

Flood Frequency Mapping using Multirun results from Infoworks RS applied to the river basin of the Yser, Belgium

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Introduction

Aminal division Water constitutes a part of the Flemish Government that is responsible for the management of some river catchments in the Flemish speaking part of Belgium. The division possesses a big network of modeled river systems, of which some have an operational status. Together with Wallingford Software, Aminal has developed a new methodology to create flood frequency maps. This method permits the creation of univocal flood frequency maps by which a certain frequency can be attributed to every stage and flow anywhere in the river system.

This paper will explain the methodology applied to the river system of the Yser in Belgium. The first part will situate the basin and give some features of the river system and the model. In the next chapter the strength of the method will be explained in respect of the former methodologies. Finally the method will be explained in detail.

Situation

Fig. 1 situates the Yser basin in the Flemish speaking part of Belgium. The basin is bordered by France and the North Sea, which is approximately 50 km away from the United Kingdom. The basin has an area of 1101 km² with 700 km² in Belgium. Its source is situated in Lederzeele (France). The Yser discharges itself in the North Sea via a sluice complex where river discharge is not possible with high tide. The total length of the river is 78 km with 45 km in Belgium. The rivers of first category, where Aminal division Water is the manager of, have a total length of 115 km. Those rivers are part of the smaller river catchments that are coming out into the Yser. The most important subcatchments of the Yser in Belgium are: Heidebeek, Poperingevaart, Ieperlee, Canal Ieper-Yser, Martjesvaart, Blankaart, and Handzamevaart.

The Yser is a typical river with a fluvial regime: the flows on the border with France can fluctuate from less than 2 m³/s in dry circumstances to 100 m³/s in severe circumstances.

The Yser together with those important and some minor tributaries are modelled by division Water. In total this corresponds with a total modelled length of almost 200 km. In this paper the model of the Yser is investigated with 3 tributaries: Poperingevaart, Martjesvaart and Handzamevaart (Fig. 2). The hydrodynamic model consists of 2300 nodes, 102 storage areas and 55 hydrological boundaries.

The last couple of decades the Yser have experienced some severe flooding events. Still recently, in July 2005, several stage records in the subcatchments were perished. For the management of the water resources, it is therefore important to have an adequate idea what the risk of inundation in a certain area is.



Fig. 1 Situation Yser Basin in Flanders, Belgium

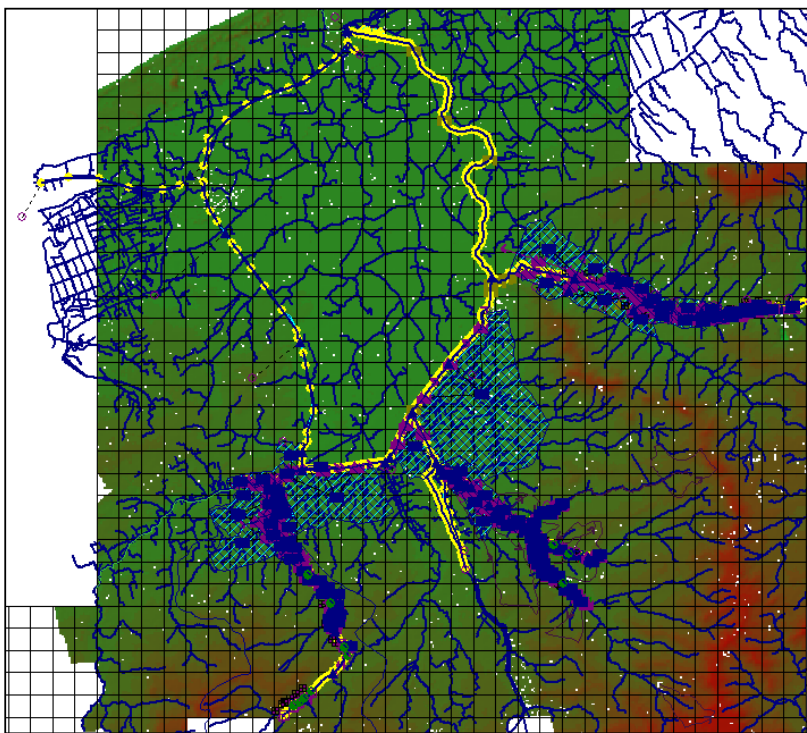


Fig. 2 Hydrodynamic model of the Yser with tributaries

Data collection

To calibrate the hydrologic and hydrodynamic model, a network of almost 20 real time flow and/or stage meters was used. The hydrologic response to the river was modeled with the conceptual PDM-model, which is a part of Infoworks RS. The input for the PDM model came from several rain and evaporation gauges in and outside the basin. These data were measured on a 15 minutes or hourly basis, and are available from 1898 onwards. The staggering of the rainfall was measured through the Thiessen polygon method. The stages and flows in the rivers and valleys were modeled with Infoworks RS. Indispensable in creating representative floodmaps is a digital elevation model (DEM). In this case study a very detailed DEM with a resolution of 5x5 m was used.

