3.4 Time series display of observed and forecast rainfall, and resulting simulated and updated discharge (example from Midlands region, UK)

### 3.1.3 Model Input and Output Presentation

Delft-FEWS allows the user to present input timeseries passed to models or output timeseries computed by models through the user-interface. See Figure 3.4. This can be done by selecting the appropriate location, parameter (e.g. rainfall, water level or discharge) and forecast run. Shortcuts with graphs for a number of predefined (configured) locations and parameters are available, allowing a quick graphical assessment of input and forecast results at relevant loca-



tions. The legend of the graph contains information on the location and parameter. The graph also includes the actual time, the system time and the forecast start time (T0) which is the operational system time at which the model run was started.

The current time is used by Delft-FEWS as the system time or time zero. The system time is typically updated in fixed intervals, e.g. using an hourly interval when forecasts are scheduled on an hourly basis. In the graphical presentation of forecast run results, this current system time or time zero is clearly indicated. Forecast results such as water levels or discharges at forecasting points can be presented graphically with time on the horizontal axis and water level or discharge on the vertical axis as illustrated in the previous paragraph. The required forecast horizon for the Po River and its tributaries ranges (presumably) between 3 hours to 48 hours and can be handled by Delft-FEWS

It is also possible to indicate which river catchment models are used. For instance in the Rhine Flood forecasting system, two partly overlapping model schematisations are used giving output on the same locations. Results of both models can be presented in Delft-FEWS, while the origin of the results is immediately clear.

Threshold levels can be defined for relevant locations on relevant parameters, e.g. on rainfall, water levels and discharges. Whenever thresholds are defined, they will be shown when displaying the forecast hydrograph. This is illustrated in Figure 3.5. Delft-FEWS allows to define an arbitrary number of threshold levels at one location, so arbitrary threshold water levels associated with various warning statuses at relevant locations can be easily accommodated.

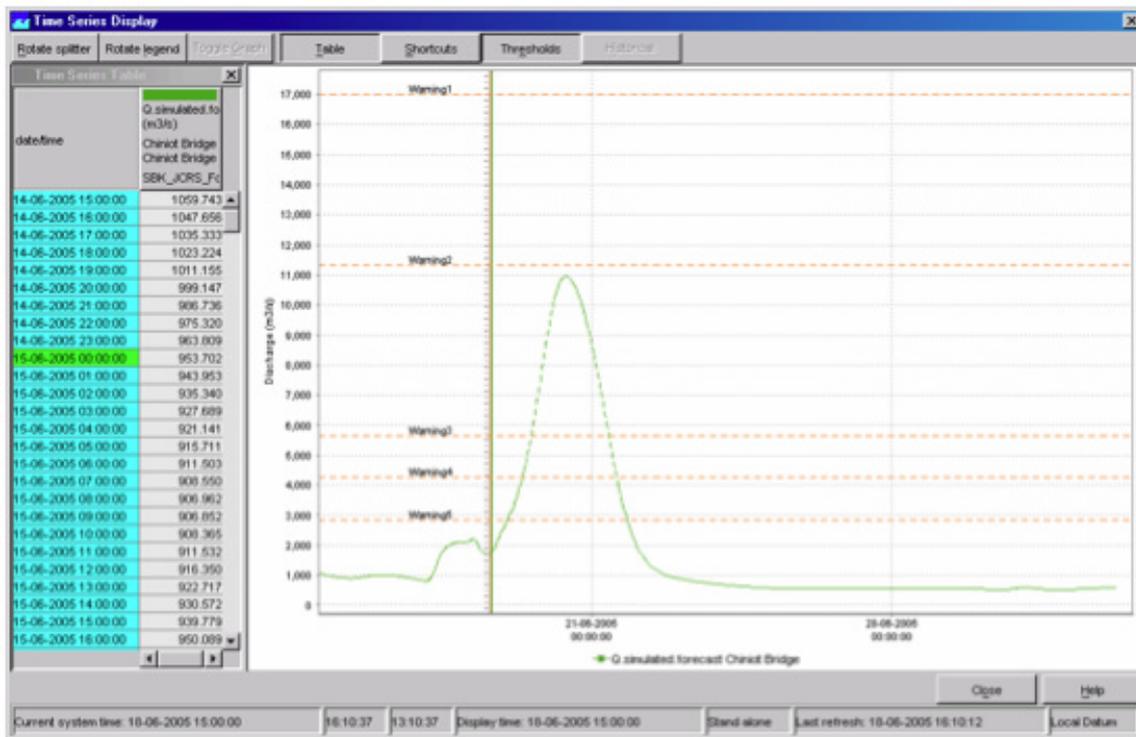


Figure 3.5 Illustration of forecast hydrograph and threshold levels

### 3.2 Performance and Skill Scores of Forecasts

By comparing forecasting time series coming from models to observed time series regarding the same timestamps (available some time later) models can be judged based on how well they perform in terms of how well they match or deviate. There are indicators which can be calculated (like e.g. bias, mean square error) which can be summarized under the so called *performance indicators*. These performance indicators can focus on a specific forecasting module (or model) or on the forecasting system as a whole. This performance indicator approach can also be used in model calibration.

Besides performance indicators the quality of the forecast can also be judged from the accuracy of forecasting threshold crossings (or peaks). Both height (forecasted and observed) and timing of the threshold crossings are important to consider.

The client might consider improving their forecasting capabilities to assess the performance and skill scores of their current models. This can be done by selecting the correct timeseries to compare and configure the specific *Performance Indicator* module in Delft-FEWS and/or switch on the so called SkillScores Display.



### Performance Indicators in Delft-FEWS

The performance indicator module is used as an analysis tool in Delft-FEWS to establish an overview of how well the forecasting system is performing in terms of accuracy of the individual forecasting module(s) or in terms of the forecasting system as a whole. Performance can be assessed in two ways;

- Performance of the individual forecasting modules. This reflects how accurate a given forecasting module is, following the traditional performance measures used widely in module calibration, for example root mean square error, Nash-Sutcliffe measure etc.
- Performance of the forecasting system itself. This reflects the accuracy of the system in forecasting. Three types of measure are proposed to this end, (i) lead time accuracy of forecast time series, (ii) accuracy of timing threshold event crossings and (iii) accuracy and timing of peak predictions.

The first type of performance assessment can be used either in calibration of the system, or in the operational setting to determine performance of modules and take actions such as the use of an alternative module due to poor performance.

The second type of measure can be assessed once observed data for which forecasts were made becomes available.

### Assessing performance of modules

The first and most simple application of the performance indicator module is in the traditional module calibration. This is by comparing two time series where one time series is the estimated series and the other is the reference time series. These time series are compared over a configurable length. As with other time series this is referenced with respect to the forecast start time ( $T_0$ ).



The time series are compared using a number of performance indicators.  $\hat{x}_i$  is the estimated value,  $x_i$  is the reference value, and  $N$  is the number of data points.  $\bar{x}$  is the mean of the reference values.

Bias (BIAS)	$BIAS = \frac{1}{N} \sum_i^N \hat{x}_i - x_i$
Mean absolute error (MAE)	$MAE = \frac{1}{N} \sum_i^N  \hat{x}_i - x_i $
Mean Square error (MSE)	$MSE = \frac{1}{N} \sum_i^N (\hat{x}_i - x_i)^2$
Nash-Sutcliffe efficiency (NS)	$NS = 1 - \frac{\sum_i^N (\hat{x}_i - x_i)^2}{\sum_i^N (x_i - \bar{x})^2}$
Peak accuracy in Mean Square Error MSE (MSE_PEAK) where K is the number of peaks identified.	$PEAK\_MSE = \frac{1}{K} \sum_{k=1}^K (\hat{x}_k^{peak} - x_k^{peak})^2$

To establish the peak accuracy, the peak must be identified - logic from the Delft-FEWS Transformation Module is to be used, although this needs extending to make sure a peak is a peak. A peak needs to be independent, and it must be ensured that the peak given is not simply the maximum value in a time window at the boundaries. Note that the peak of the estimated series does not need to fall exactly on the same time as the reference peak, but must be identified within a window.

Procedure in peak comparison is

- Find peaks in reference series.
- Find accompanying peaks in estimated series - if there is no identifiable peak, use value at time of peak in reference series.
- Determine performance.

(PERC_VOLUME)	$PERC\_VOLUME = 100 \times \frac{\sum_{i=2}^N (\hat{x}_i + \hat{x}_{i-1})}{\sum_{i=2}^N (x_i + x_{i-1})}$
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On establishing the performance, the indicator is returned as a time series (simulated historical). This time series is a non-equidistant time series, labelled as a forecast historical with the time stamp set to T0.

#### Other forms of Performance Indicators

##### Assessing performance of forecast values - lead time accuracy

Performance of forecast is assessed on the basis of lead time accuracy. This is done by comparing the forecast lead time value against the observed value at the same time (received later!). For each lead time, this value is assessed over a given number of forecasts. Lead time accuracy is evaluated using again the Mean Square Error (MSE), Mean Absolute Error (MAE) or Bias.

##### Assessing performance of forecast values- timing of thresholds

An important indicator of performance is the timing of predicted threshold event crossings. Again, this is evaluated over a number of forecasts. To evaluate this the threshold crossings in the indicator and the reference series are considered. For each pair of matching thresholds (matched on threshold id's) the time between the two is evaluated, and expressed either as a time bias (T\_BIAS) or a time absolute error (T\_MAE). Times are evaluated in terms of seconds.

$$T\_BIAS = \frac{1}{J} \sum_{j=1}^J \hat{T}_j - T_j$$

$$T\_MAE = \frac{1}{J} \sum_{j=1}^J |\hat{T}_j - T_j|$$

where  $T_j$  is the time of the threshold in the reference series,  $\hat{T}_j$  is the time of the threshold in the estimated series.

