Presentation of uncertainty in model output to decision makers in flood management

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Summary

Presentation of uncertainty in model output to decision makers in flood management.

A combination of an increase in extreme weather situations and restricted capacity of water systems impose higher demands on the operational water management. Therefore, an increasing number of water boards decided to develop a Decision Support System (DSS), which is based on hydrologic and hydrodynamic models. These models are simplifications of reality and as a result of that uncertainty appears. This uncertainty could be located in several places of the model; for example model input, model structure and/or model output. To prevent decision makers from 'wrong decisions' with far-stretching consequences, it is essential that the uncertainty in the model output is communicated correctly to the decision makers, especially in flood management. The objective of this research is therefore, to determine the best presentation forms to communicate uncertainty in model results to decision makers in flood management.

A high water event of the 20th of January 2008 in the area of Water Board Hunze & Aa's is examined on uncertainty in model output, by means of conversations with experts about the uncertainty in the DSS Hunze & Aa's, a sensitivity analysis and a Monte Carlo analysis. The results of the Monte Carlo analysis are used to design presentation forms. The decision makers were asked to rank the presentation forms and make comments on them.

The interview results pointed out that the 'Bandwidth' is the best presentation form, because it easily could address the next three matters. First, the peak in the water level with the uncertainty range. The decision makers stated that the 30%, 50% and 90% lines of the DSS presentation should be used to simulate the 'minimal water level', 'most appropriate water level' and maximum water level'. Second, the development of the water levels in time is essential, because the decision makers need to know how much time there is to prepare and if it is necessary to take measures. Information about the actual water level and the water levels of the last two days is preferred. Third, the critical values have to be visually available in the graphical presentation. It should be visible at a glance if a situation is going to be threatening or not. Therefore, the actual presentation of uncertainty in model output to decision makers in flood management should be extended with historical water levels and the critical water level.

Samenvatting

Presentatie van onzekerheid in modelresultaten naar besluitvormers in het hoogwaterbeheer.

Toename van het aantal extreme weersituaties en beperkte capaciteit van watersystemen, stellen hogere eisen aan het operationele waterbeheer. Steeds meer waterschappen geven daarom prioriteit aan het optimaliseren van het operationele waterbeheer ten tijde van extreme situaties met behulp van beslissingsondersteunende systemen (BOS). Al deze systemen zijn gebaseerd op gedetailleerde hydrologische en hydrodynamische modellen. Echter kleeft er aan het gebruik van modellen altijd een onzekerheid, aangezien modellen slechts een vereenvoudigde weergave zijn van de werkelijkheid. Onzekerheid in model resultaten kan verstrekkende gevolgen hebben voor de besluitvorming. Daarom is het verstandig om de onzekerheid die de modelresultaten met zich meebrengen, te communiceren naar besluitvormers in het hoogwaterbeheer. .

De hoog water gebeurtenis van 20 januari 2008 in het gebied van het Waterschap Hunze & Aa's is onderzocht op onzekerheid in model output, door middel van gesprekken met experts van het BOS Hunze & Aa's, een gevoeligheidsanalyse en een Monte Carlo analyse. De resultaten van de Monte Carlo analyse zijn gebruikt om presentatievormen te ontwerpen voor de interviews. De besluitvormers zijn gevraagd om de presentatie te ordenen op basis van geschiktheid voor communicatie van onzekerheid. Daarnaast wordt de besluitvormers gevraagd om commentaar te geven op de voorgelegde presentatievormen

De interview resultaten wezen uit dat de 'Bandbreedte' is de beste presentatievorm, omdat de volgende drie zaken gemakkelijk in de presentatievorm kunnen worden opgenomen. Allereerst, de top van de waterstand met de bijbehorende onzekerheidsband. De besluitvormers stellen dat de 30%, 50% en 90% lijnen van het BOS presentatie gebruikt moeten worden om de 'minimale waterstand', 'meest waarschijnlijke waterstand' en de 'maximale waterstand' na te bootsen. Ten tweede moet het verloop van de waterstand getoond worden, want deze is essentieel, omdat de besluitvormers moeten weten hoeveel tijd ze nog hebben om maatregelen voor te bereiden en maatregelen te nemen. Informatie over de actuele waterstand en de gemeten waterstanden van de laatste twee dagen worden hierbij op prijs gesteld. Ten derde moeten de kritieke waarden ook in de presentatie vermeld worden. Het moet in een keer duidelijk zijn of de situatie dreigend wordt, of niet. Daarom moet in de huidige presentatie van onzekerheid in model output naar besluitvormers in hoogwatermanagement worden uitgebreid met de historische waterstanden en de kritische waterstand.