Why this method?

As mentioned before, flood frequency maps are very important in weighing up the management of the water resources. The effectiveness of the protection measurements on the field can be weighed better when the accurate flooding risk in a certain zone is known.

In former and some current methodologies the frequency results at one or several gauges are used to obtain flood frequency maps. These methods starts that the frequency results at one location (e.g. flow gauge) can be propagated throughout the modelled network. In many cases this is not correct. An event may be critical at one place but not at another place or the other way round. Take a local severe summer storm which can be felt in the upstream sections of the river basin but which will be unnoticeable in the downstream sections of that river. Inundations along small rivers are often the result of a short and intensive shower of rain, inundations along bigger rivers, which can transport higher discharges in a shorter time, are often the result of long-term high precipitation values.

With this methodology it becomes possible to delineate precise flooding risks at every node in the network. So the different behaviour of many storms along the course of the modelled network can be taken into account. In this matter a more thorough investigation of the frequency of inundation can be done.

The flood frequency maps form the ideal instrument to base some drafts on. A possible draft could be the protection of a residential nucleus by building a bank around it. If this zone lies in an area without measurement gauges, defining the proper height of the bank will be difficult. This new method provides the necessary information concerning the height of the bank.

Methodology

The different steps to create uniform flood frequency maps are given in Fig. 3. The methodology consists of following steps:

- Selection independent events;
- Calculation selected events;
- Statistical analysis;
- Frequency mapping.

The automatisation of these steps by Infoworks RS makes it possible to obtain flood frequency results in a quick matter. On the right-hand side of the figure, the Infoworks RS tools are given.

By this the methodology will be explained in more detail.

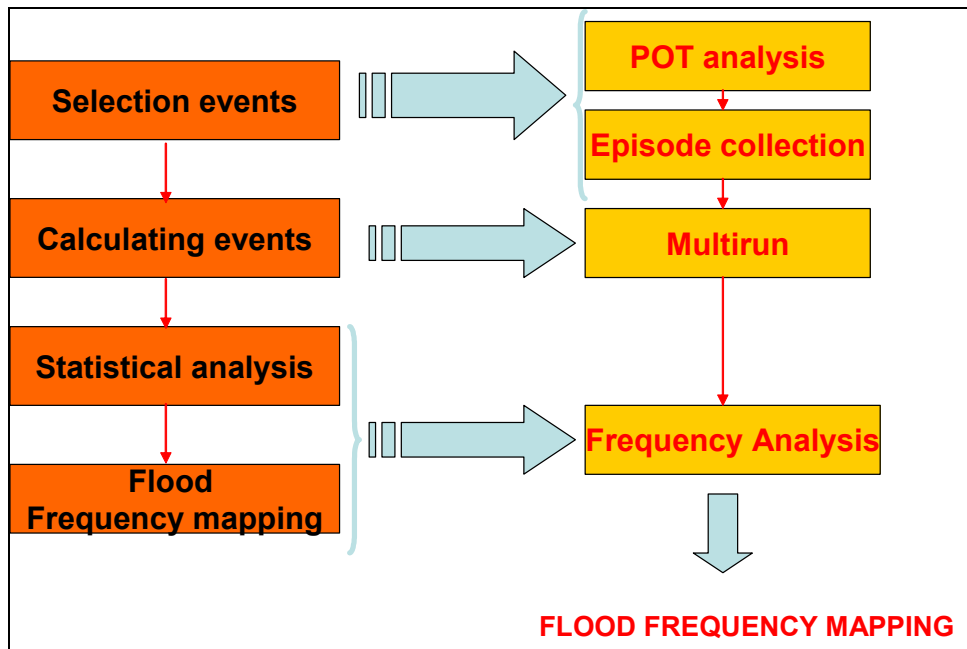


Fig. 3 Methodology for creating flood frequency maps in Infoworks

Selection independent events

Ideally, the long-term hydrological calculated series of flows should be analysed with the hydrodynamic model. Unfortunately, most of the current computer processors are too weak to perform this task. A calculation of 100-year data through a detailed network in Infoworks RS could easily take several months. Therefore, a selection of the most critical events along the course of the river is made. By making this selection the speeding process of the computer is optimised without eliminating the critical events.