The thresholds to consider are determined in configuration by providing one or more ThresholdID's

The results of the evaluation are written as a time series (simulated historical), with as a reference time the T0 of the evaluation run and a time stamp for each  $\tau$

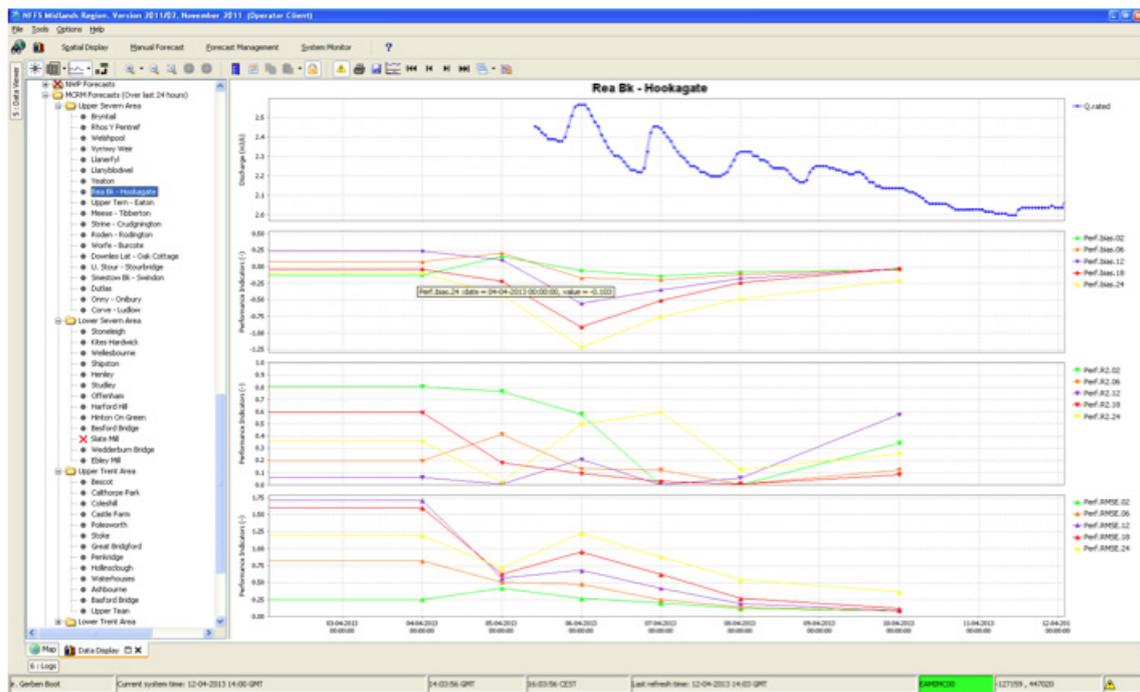


Figure 3.6 Example of output of the Performance Indicators Module

### Skill Scores in Delft-FEWS – Skills Scores Display

This display provides an overview of all threshold crossings in the observed and forecast time series. By matching observed and forecast thresholds, various skill scores can be computed.

### Background

The first step is to set up a contingency table. Given criteria on time intervals to consider when matching threshold crossing events, the values of a, b, c and d in the table below can be filled in (where e.g. a is the number of matched observed and forecast threshold crossing events).

		Threshold Observed	
		Yes	No
Threshold Forecast	Yes	a	b
	No	c	d
Forecast Available	Yes	e	
	No	f	



Once the contingency table has been filled, different skill scores can be established:

False Alarm Rate	$FAR = \frac{b}{a+b}$
Probability of Detection	$POD = \frac{a}{a+c}$
Critical Success Index	$CSI = \frac{a}{a+b+c}$
Critical Reliability*	$CR = \frac{e}{e+f}$

\* checks if a forecast is available at least some time (but not too late) before the observed threshold crossing)

#### Setting Criteria for Analyses

To specify when two threshold crossing events are considered as matching or not, a number of event matching criteria can be used. In the Delft-FEWS configuration file for the Skill Scores Display it is possible to define default event matching criteria, which can be different for different locations and/or groups of locations. When the Skill Scores Display is opened (Figure 3.7), then the global criteria and the criteria settings for each location and group of locations are read from the configuration file. If for a given location/group individual criteria have been defined, then these are used and the location/group gets a green tickmark in the filterbox at the left hand side of the skill scores display. If for a given location/group no criteria have been defined, then the global criteria are used for that location/group. See the image below of the Skill Scores Display with different criteria set for different locations. The matching criteria of certain location(s) and/or group(s) can be altered through the GUI.

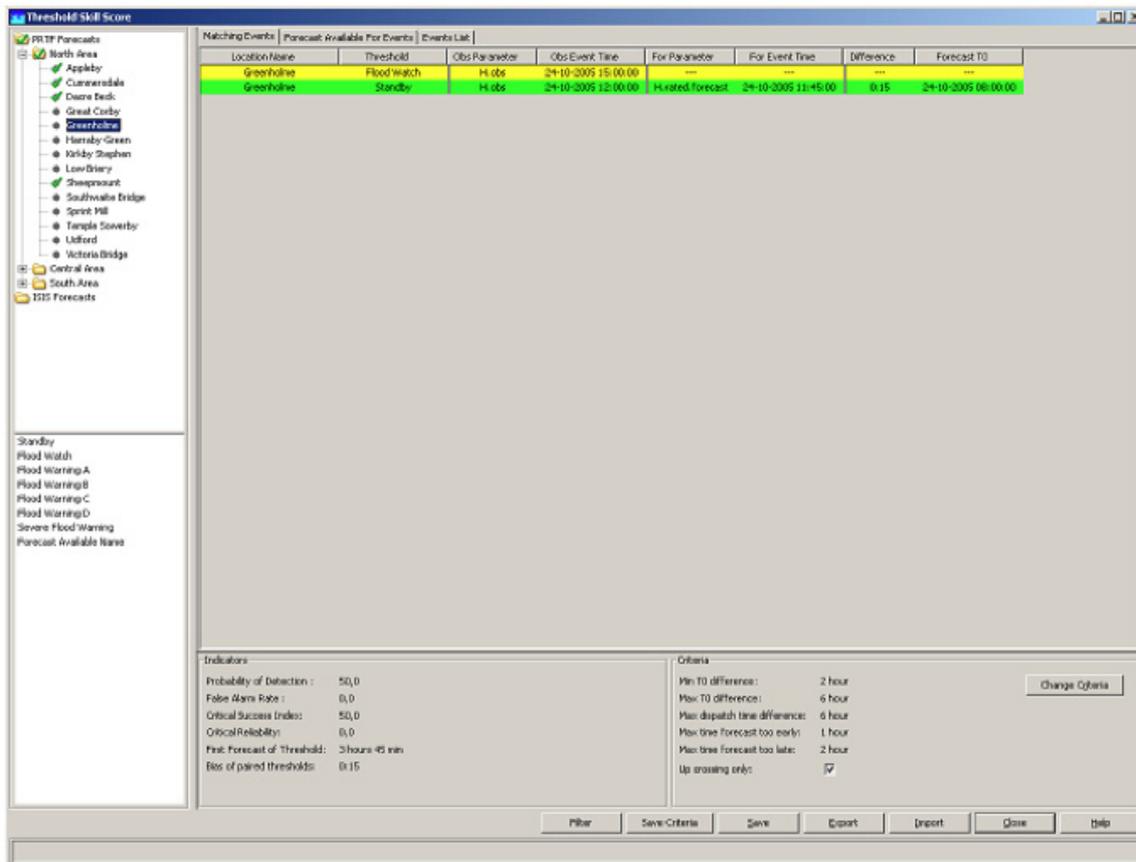


Figure 3.7 Example of Skill Scores Display

### Matching Events

In the Matching Events tab (Figure 3.8) different background colours are used to indicate in which sector of the Contingency Table events fall.

- Green: observed and forecast threshold crossing event match (sector a of contingency table).
- Yellow: a threshold crossing has been observed but not forecasted (sector c).
- Orange: a threshold crossing has been forecasted but not observed (sector b).

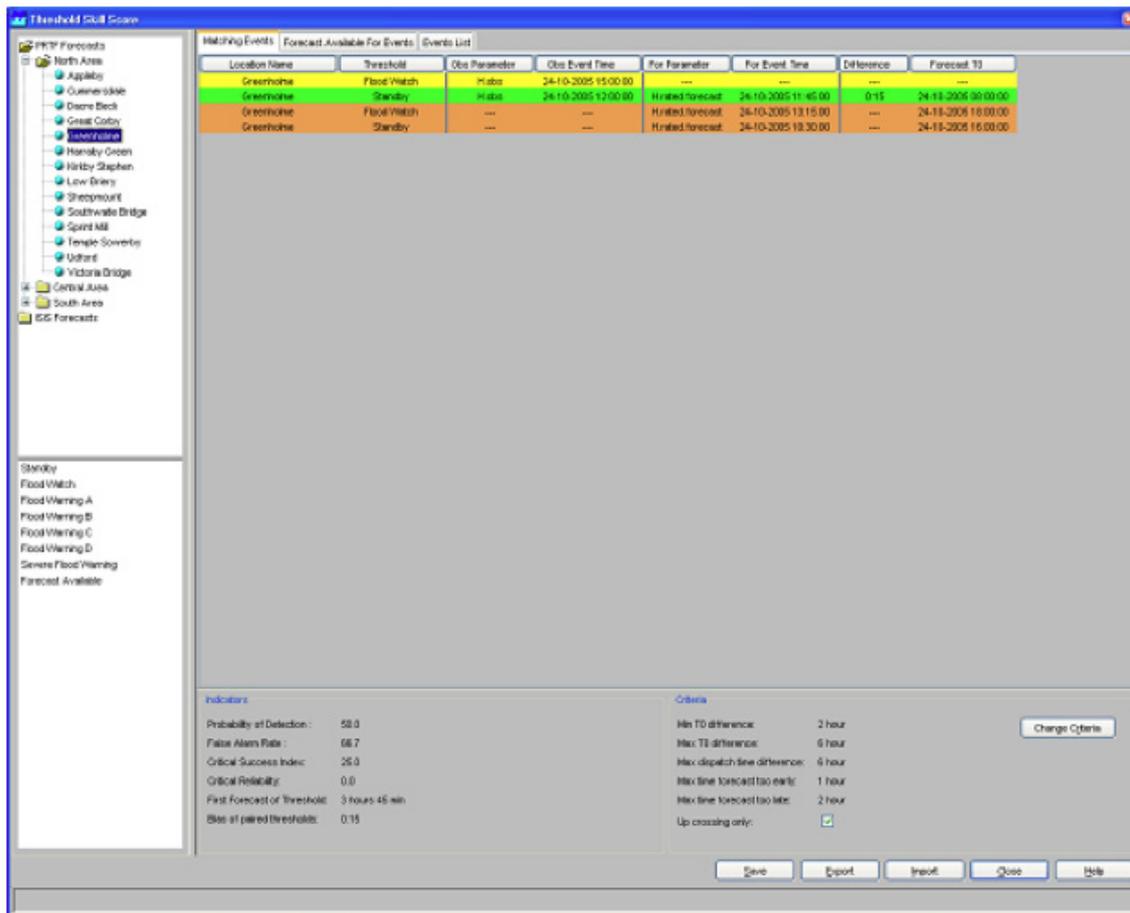


Figure 3.8 Example of Skill Scores Display (2)

In general, skill scores are determined for all forecast locations being at a gauging station and having level thresholds. Typically these are determined separately, but the structure of the display allows skill scores to be established for different models. This way the skill scores of the different models can be compared.