The selection is based on the partial duration series or peak over threshold (POT). The data are so selected that their magnitude exceeds a certain threshold. This selection is easily done inside Infoworks RS by using the POT analysis tool and the Episode Collection tool.

De POT-tool enables to make the selection of the independent storms above a certain threshold. The Episode Collection tool merges all the independent storms that are obtained in the different POT analysis.

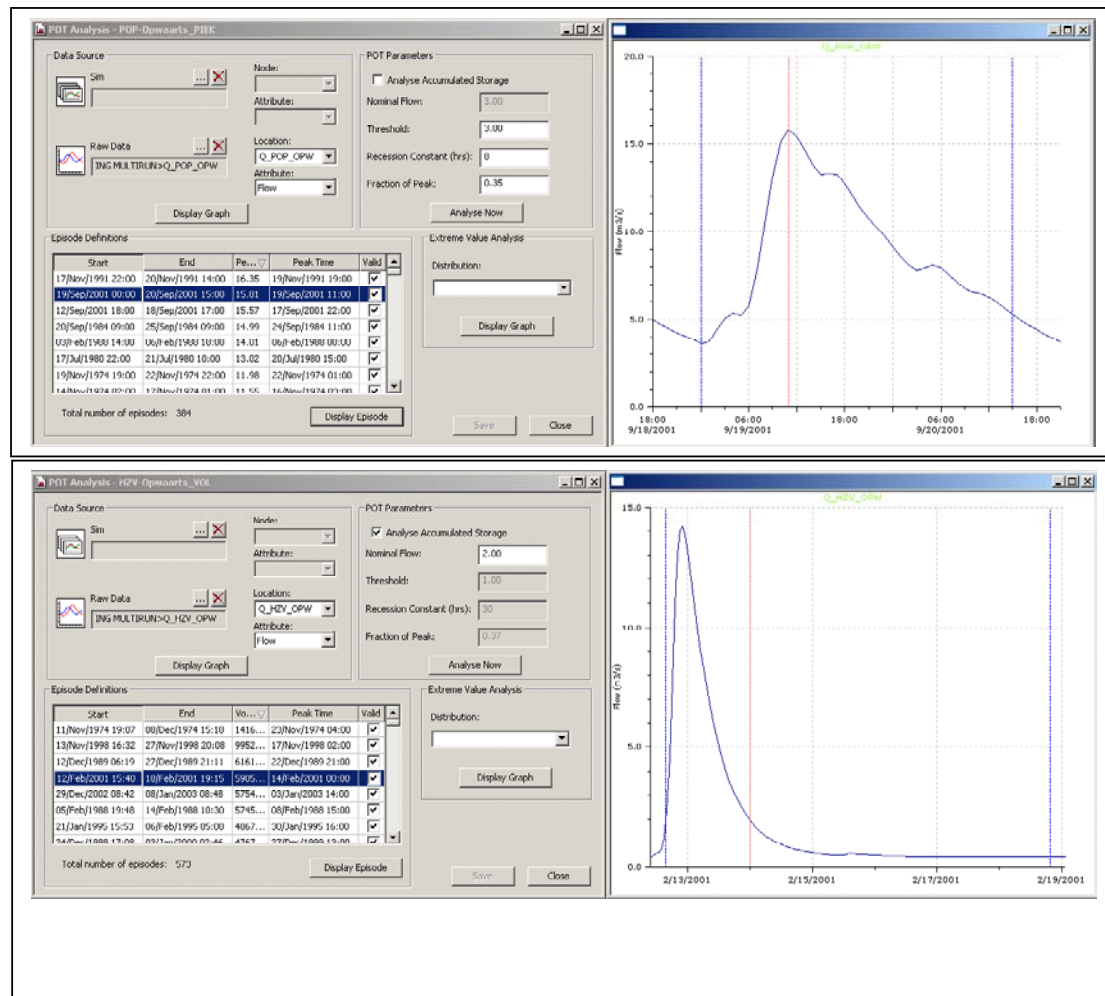
In the case of the Yser the POT analysis was done on peak discharges and accumulated storage (Fig. 4). Those two different approaches are incorporated to make it possible to select (summer)storms, distinguished by low volumes and high discharges on the one hand, and high volume long-term (winter)storms on the other hand. The input was given by the calibrated hydrological PDM model over a period of almost 50 years.

The analysis was executed on 4 different locations in the network. In this matter the spatial distribution of the rainfall over the last 50 years is taken into account.

The criterion of independence for the selection of peak discharge is based on the recession constant of the runoff flow (Willems, 2000). It contains 3 variables: recession constant, minimum flow above base flow, and minimal dry weather period between two independent events. The last criterion comes down to a decrease of the discharge with 37 %. A guidance of selection in the case of the Yser is $12n$ where n is the total amount of available years to perform the analysis on.