#### Forecast Available for Events

In the Forecast Available for Events tab (Figure 3.9) different background colours are used to indicate in which sector of the Contingency Table events fall.

- Green: a forecast is available for an observed threshold crossing event (sector e of contingency table).
- Yellow: no forecast available for an observed threshold crossing event (sector f).

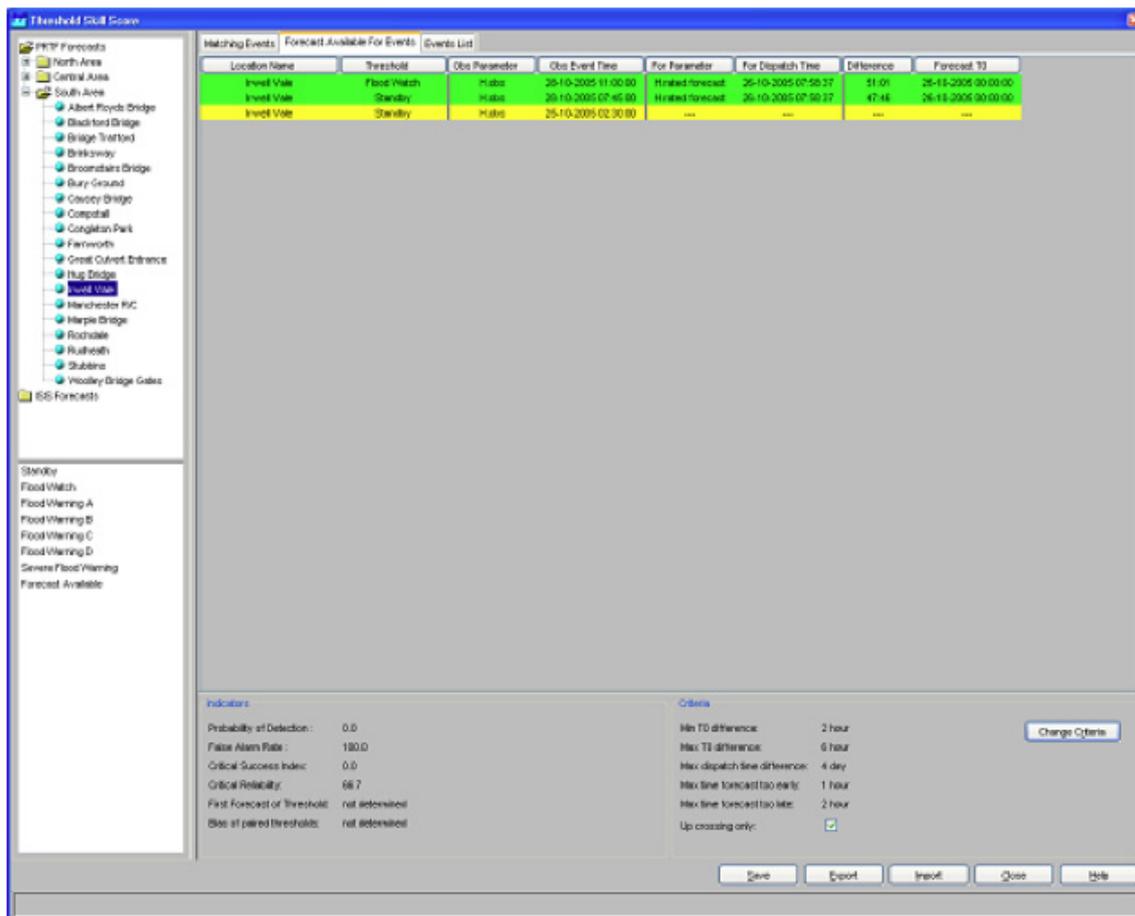


Figure 3.9 Example of Skill Scores Display (3)

### Archiving Events

As the threshold crossing events are stored in the operational database for only some days (according to the length of the Rolling Barrel), it's possible to manually export the list of threshold crossing events to a file or to the Delft-FEWS archive for storage or to be re-used in e.g. post-flood analysis.

### Ad. 4 Data Assimilation

To improve the accuracy and give an estimate of the (predictive) uncertainty it is necessary to apply some forms of data assimilation and post-processing.

The easiest and cheapest form is AR(MA) correction of deterministic and also ensemble hydrologic forecasts. An example is shown in Figure 3.10. The ARMA method is used in almost every forecast system. The AR model can be estimated on the fly or a predefined and determined AR(MA) model can be used.

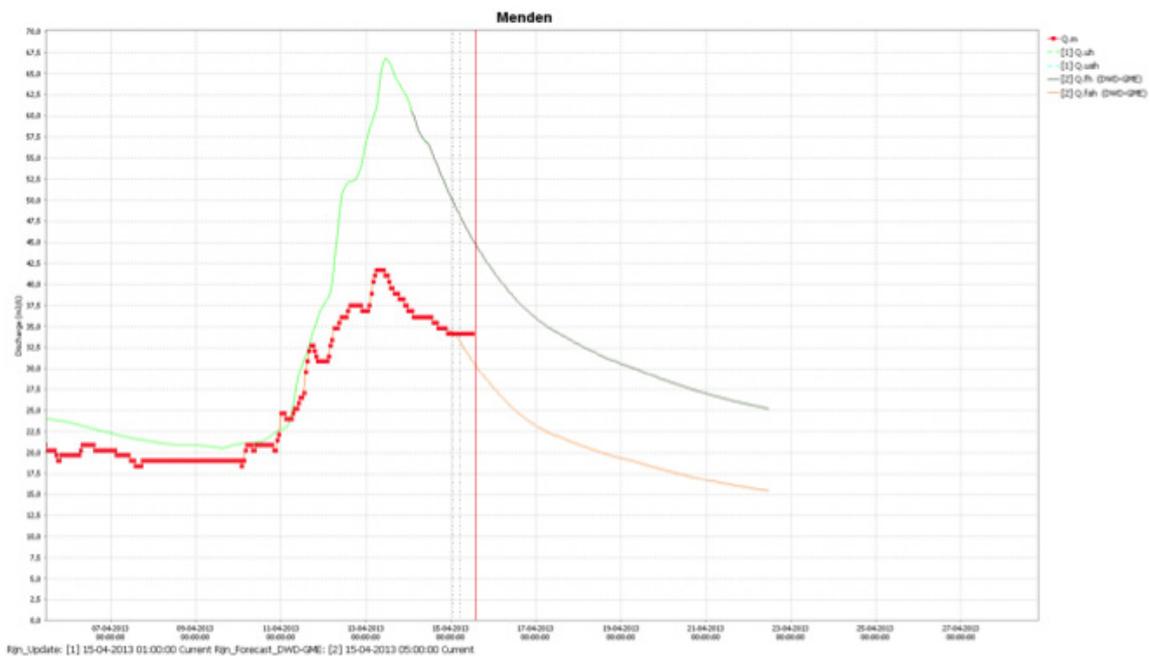


Figure 3.10 Example of AR correction with raw hydrologic model simulation (green) and forecast (black) and corrected model (orange line) and measurements (red squares).

Sometimes this error correction option is included in the model otherwise it is available within the error module of Delft-FEWS.

Apart from this ‘simple’ correction procedure, other forms of post processing methods that also give an estimate of the (predictive) uncertainty can be applied. The requirements of using these post-processing methods are that a certain (homogeneous) historical record including meteorological forecasts is available for deriving a reforecast dataset. From this reforecast data set statistical properties of the model and /or forecast error can be derived and applied real-time to correct or estimate the (predictive) uncertainty. The advantage of these methods is that they are relatively easy to derive and implement. The disadvantage is that require regular calibration for instance when the model is changed or anything else is changed.

Below an example of such a method for dressing an ensemble forecast (see Weerts et al., 2011).