The criterion of independence for the selection of accumulated storage is based on a threshold value. This threshold corresponds in this case with 60% of the average annual

discharge. The episode starts when the flow exceeds the threshold and ends when the accumulated storage returns to zero.



The analysis resulted in the selection of hundreds of events. These events were sorted by magnitude. The less critical storms were eliminated.

By using different analysis on different places, the storms that were held back represents all potential critical storms at all places along the course of the modelled river.

A lot of events derived from the different POT analysis are overlapping. In order to obtain one series of events, all episodes from the POT analysis were merged into the Episode Collection tool. An example is given in Fig. 5. As with the POT tool the possibility remains to fine-tune some periods.

In the case of the Yser 79 storms originating from almost 50 years of data were held back in the episode collection.

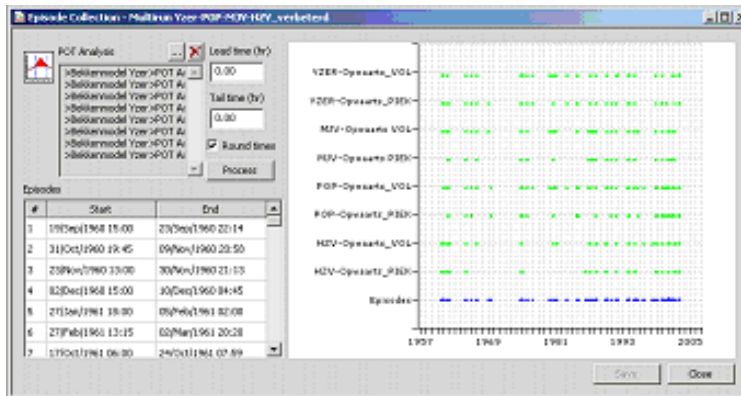


Fig. 5 Example of Episode collection in Infoworks RS

Calculating Events

The results of 79 storms were dragged to the Multirun tool that executes the events out of the episode collection (Fig. 6). Once those critical events were calculated the frequency analysis on every node in the network could start.

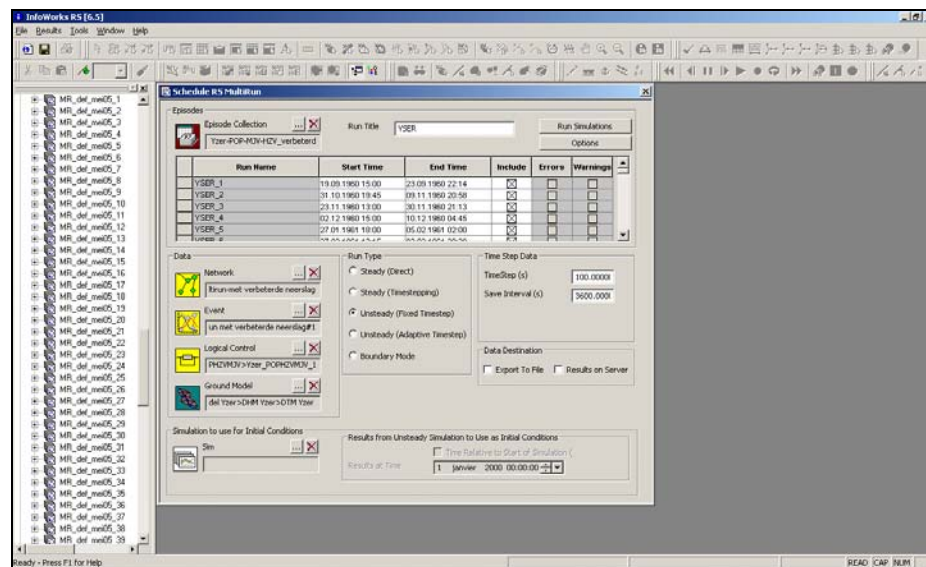


Fig. 6 Example of Multirun in Infoworks

Statistical analysis

Every node, such as river sections and storage areas, out of all simulated runs in the Multirun can be statistically investigated. In Infoworks RS this is done by the Frequency Analysis tool. With relation to flood frequency mapping, especially the storage areas, extended river sections and parallel river sections are important.

This method gives for every location the numerically sorted maximum stages (or flows) that corresponds to a probability. By fitting a distribution curve it becomes possible to estimate a probability for every arbitrary stage (or flow).