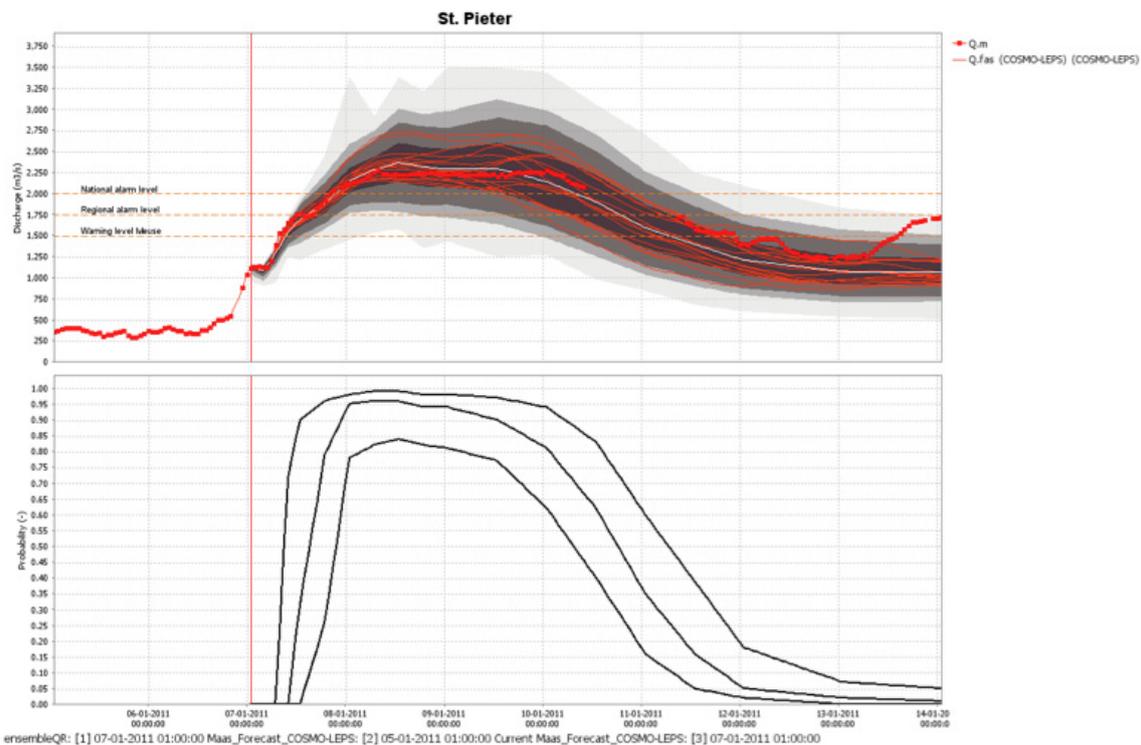


Figure 3.11 Example of ensemble dressing using Quantile Regression. The top figure gives the dressed (grey shaded area) and naked ensemble (red lines). The bottom figure gives the probabilities of exceeding a certain flood level/criteria

Besides post processing one can use data assimilation methods like Ensemble Kalman Filtering and Smoother (e.g. available in OpenDA). However this requires that the model implements the OpenDA interface. When this is available it allows that the observations can be used for updating the hydrologic/hydraulic model in real-time to improve the model predictions.

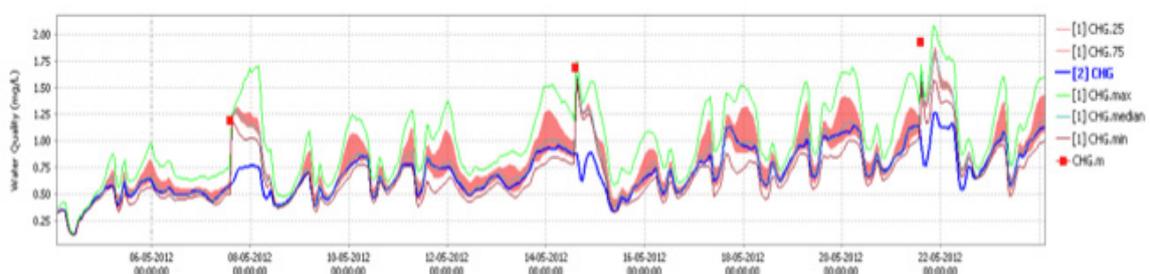


Figure 3.12 Example of EnKF data assimilation using OpenDA-compliant EFDC model in Delft-FEWS for ensemble water quality predictions (assimilating Algae measurement red squares)

The advantages of ensemble data assimilation is that uncertainty of the model and model input is modelled and taken into account (see for instance Rakovec et al., 2012a)). The disadvantages of course are the computational aspects of running the model in ensemble mode. However, when initial conditions are crucial data assimilation is a must. Examples of applying EnKF to distributed hydrological models (e.g. OpenStreams) are available in the literature (Rakovec et al., 2012b)



### 3.2.1 Model Input Data

Before running a model, the most recent available data need to be imported. This is typically achieved by running an import workflow in Delft-FEWS, which imports data from external databases. The data import into Delft-FEWS and the subsequent matching of locations and parameters between the external sources and the locations in the system will be configured. Before a forecast model is run, the imported data can be displayed and adjusted using the time series editor in Delft-FEWS.

During import, the imported data can be validated. Delft-FEWS allows to define hard and soft lower and upper limits on data, thus enabling a quality check and flagging of outliers.

At present the Hydrographic Service is using the telemetry and information system by different manufacturers. Rainfall and water level data are gathered from the various gauging stations and are stored in an appropriate data base. The present functionality of Delft-FEWS includes the possibility of extracting the rainfall and water level data directly from the existing databases for modelling/forecasting and for display (assuming that the necessary ODBC or JDBC drivers are available). Optionally, Delft-FEWS can also compute rated discharges using rating curves.

Delft-FEWS already supports a number of import formats of data streams currently handled at various Hydrographic Services for storage of the hydro-meteorological and weather forecast data (e.g. GRIB data), as indicated in the (non-exhaustive) table below. However, should the present formats be different from the data formats presently handled by the system, the data should be transformed by the client into a format that can be read directly into Delft-FEWS.



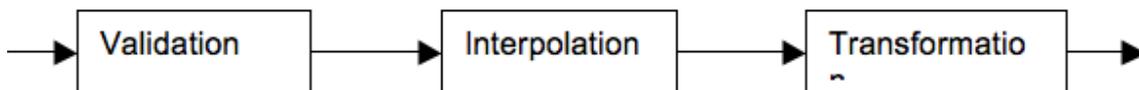
Table 3.1 Supported hydrometeorological data formats

Data Type	Format	Source	Comment
<b>Time Series data</b>			
EA-XML	XML	EA	Data exchange between systems in the UK Environment Agency
MSW	ASCII	RWS	On-line hydrological data from the Dutch Ministry of Public Works and Water management
BC2000	ASCII	RWS	Hydrological database used by the Dutch Ministry of Public Works and Water management
KNMI-Synoptic	ASCII	KNMI	Synoptic data from the Royal Dutch Weather Service
DWD-Synop	ASCII	DWD	Synoptic data from the German Weather Service
DWD-TTRR	ASCII	DWD	On-line rainfall and temperature data from the German Weather Service
WISKI	ASCII	WISKI	Data exchange format from the WISKI hydrological database (Kisters AG)
EVN	ASCII	FOWG	On-line hydrological data from the Swiss Federal Office of Water management and Geology
PMD	ASCII	PMD	On-line and synoptic data from the Pakistan Meteorological Department
WAPDA	ASCII	WAPDA	On-line hydrological data from the Pakistan Water Authority
HYMOS-SQL	Database	HYMOS	SQL based import of data from HYMOS hydrological database (applied in e.g. Taiwan)
<b>Gridded data</b>			
GRIB	Binary	Various	Standardised data exchange format for numerical weather prediction. Used by most Met. Agencies, including UK Met. Office, ECMWF, KNMI etc.
DWD-GME	ASCII	DWD	NWP Forecast data for the Global model run by the German Weather Service
DWD-LM	ASCII	DWD	NWP Forecast data for the local area model run by the German Weather Service
SMA	ASCII	SMA	NWP Forecast data for the local area model run by the Swiss Met. Office
SMA-ECMWF	ASCII	SMA	NWP Forecast data for the ECMWF based global model run by the Swiss Met. Office
BIL	Binary	Austrian Met Service.	NWP forecast data from the local area model (based on the French Aladdin model) run by the Austrian Met Service. Note: BIL is a standard grid data format.
HYMOS-SQL	Database	HYMOS	SQL based import of data from HYMOS hydrological database (applied in e.g. Taiwan)



### 3.2.1.1. Model Input Hierarchy

Particular emphasis is placed in Delft-FEWS on quality control of data. Through a step-wise procedure of successive data processing the data that is eventually supplied to a forecast model has been sufficiently quality controlled. This data-centred approach is the backbone of Delft-FEWS. Three Delft-FEWS modules cover all the respective processing steps:



Please note that in operational systems the consecutive steps in data handling are configured to be performed automatically in workflows. Delft-FEWS offers the opportunity to configure nested workflows, and each workflow can be started manually.

### 3.2.1.1. Model Interaction

The necessary data to drive the hydrologic and hydraulic models are passed by the respective adapters to the models. This regards measured precipitation and temperature data as well as their respective forecasted values. Hydrodynamic models require moreover upstream and downstream boundary conditions. These are transferred to the models in terms of hydrographs at the respective upstream and downstream end of the system.

Models usually compute the relevant dynamic variables in terms of time-series of either discharges or water levels for critical locations. These are transformed from the model-native format into a Delft-FEWS native format and imported in the DB.

The operation of models requires accurate bookkeeping of the state variables and parameters. These need to be administered and retrieved at each model run from appropriate storage locations in the system data base.

Further interaction between the model and Delft-FEWS consists in the exchange of logs allowing to monitor proper model execution.

### 3.2.1.1. Model Input Data – Editing

Delft-FEWS allows to edit and correct data which is imported from external sources. Data can be edited through the Delft-FEWS data editor. The Delft-FEWS data editor has the same lay-out



as the data display, the only difference being that the data can be changed. The data is shown in both table and graphical form. Any changes entered in the table are immediately reflected in the graph.

In many applications, a catchment or 1D-hydrodynamic model run in Delft-FEWS does not use the imported data directly, but respective derived data. A typical rainfall-runoff catchment model requires average catchment precipitation, which has been derived from available rainfall stations. Also imported data may contain missing values, which may cause run-time errors in the models. Delft-FEWS therefore has tools for serial and spatial interpolation especially designed to deal appropriately with these issues.

The user may want to edit both, the original imported data (e.g. filling of missing values), as well as the interpolated derived data which Delft-FEWS will transfer to the models. This can be arranged by distinguishing workflows for data import, data preparation and running models, and by making both the imported data and the derived data by Delft-FEWS visible and editable in the Delft-FEWS user-interface.

Delft-FEWS also has provisions for so-called What-if scenario's, as illustrated already in Figure 3.3. Which 'what-if' scenario's are to be distinguished will be discussed with the client. How what-if scenario's can be edited through the Delft-FEWS user-interface is illustrated in Figure 3.13.

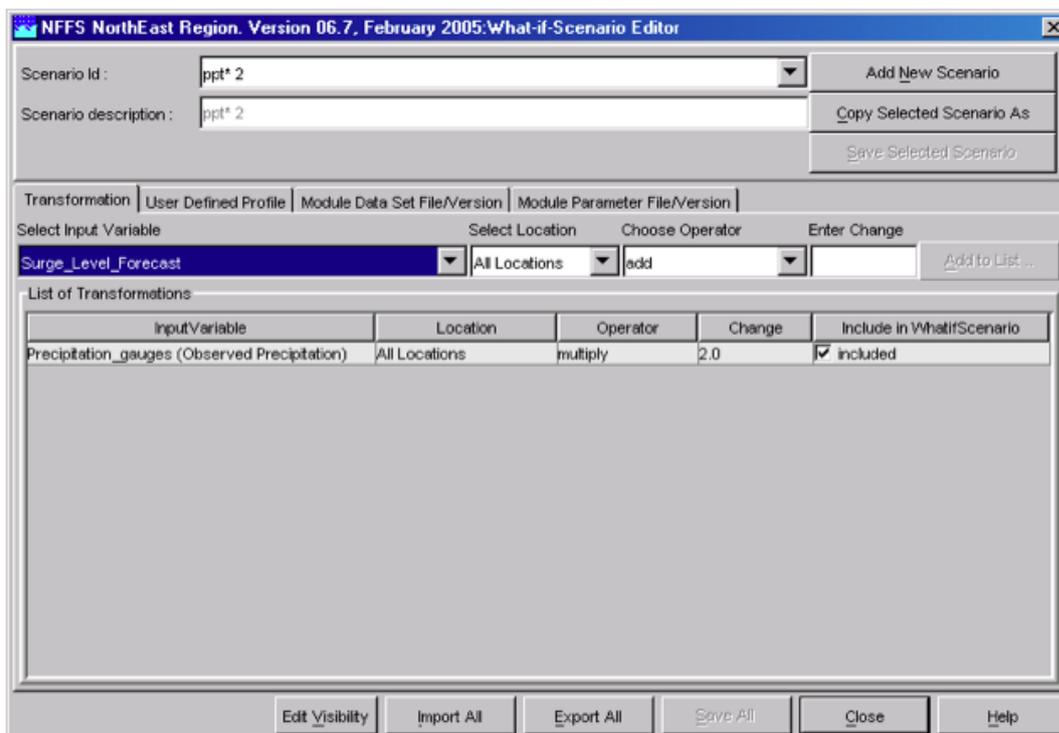


Figure 3.13 Example of What-if scenario specification.



### 3.2.2 Saving Forecast Model Runs

The results of model forecast runs are stored in the database of Delft-FEWS. The user can access old forecasts by opening them from the Forecast management menu, as illustrated in Figure 3.14.

In this way, several forecasts can be analysed at the same time. Results of different forecast runs can thus be compared and it is possible to compare real data with model simulation results. Delft-FEWS includes a Performance Indicator module that allows to evaluate the differences between observed and calculated time-series. Please refer to FEWS online documentation for a description of the Performance Indicator.

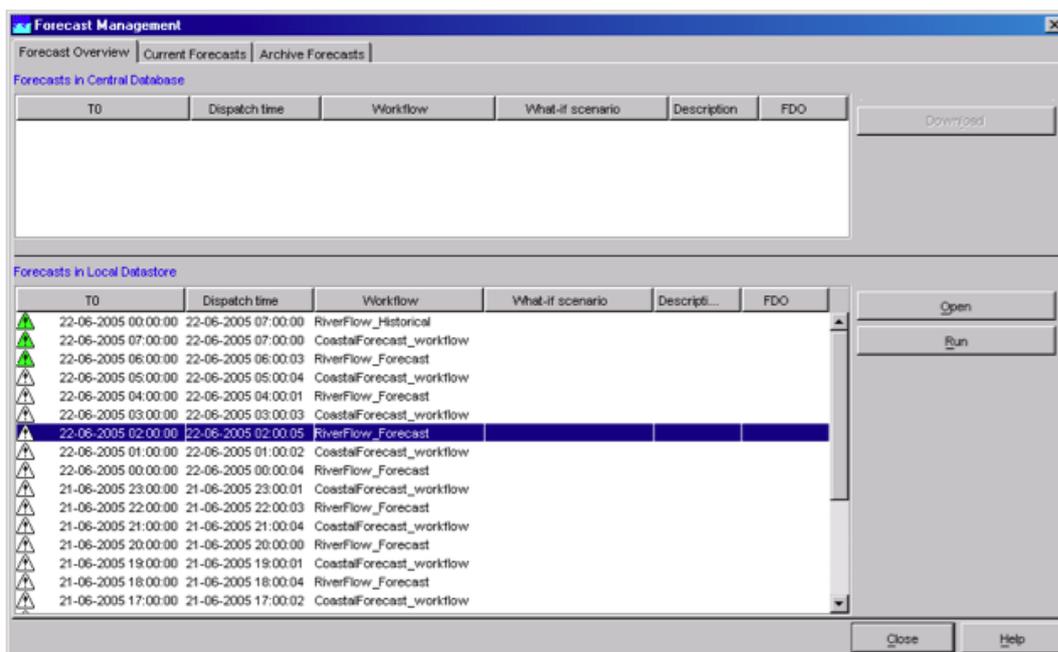


Figure 3.14 Opening an old forecast run

### 3.2.3 System Distribution – Scalability

The Delft-FEWS technology is fully scalable and can be implemented as stand-alone system or as a client-server based system, as well as a dual-side system. Given the requirements of the Civil Protection Service of the Province of Bolzano, in particular the concurrent use and scheduling facilities, we propose a client-server implementation. A client-server based solution also offers the possibility that users can share forecast information. At the moment this type of implementation is already implemented for the entire Rhine river basin, part of Austria and in several regions of the UK Environment Agency in England and Wales.



Expanding the initial setup by including additional hydrological/hydraulic modelling systems is fully supported by Delft-FEWS. Additional catchments can also be configured without technical problems into an existing configuration of Delft-FEWS. As Delft-FEWS is an open system, the configuration can be extended and adjusted through the XML-configuration files. New users of Delft-FEWS may need additional training to get accustomed with all functionality available within the system.

### 3.2.4 Error handling

The Delft-FEWS user-interface has a log window in which messages from the Delft-FEWS tasks are visualised. The messages are separated into errors, warnings, log and debug level events. These events are logged in the Delft-FEWS database. They can be accessed from the Delft-FEWS toolbar using the System Monitor option (See Figure 3.15).

Every task or subtask within Delft-FEWS writes log messages. These log messages indicate possible errors encountered, or are just notifying the progress of the task. Error messages are given in English and identify a problem and possible actions. Of course the messages generation and handling of e.g. a 1D-hydrodynamic river models run as a plug-in in Delft-FEWS are the responsibility of the hydrodynamic model vendor.

Delft-FEWS can be configured for different user levels enabling user to hide certain messages for specific user levels. The system manager or administrator can view all messages.

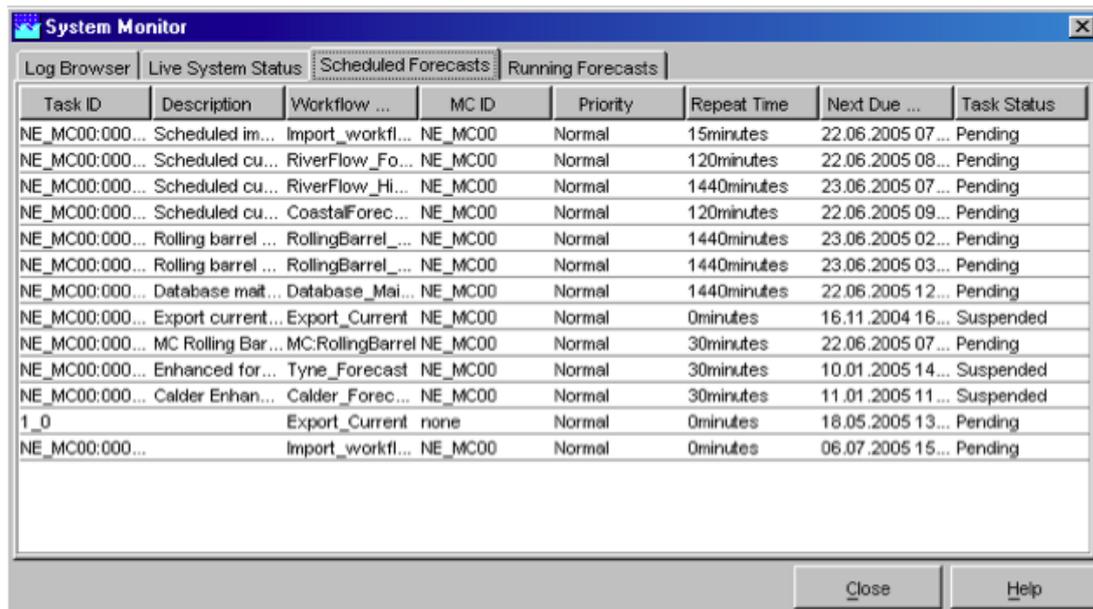


Figure 3.15 Scheduled Forecasts tab in the System monitor



### 3.3 Reservoir management

In the forecasting region managed by the Civil Protection of the Province of Bolzano there exist a series of managed reservoirs (mainly for hydropower generation) that play a fundamental role in flood mitigation, water storage and energy production. These reservoirs have an impact on the natural flows due to reservoir operations. Delft-FEWS includes a series of basic modules which enable modelling of the reservoirs via a fast configuration. The module enables the solution of the reservoir equation based on operational rules that are synthesized and described via look-up tables.