The probability in this case is obtained by using the Gringorten method (Chow, 1964):

$$F(x(i)) = (i-0.44)/(n+0.12)$$

Where:

n = sample size

$x(i)$ = ordered maxima values

A choice between different distributions can be made: GEV, Generalised Logistic, Pareto, and Weibull distribution. At the moment of writing it is only certain that a Pareto and Weibull distribution is valid for analysis deduced from a partial duration series. In the future it should be made possible to include an exponential distribution, which is a special case of the GEV. In the case of the Yser a Pareto distribution is used. The frequency analysis box is given in Fig. 7.

Infoworks RS has included an automatic fitting algorithm which is applicable to all points (e.g. maximum stages) or to all points above a certain (inundation) threshold. This threshold is very important for storage areas. There it is impossible to delineate a proper distribution on all points when not all storms cause inundation. This is shown in Fig. 8. This figure gives the probability fitting of a certain storage area in the Yser basin. Most of the 79 storm resulted in no flooding at that location. The maximum stages for those storms will correspond with the initial water level in the storage area. The first storm that causes inundation in this storage area has a maximum stage of approximately 4,00 m Taw (Tweede Algemene Waterpassing or Second General Levelling). All more critical events will result in extremer maximum stage values. A decent fitting can't be done on all simulated maximum stages. A fitting should be made above the threshold which corresponds to the first or lowest inundation point. Below the threshold a linear fitting is applied.

An algorithm in Infoworks provides the automatic detection of the threshold. In many cases this works fine, but manual adjustment of the threshold in the frequency analysis tool stays very important. Some fitting examples of storage areas and river sections are given in Fig. 9. Fig. 9 reproduces also a storage area with no inundation at all. This is translated in a horizontal line.

It is important to underline that the threshold value doesn't always match the inundation point of the storage area. In some cases, e.g. when the interest lies in frequency values that are higher than a defined probability (or return period), a higher threshold will optimize the fitting.

There are a few exceptions when the fitting won't give a proper solution. This is the case for a storage area with one or two inundation points. An example is given in Fig. 10. Out of this figure it clearly appears that the probabilities of the inundation stages doesn't match the distribution function. This is typical to the analysis which needs at least 3 point to fit. The solution of this problem lies in the manual correction of the distribution function outside Infoworks RS. One can take into account the distribution function of a nearby storage area or one can calculate the empirical probability. The adjusted return period curves can then be imported in Infoworks RS.