These look-up tables relate the outgoing flow to reservoir water levels according to pre-defined tabulated rules. In presence of a reservoir cascade an upstream reservoir can be interconnected with the ones situated further downstream through third-party flow transfer models, which route water downstream. The outlined basic reservoir modelling functionalities in FEWS have been developed for the purpose of implementing the reservoirs directly within FEWS, without the need to include a separate third-party model of the reservoirs. It is however noted that the outlined reservoir module is not designed to perform complex constrained reservoir optimization.

If such a reservoir optimization is indeed required, it is necessary to use the RTC (Real-Time Control) package. The RTC package originates from the integration of multiple project-specific reservoir simulation modules in flood forecasting systems for Austria, Germany and Pakistan. In its original design it was referred to as Delft-FEWS reservoir module, and aimed at the simulation of pool routing in reservoirs and reservoir systems, including related reactive controllers and operating rules. Support for more advanced model predictive controllers was introduced in 2008 and extended in 2009. This includes the implementation of a kinematic wave simulator as an additional internal routing model for the predictive controllers as well as the introduction of additional systems for selected modeling components. The latter interventions resulted in significant speed-ups of these controllers.

During 2010, the concept of RTC triggers for activating controllers and operating rules was introduced with the aim to simulate more sophisticated heuristic control schemes. Furthermore, the software was redesigned in C++ and enhanced by a C# OpenMI wrapper to facilitate integration into modeling packages such as SOBEK or Delft3D.

Based on the complexity and operational needs of the client, a decision must be taken on which of the two possible approaches to be used. DELTARES can provide a) a configuration for the basic reservoir handling module in Delft-FEWS or b) provide a complete RTC reservoir management and optimization solution based on RTC package.



### 3.4 Implementation of Ensembles

A key element to the handling of time-series data within the framework is that the ensemble dimension is included, thus allowing ensembles of time-series (scalar and grid) data to be stored and processed. In other words Delft-FEWS is ensemble aware.

When running through a cascade of data processing and modelling steps, or workflow, there are essentially two methods available in running through an ensemble, given as follows:

- 1) Each ensemble member is run individually, which means the coordination of the ensemble run is within the forecast processor in Delft-FEWS which is used to process the required sequence of steps. The model is used in exactly the same way as in a deterministic run.
- 2) The ensemble is passed to the data processing step or the process model as a whole. In this case, the responsibility of dealing with the ensemble is vested in the data processing step itself. Typically, this method is used to compute statistical properties of the ensemble.

Both options above give the possibility of running ensembles and deriving ensemble statistics. Often ensemble input is derived from meteorological ensembles.

Most meteorological forecast products for the short and medium range are skilful (over climatology) and relatively unbiased (e.g. ECMWF). The advantage of using meteorological ensembles forecast over a deterministic forecast for hydrological forecasting is that one takes into account the natural variability.

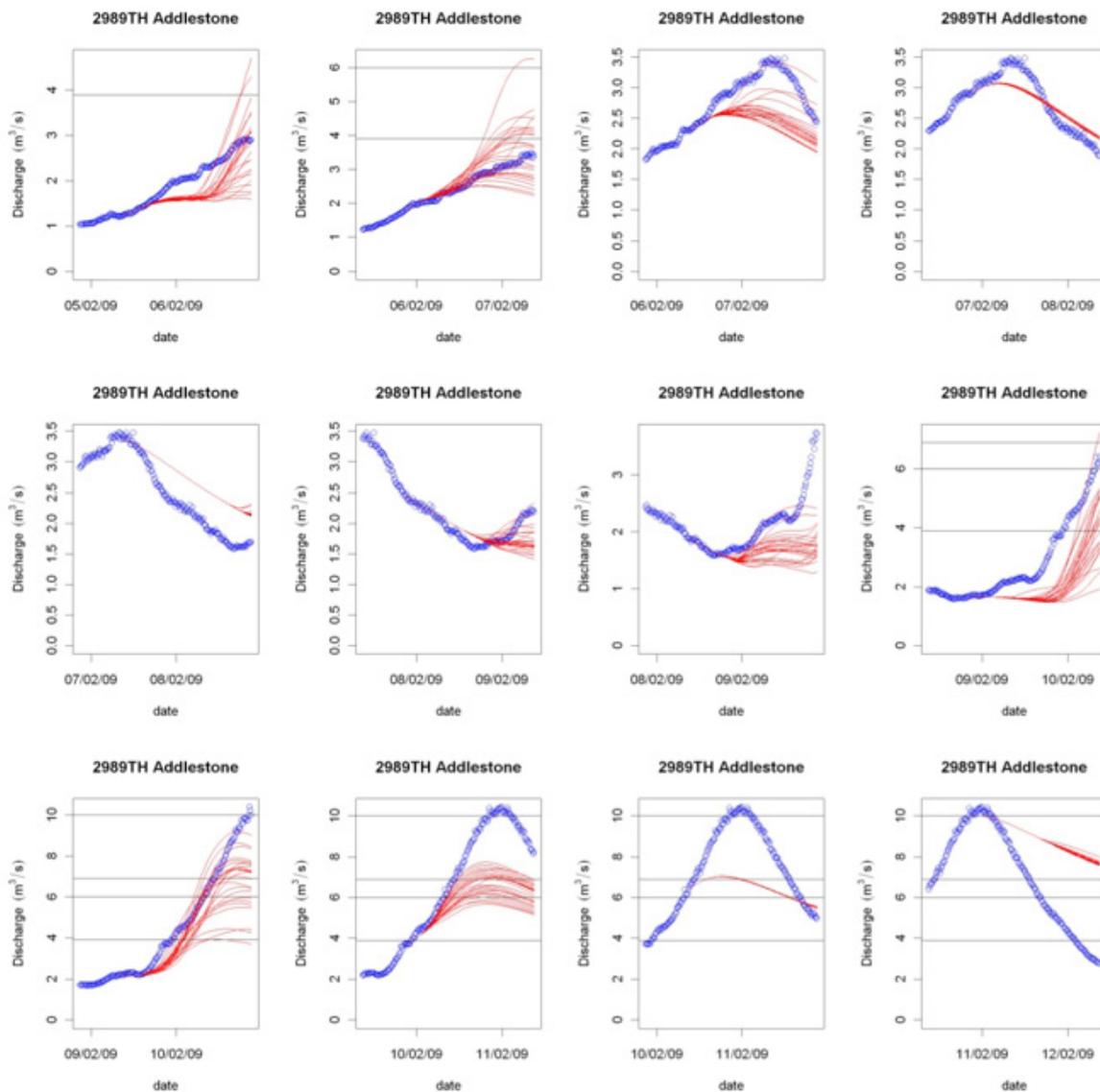


Figure 3.16 Example of a hydrological ensemble forecast (see Schellekens et al., 2010)

Of course the hydrological behaviour of such an ensemble forecast is highly depended on the hydrological, routing and/or hydraulic model (e.g. integrated catchment model) used.

Figure 3.17 and Figure 3.18 give a few examples how ensemble information can be displayed in Delft-FEWS.

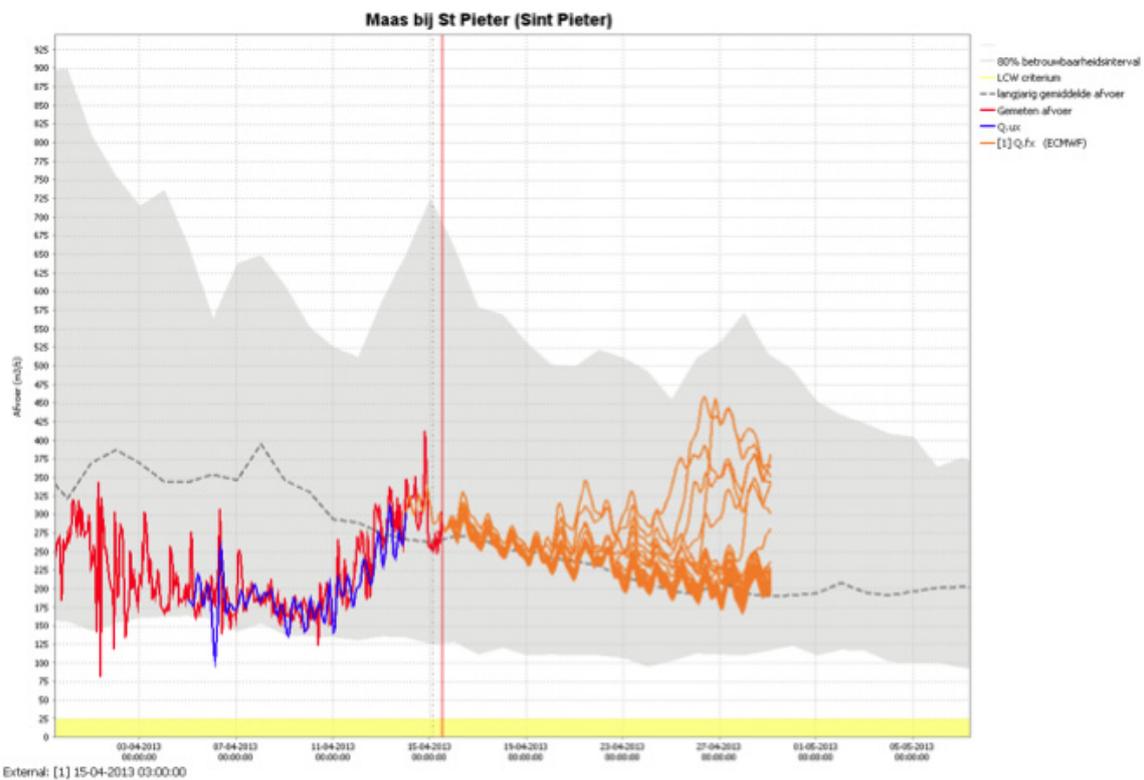


Figure 3.17 Example of a display of a historical state run (blue line) and an ensemble hydrological discharge forecast (orange lines) against climatology (grey indicating 80% confidence interval & dotted line the median) and measurements (red line). The yellow bar is the low flow criteria

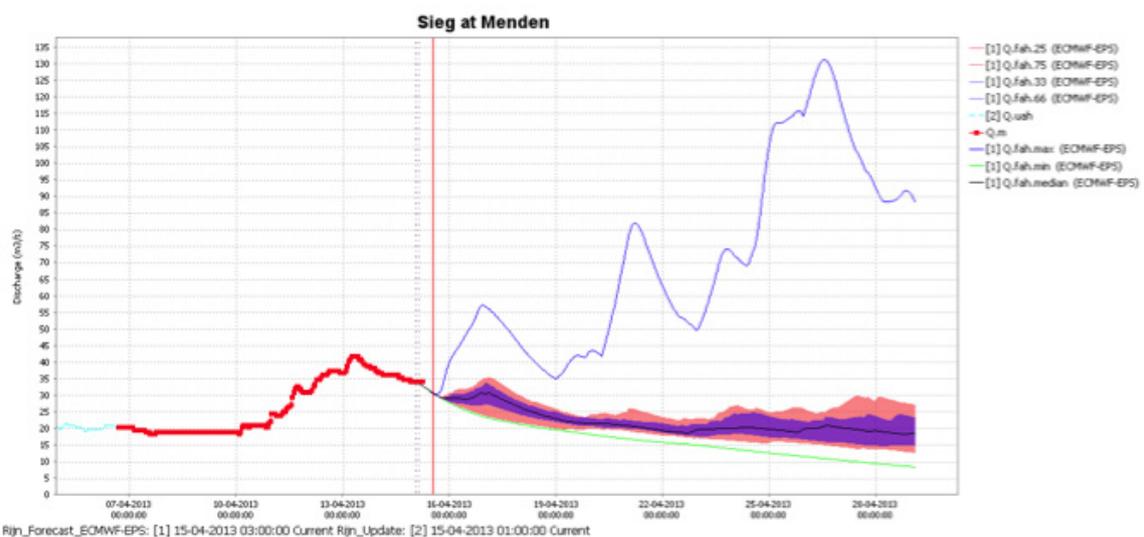


Figure 3.18 Example of a display of a historical state run (light blue) and an ensemble hydrological discharge forecast (max-blue, min green, 25/75 purple shaded and 10/90 pink shaded area) and measurements (red line squares)



Many other ways of displaying this information is possible, for instance how many ensembles cross a specific criteria as a function of time. This can give an idea how persistent the ensemble forecasts are.

Ensemble forecasts come at the cost of more computational time and storage. However, they provide additional information over single valued forecasts. This probabilistic information is often viewed as a necessity. The use of ensemble forecasts also requires that procedures based on single valued forecasts need to be adjusted to take advantage of the probabilistic information provided by the ensemble forecasts.

### 3.5 Software/Datasets Licences

Delft-FEWS has been developed by Deltares in assignment of various end-users. The development costs of Delft-FEWS have been covered by these assignments and Deltares holds the intellectual property rights of Delft-FEWS. Our licensing policy for Delft-FEWS includes issuing of a license to a new licensee at zero costs, provided that the new licensee is an end-user, Deltares is assigned to prepare the initial configuration of Delft-FEWS for the new licensee and the new licensee agrees with the standing licensing conditions.

Amongst others, the licensing conditions include that Deltares grants the licensee a non-exclusive, non-transferable license, without the right to sub-license, to use within the organisation of licensee. This means that we only provide a license to non-commercial end-users. There is no limitation to the number of licenses of Delft-FEWS within the organisation of the licensee (e.g. Civil Protection of the Province of Bolzano).

The licensing conditions also mention that Deltares will retain the Intellectual Property Rights (IPR) of the Delft-FEWS software. The IPR of the system configuration of Delft-FEWS, including the model applications, will remain property of the licensee unless specified otherwise. This means that a client will hold the IPR of the Flood Forecasting System. The IPR of any additional features to Delft-FEWS developed in assignment of the licensee will remain with Deltares and will be made available to all users holding a support and maintenance contract of Delft-FEWS. The Licensing Conditions of Delft-FEWS are included in the Appendix B.

The zero costs for licenses of Delft-FEWS (for a network-wide usage) is included in the Pricing Schedule.

Please note that we are willing to discuss procedures to grant a client access to the source-code (including the additional features of Delft-FEWS developed for the client), in case Deltares can no longer meet her contractual obligations.

Licenses to particular datasets are not addressed in this feasibility study.



## 4 Feasibility of FEWS Südtirol

The present section analyses the applicability of the Delft-FEWS as platform for the realization of a flood forecasting system based on the simulation modules in ARFFS. The study examines the feasibility of a migration of the existing ARFFS setup towards a Delft-FEWS system. The following sections examine possible advantages and disadvantages of such a migration.

### 4.1 Advantages

1. The use of the Delft FEWS provides the flexibilities which come with an open-architecture platform. The Delft FEWS allows including new data streams and models by editing XML configuration files and using suitable model wrappers (also called “adapters”). A series of wrappers has been developed by Deltares and third-party module vendors which are offered in the Delft-FEWS package.
2. The configurability and the structure of the customized internal operational data base of Delft-FEWS allow to utilize the system for a series of operations, which go beyond just flood forecasting. Possible applications include low-flow forecasting, groundwater modelling, water quality applications, real-time control applications in combination with surface water flow and reservoirs. In the particular case of the Province of Bolzano, applications including the operational management and visualization of snow cover data (snow stability analysis), real-time spatial data and information on slope stability or other data can be envisaged.
3. Delft-FEWS allows for the use of a series of data bases, among which proprietary ones (ORACLE, Microsoft ACCESS, WISKY) or open-source applications (Firebird, PostgreSQL). This flexibility in the use of data base application allows for a series of choices by the client.
4. Delft FEWS is platform-independent. The platform has been developed in Java. Applications on MS Windows, Apple or Linux systems are in principle possible. The platform-independence is however not necessarily extendable to the simulation models, which are only platform-independent if developed in that way by the model vendor. For example DHI models can only be run on MS Windows, unless they are compiled to run also on the LINUX operating system.
5. The open structure allows an organisation adopting Delft-FEWS to preserve already performed investments on the simulation models, while making use of an advanced operational data base, Graphical User Interface and a vast library of functionalities and data handling routines (e.g. radar data, Meteosat data, different weather forecasting products).



6. Delft FEWS can be operated in stand-alone mode, or as a client-server system, whereby the system can be configured in such a way as to ensure maximum redundancy and stability. Operations can for example be executed on multiple machines or on a single machine with other machines in stand-by mode.
7. Delft-FEWS allows extending a system from deterministic forecasting to ensemble forecasting, as an ensemble forecasting facility is in-build into the system.
8. Delft-FEWS offers extensive archiving and customizable reporting facilities.
9. Deltares provides an on-going support and maintenance service, which assures continuity of the product development. Subscribers to the support and maintenance service become yearly updates of the software and receive telephone or remote support in case they encounter problems with the operation of their system.
10. Once an organisation becomes a client of Delft-FEWS, it joins a world-wide user community. The users meet on a yearly-basis in Delft during the Delft user days, with the aim to share common experiences and novel applications.

#### 4.2 Disadvantages

1. In the present form of ARFFS, the models are solidly interconnected with the data base PantaRhei and the graphical user interface. At present the model writes the output directly to the data base and not to output files, which are successively written to the data base. This architectural choice makes the overall ARFFS system structure non-modular.
2. As a result the simulation modules cannot be easily disconnected from the system and incorporated into Delft FEWS using simple adapters. The models need to be restructured by changing the I/O interface. The input needs to be read from file and the output written to file. Moreover the model needs to exchange some basic messaging in a pre-defined format to inform a Delft-FEWS user working with the embedded model if a model simulation run has been successfully executed. All these functionalities need to be added to HFS, which at present works in close connection with PantaRhei and produces no intermediate output to file.
3. The use of Delft FEWS would require the abandonment of the PantaRhei data base, which needs to be replaced by the Delft-FEWS internal data base.
4. The use of Delft-FEWS requires the abandonment of the current Graphical User interface system (CAVI) of the ARFFS system.



5. The use of Delft-FEWS requires the abandonment of the existing ARFFS libraries to perform data pre- and post-processing, because the respective modules incorporated in Delft-FEWS need to be used instead. These are however fully configurable and extendible to generic simulation models.
6. Delft-FEWS at present does not allow storing explicitly model parameters in the data base as done by ARFFS. Instead older model versions with their respective parameter sets need to be preserved and run in different simulations, using different model versions.
7. Support and maintenance cover extensive services, but are most likely more costly than the current service arrangements for ARFFS via the service provider AT-Soft and the University of Padua.

#### 4.3 Required steps for migration to Delft-FEWS

FEWS-Südtirol constitutes a standard system with a limited amount of simulation models to include in Delft-FEWS. Moreover, the amount of forecasting products (mainly numerical weather forecasts) is limited. This makes the system suitable for a migration. However, the current “solid” interconnection between the two systems requires that the simulation models as well as their parameter structure are made independent of the Pantarhei data base. This is impossible without rewriting the I/O interface for the models.

The rewriting of the I/O interface must be performed by the model vendor (e.g. University of Padova/ AT-SOFT) following specifications supplied by Deltares as described further below.

Moreover, an XML message exchange file system needs to be added, which allows exchanging information about success/failure of model executions between the Delft-FEWS system and the simulation models.

By isolating the simulation models from the rest of the ARFFS system, the Pantarhei data base, data processing libraries and the Graphical User Interface become redundant, as these functionalities are already provided by Delft-FEWS. This aspect must be carefully considered by the client in any further decisions, as the investments already made in the development of these features will be lost when migrating to Delft-FEWS.