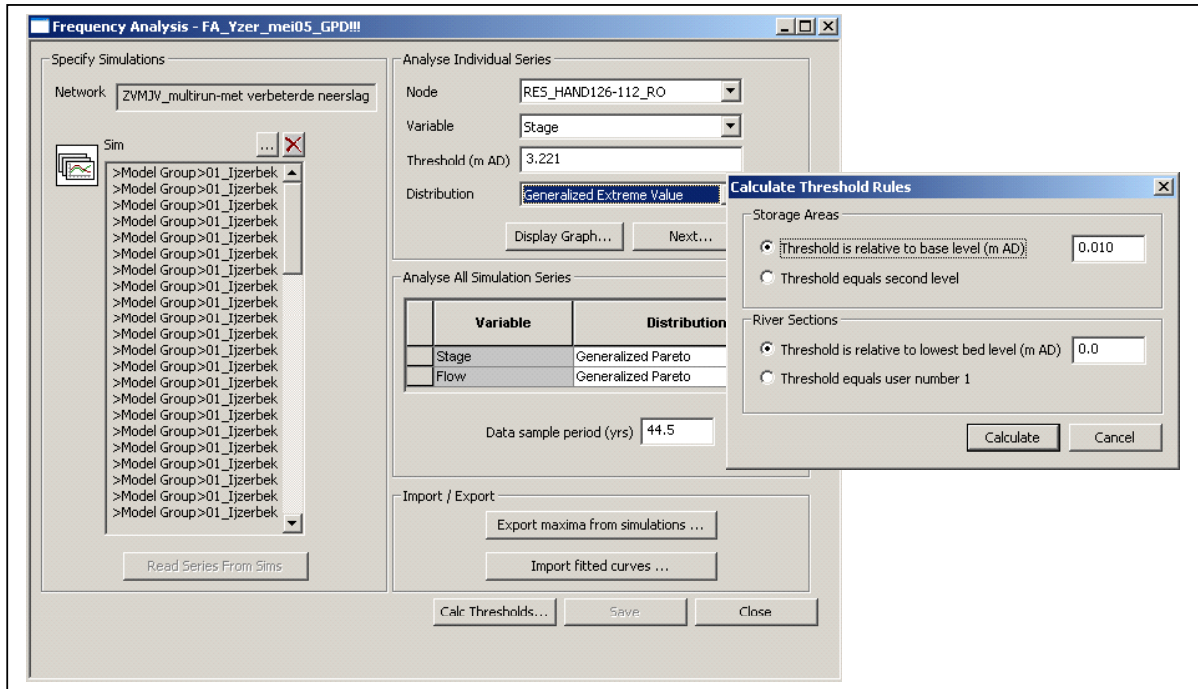


Fig. 7 Frequency analysis tool in Infoworks RS

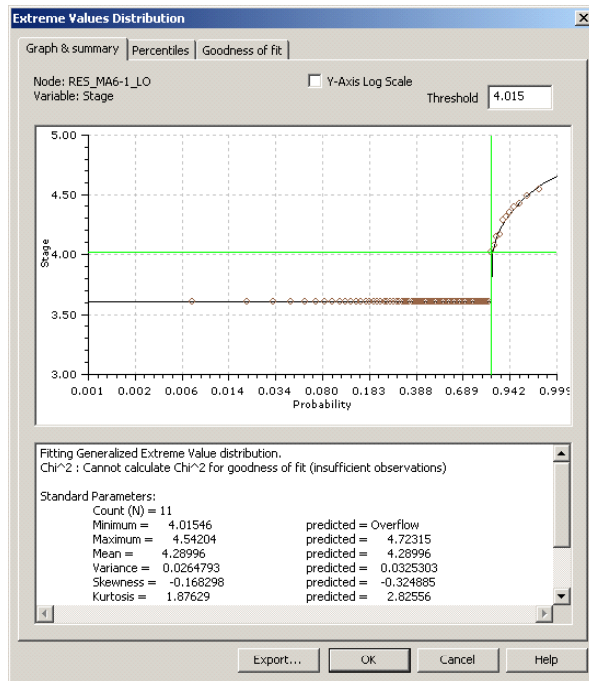


Fig. 8 Frequency analysis with threshold in a storage area

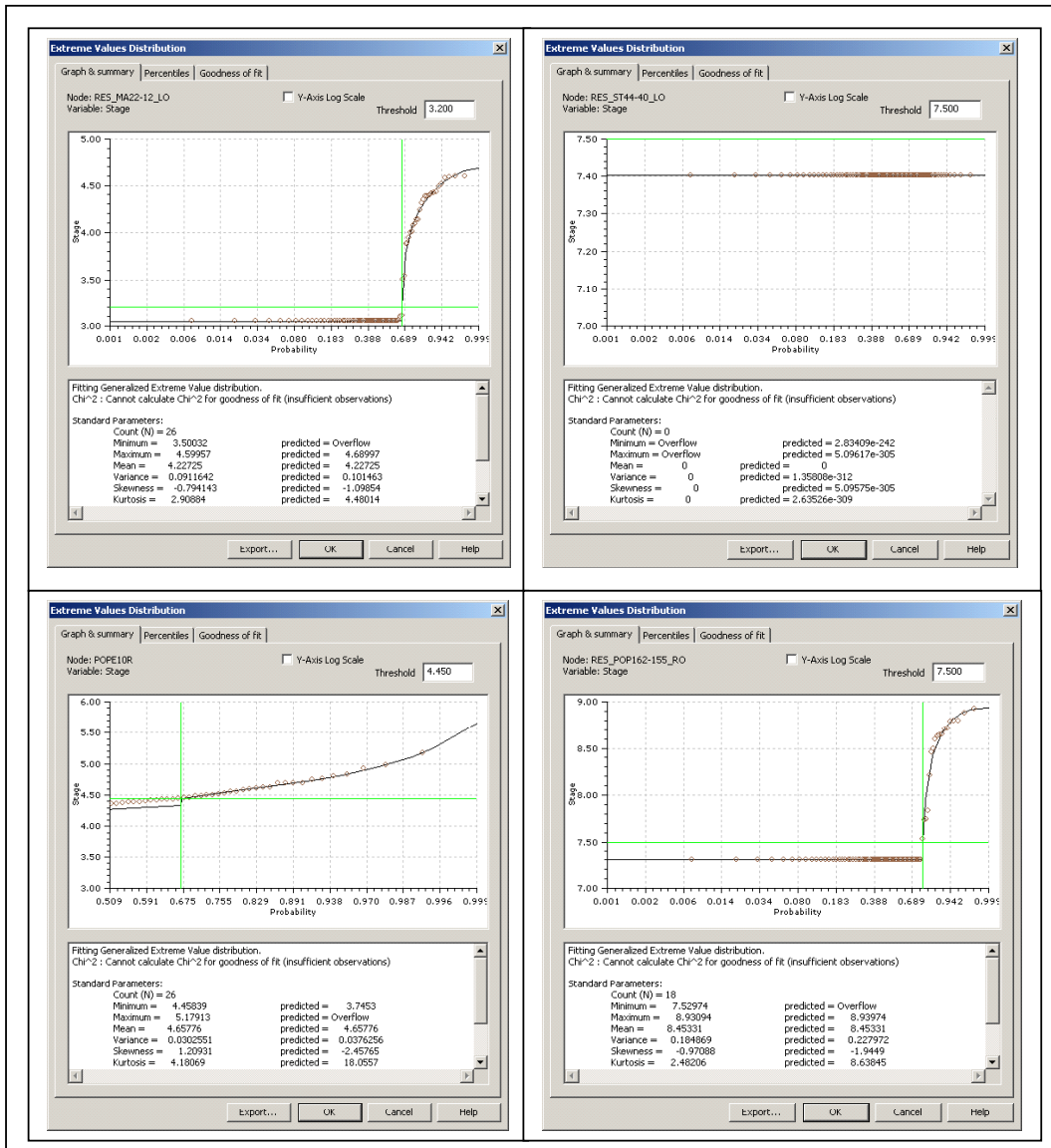


Fig. 9 Frequency analysis in storage areas and river sections

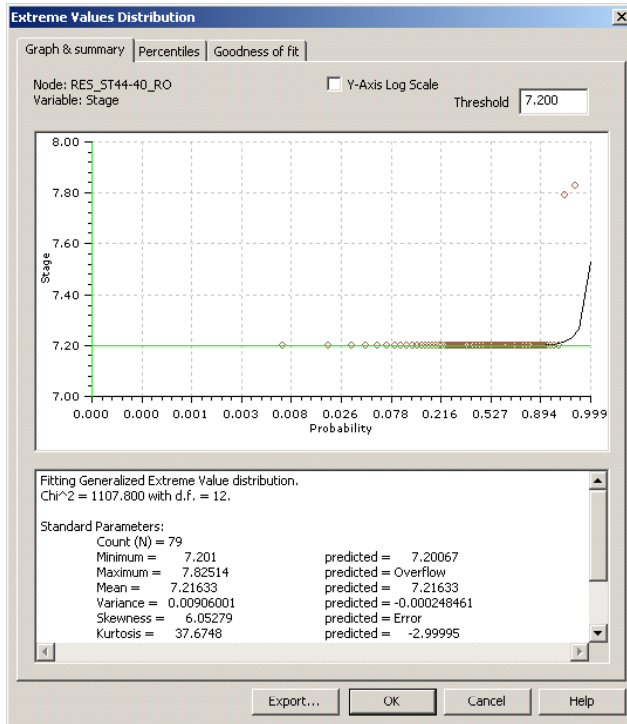


Fig. 10 Frequency analysis in a storage area with two inundation points

Flood Frequency Mapping

For each return period the frequency results can immediately be visualized (Fig. 11). The return period is given by:

$$T = n / (t*(1-p))$$

Where:

n = data sample period

t = number of simulations

p = exceedance probability from the fitted probability distribution

As seen in Fig. 11 the results can be reproduced in the form of flood frequency maps, tables and figures. A bunch of export opportunities can bring the output in the desired format.

Fig. 12 shows a 3D detail of a flooding contour along the Poperingevaart. On the left side an isolated house with a protection bank is visible. The figure demonstrates that the building is protected for a return period of 5 years. With a return period of 30 years the building will be flooded.

An important remark regarding the extrapolation of the return periods has to be made. In the case of the Yser the flooding results are very reliable up to a return period of approximately 50 years, as only the period of the last 50 years is taken into account. Extrapolation of the distribution curve past the most severe storm can give an indication of higher return periods, but this remains uncertain. In other studies done by the division Water, 104 years of data were used. This gives reliable return periods up to more than 100 years.