The Delft-FEWS system needs to be configured to perform the functionalities already executed by ARFFS, and to include the hydrological simulation models using a suitable model adapter. Given that the hydrological models used in ARFFS need to be incorporated in Delft-FEWS for



the first time, there is no pre-developed adapter available, which could be re-used. In principle there are two options for the development of the adapters:

1. In case the model vendor decides to produce model I/O in ASCII table format or XML, the General Adaptor (GA), which is already available in Delft-FEWS, can be utilised, thus limiting development costs.
2. In case (unpublished) binary file formats are used for the I/O of the simulation models by the vendor, a dedicated adaptor needs to be developed by the vendor following Deltares-supplied specifications.

Finally it is necessary to train the staff of the Civil Protection Service in the use of the system. Three types of courses are offered: 1) Forecast officer courses (system use), 2) Configuration course (system configuration) and 3) System administrator (ITC training for administrators). These courses allow staff of the Civil Protection Service to intervene on the system and to change the configuration if needed, such as including additional stations, data sets or models.

If the client is not interested in managing the system using its own internal staff, the full support can be outsourced to Deltares at a cost. Deltares will be able to provide remote support by logging securely onto the ITC system of the Civil Protection service and executing support and maintenance services.

#### 4.4 Conclusions

In summary, the migration of ARFFS towards Delft-FEWS is feasible, but requires the abandonment of a significant part of the currently used ARFFS system, while essentially preserving only the simulation model component. The PantaRhei data base as well as the user interface CAVI will not be utilized with Delft-FEWS

#### 4.5 Cost estimate

The cost estimated for the implementation of a FEWS-Südtirol system based on the hydrological modelling system in ARFFS is estimated in the present section. We recall that these estimates are approximate and vary according to system complexity and support provided by the client during the development phase. The costs are itemized as follows:

- *Development of the Adapter.* This task can be either executed by the model vendor or performed by Deltares in close collaboration with the vendor. The cost can vary according to the complexity of the I/O file system of the model chosen by the vendor. A first cost estimate for this task is around 20.000 €.



- *System Implementation.* The implementation of FEWS-Südtirol consists of configuration and system roll-out. Depending on support by the client, the cost is estimated to vary between 80.000 and 120.000 €.
- *Training:* Training including three courses (forecaster course, configuration course and system administration course). The course can vary in cost according to the fact if it is held in Bolzano or in Delft and the number of participants attending. A cost estimate for a package of three courses to be held in Bolzano (in Italian or German Language) with two instructors and a duration of 4 to 5 days is about 12.000-18.000 €.
- *Support & Maintenance:* The cost for support and maintenance (per year) varies according to the type of support chosen (standard support to full support). The package is tailor-made for a particular situation and system complexity. The cost for a standard package starts from 12.500 €/year. The structure of a standard S&M contract is outlined in Appendix A.

We note that these costs constitute an indication and can be revised according to circumstances, which need to be elaborated in the frame of a more detailed proposal phase. All indicated costs are exclusive of V.A.T. and refer to 2013 personnel hourly rates.

## 5 Acknowledgement

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Programma di Cooperazione Transfrontaliera Italia-Svizzera 2007-2013  
Le opportunità non hanno confini





## 6 Literature

Norbiato, D., M. Borga, S. Degli Espositi, E. Gaume and S. Aanquetin, (2008): Flash flood warning based on rainfall depth- duration thresholds and soil moisture conditions: An assessment for gauged and ungauged basins. *J. Hydrology*, 362(3-4), 274-290, 10.1016/j.jhydrol.2008.08.023. *J. Hydrology*, 362(3-4), 274-290, 10.1016/j.jhydrol.2008.08.023.

Daniele Norbiato, Marco Borga, Ralf Merz, Günther Blöschl, Alberto Carton, (2009): Controls on event runoff coefficients in the eastern Italian Alps, *J. Hydrology*, 375 (2009) 312–325, doi:10.1016/j.jhydrol.2009.06.044.

Todini, E., 1996. The ARNO rainfall-runoff model. *J Hydrol.*, 175: 339-382.

US Army Corps of Engineers - UNET One-Dimensional Unsteady Flow Through a Full Network of Open Channels V 4, April 2001.

Werner, M., J. Schellekens, P. Gijssbers, M. van Dijk, O. van den Akker, K. Heynert, The Delft-FEWS flow forecasting system, *Environmental Modelling & Software*, Volume 40, February 2013, Pages 65-77, ISSN 1364-8152, 10.1016/j.envsoft.2012.07.010.



## A Structure of S&M Services for Delft-FEWS

### A.1 Service

The support & maintenance service comprises the following items:

- supported components.
- helpdesk support hours (single point of contact).
- target response and resolution times.
- new & maintenance releases.

### A.2 Supported components

With reference to the individual components of a Flood Forecasting System, 3 Categories of supported components are envisaged:

Table A. 6.1 Support categories

Category	Response, analysis, support	Resolution
A	System Software (excluding OS) Delft-FEWS software Delft-FEWS configurations Models and Model-adapters	Delft-FEWS software
B	System Software (excluding OS) Delft-FEWS software Delft-FEWS configurations Models and Model-adapters	Delft-FEWS software Delft-FEWS configurations
C	System Software (excluding OS) Delft-FEWS software Delft-FEWS configurations Models and Model-adapters	System Software (excluding OS) Delft-FEWS software Delft-FEWS configurations

Delft-FEWS S&M always includes the Response, Analysis and Support of issues related to System Software (excluding the Operating System), Delft-FEWS software, Delft-FEWS Configurations, Models and Model-adapters.

The way the difference between Categories is handled refers to the Resolution of the issues. Please note that S&M regarding the Hardware and the Operating System (OS) is not included in this offer. Note also that the resolution of bugs in third party models and third-party model-adapters is excluded as well.



### A.3 Helpdesk support hours

Deltares’ Helpdesk is available for user support. A choice can be made of the following support hours:

- Office hours 09:00 - 17:00 (CET)
- Every day 09:00 - 17:00 (CET)

Office hours refer to those in The Netherlands. Two months before the start of a new year, a list will be provided of the working days in The Netherlands.

Calls for support can be made by phone or email and should be accompanied by a written account of the problem encountered or the type of advice needed.

A single point of contact should be nominated by the customer for communication with the Delft FEWS Helpdesk.

### A.4 Target response and resolution times

The system of target response, analysis and resolution times discussed in this section applies to all variants of a support & maintenance contract. It is independent of the selected supported components and support hours.

When maintaining an operational system it is recognised that not all calls for S&M require the same type of response. In the table below, a categorisation of severity of calls is presented. Per single call, the classification of the call will be decided upon mutual agreement.

Table A.2 *Category of call*

Call Category	Type of call	Description	Priority
1	Critical fault call	Due to an error in the system, no forecasts can be generated at all. System is down.	High
2	Severe fault call	The users are unable to undertake their core business efficiently but are able to work around the problem.	Medium
3	Fault call	A fault is noted having no impact on core business. A workaround is available.	Standard
4	Support request	A request is made for assistance in running or configuring the system.	Standard



The table below presents the target response, analysis and resolution times.

Table A.3 response time of call

Call Category	Response time (hours)	Analysis time (hours)	Resolution time (hours)
1	2	4	8
2	2	8	40
3	2	40	next release
4	2	-	-

Within the response time, the reception of a support call will be acknowledged by the Helpdesk.

Within the target analysis time, the reported fault will be analysed and a resolution strategy will be defined. Also in case the responsibility for resolving the problem is outside the scope of the S&M agreement, the client will be informed.

Within target resolution time, the fault will be attempted to be repaired.

Please note that the hours listed in the table above should be counted within the support hours.

Category 1, 2 and 3 calls are related to the “Maintenance” of the system, whereas Category 4 calls are related to the “Support”. During a guarantee period, the response, analysis and resolution times of all Maintenance calls are considered as per Category 3 calls in Table A.2.

### A.5 New & maintenance releases

All support & maintenance contracts include the right to obtain new releases of the Delft-FEWS software free of cost. New releases of the Delft-FEWS software are issued approximately annually. A new release includes the resolution of category 3 calls, and upgraded and additional functionality (implemented in other assignments).

Deltares advises the Customer to install the new releases to make sure that all new functionality is available. The installation will be carried out remotely from Deltares.

A *maintenance release* (or patch) includes the upgrade of existing functionality, i.e. the resolution of a category 1 or 2 fault call. Maintenance release will be made available to the Customer by email or via an internet download facility.

Please note that Deltares should be granted remote access to the system of the customer to enable remote implementation of maintenance releases.



## A.6 Cost structure of the S&M contract

The annual cost for the S&M to Delft-FEWS is calculated on the basis of the selected service level (supported components, support hours, number of calls per category and maintenance releases) and the complexity of the system (number of data feeds, models, forecasting locations, configured Delft-FEWS utilities, stand-alone or client-server) that is supported.

The annual cost items are subdivided into the Base Costs for a “*Standard Package*” of S&M for Delft-FEWS and “*additional costs*”.

### A.6.1 Standard S&M Package

The Standard Package for Delft-FEWS Support & Maintenance includes:

- installation of the supported Delft-FEWS application at the Deltares Helpdesk,
- 60 hours of telephone support (Categories 1-4 calls, see Table A.3)
- All supported system components are considered as of category C in Table A.1 with respective full resolution (including System Software, Delft FEWS and configuration)
- the response, analysis and resolution times of all “*maintenance*” calls are considered as per Category 1-3 calls in Tables A.2 and A.3
- The response, analysis and resolution of all “*support*” calls are considered as per Category 4 in Tables A.2 and A.3
- Remote installation of a new release of Delft-FEWS once a year
- One on-site visit per system per year by a Deltares expert if required

### A.6.2 Additional costs

Additional costs can include:

- 1 Additional costs related to enhanced resolution time beyond those specified in Table A.2
- 2 Additional costs related to additional maintenance releases, and additional costs related to the

Additional support hours outside those offered in the Standard Package will be billed extra on a hourly basis, to be negotiated with the client.



## **B Delft FEWS licensing conditions**