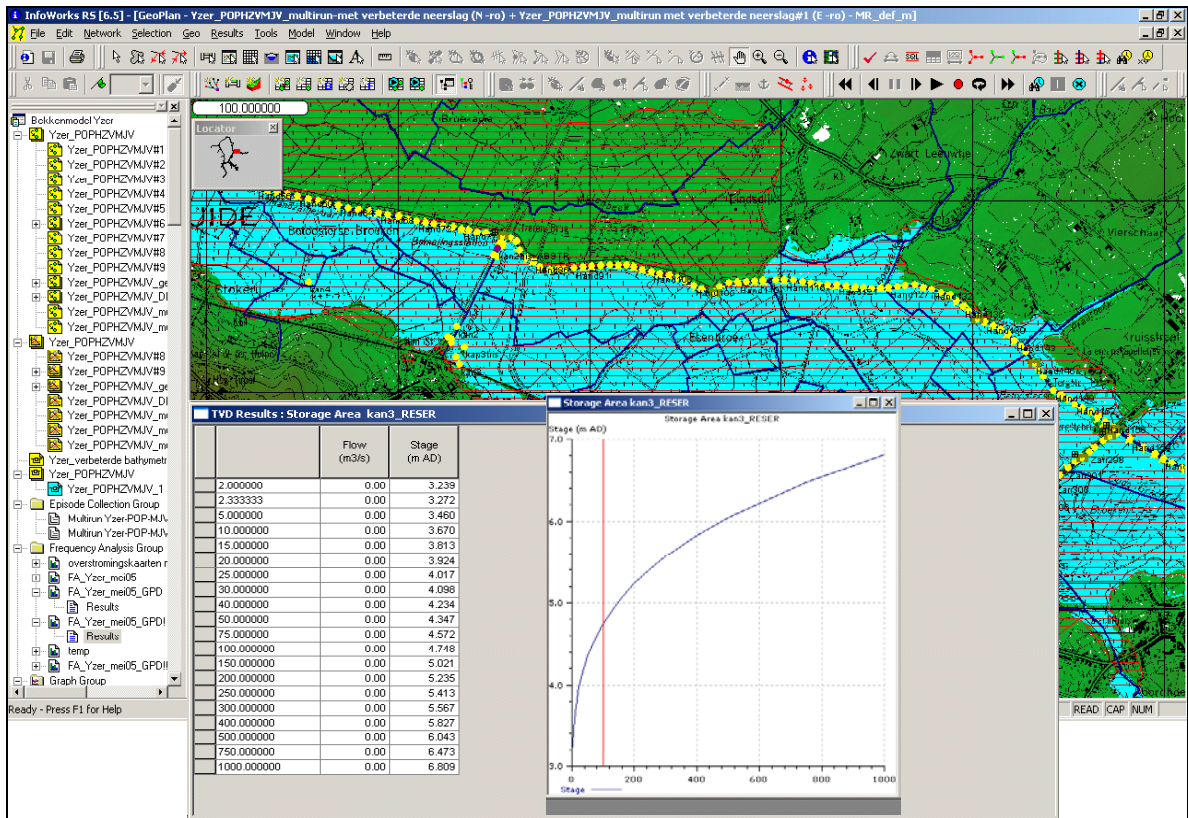


Fig. 11 2D example of floodmapping in the Yser basin

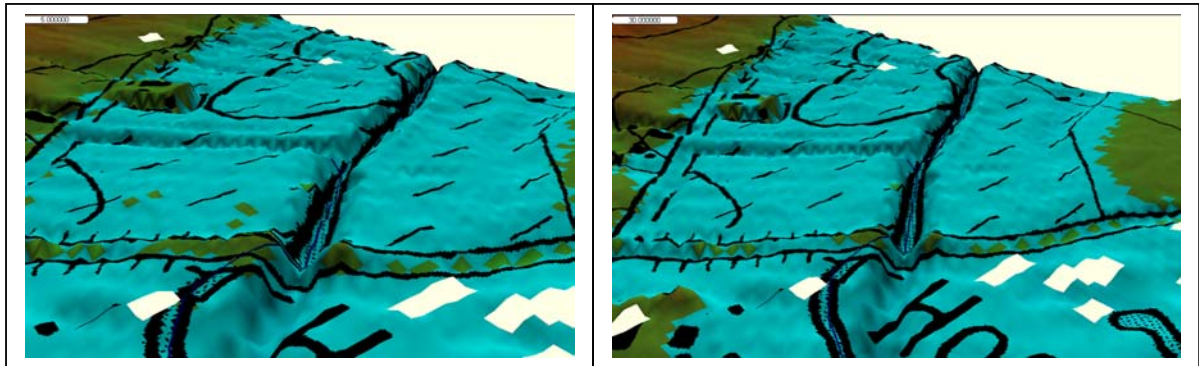


Fig. 12 3D example of floodmapping in het Yser basin

Conclusion

The study of the river catchments of the Yser handles a new approach in creating flood frequency maps. The strength of the methodology lies in the frequency analysis at each location, by which the correct flood frequency contours along the course of the modeled river and valley can be calculated.

The flood frequency mapping of other methods are often based on the probability distribution at one point (e.g. flow gauge). However, the uncertainty becomes greater when moving away from that gauging point. The new method prevents this problem.

With this method the division Water has at his disposal a better instrument for weighing up the necessary measurements.
The automatisisation in Infoworks RS makes a fast visualization of the flood frequency maps possible.