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Chapter 1 Introduction

1.1 Project background

Water Boards use operational Decision Support Systems (DSS) that are used to compute water levels as result of large rainfall and/or high water at sea and estuaries. Besides that, the DSS is designed to show the effects of measures on the water level for purposes such as safety against flooding. Basis of the DSS are river models, which are in fact simplifications of reality. This simplification originates "when people try to express their perception of the real world in words, numbers or equations. During this process of schematization, choices have to be made such as which process to include at which scale, relations, variables and input to use" (Warmink, 2009). This results in uncertainty within the model itself and within the model output, especially related with forecasting.

There are several definitions of uncertainty; all have been developed for many different purposes. An important barrier to achieve a common understanding is the diversity of meanings associated with terms such as "uncertainty" and "ignorance" (Norton et al., 2006).

Funtowicz and Ravetz (1990) describe uncertainty as a situation of inadequate information, which could be divided into three sorts: inexactness, unreliability, and border with ignorance. However, this does not exclude that uncertainty can also prevail in situations where a lot of information is available (Van Asselt & Rotmans). Furthermore, new information can decrease or increase uncertainty, because the new knowledge on complex processes may reveal the presence of uncertainties which were previously unknown or understated (Van der Sluijs, 1997; as cited in Walker, 2003). This means that uncertainty is not simply the absence of knowledge (Walker et al., 2003).

The definition of uncertainty by Walker et al. (2003) is especially based on uncertainty in models and will therefore be used in this report. The definition reads: '*Any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system'.* Besides that, Walker et al. (2003) distinguished three dimensions of uncertainty. Firstly, the location of uncertainty is an identification of where uncertainty manifests itself within the whole model complex. Secondly, the level of uncertainty classifies where the uncertainty manifests itself within the entire spectrum of different levels of knowledge exists, ranging from the unachievable ideal of complete deterministic understanding at one end of the scale to total ignorance at the other. Third, the nature of uncertainty reflects whether the uncertainty is due to the imperfection of our knowledge or is due to the inherent variability of the phenomena being described.

Uncertainty analysis can be used to determine the size of the uncertainty. Refsgaard et al. (2007) mention 14 different methods for uncertainty analysis, but more methods are available. Depending on the sort of uncertainty, the level and the nature an appropriate method can be used.

Wardekker & Van der Sluijs (2005) conclude that a shift of focus is needed from reducing uncertainties to explicitly coping with them, because more research does not automatically reduce uncertainties and uncertainties are not necessarily a problem for the quality of the information. Kloprogge et al. (2007) agree and state that an effective communication of the results of the uncertainty analysis might be even more important than a careful analysis of the uncertainty. Morgan & Henrion (1990) emphasize that, by concluding that it is even more important to deliver insights in the model output than only giving pure numbers to the decision makers. Instead of delivering one predicted value for the most appropriate water level, a connection should be made between the uncertainty and its consequences for the decision making (Kloprogge et al, 2007). If the uncertainties are not communicated properly, the decisions could have far-reaching consequences. Such as, areas can be flooded and the lives of people can be at risk. Knowledge of the type and magnitude of the uncertainties is crucial for a meaningful interpretation of the model output and to identify the usefulness of the output in decision making (Morgan & Henrion, 1990).

Wardekker et al. (2008) stress that every group of decision makers has different information needs, therefore only the information that suits the decision should be presented to the decision makers. However, little research has been done on the representation of uncertainty (Wardekker & Van der Sluijs, 2005) and in case of decision makers in water management there is no scientific literature about the presentation of uncertainty in water levels to decision makers.

The combination of the necessity of uncertainty communication and the lack of scientific literature on the presentation of uncertainty for decision makers in water level management, leads to the objective of this study.

1.2 Objective and research questions

1.2.1 Objective

The objective of this study is to determine the best presentation form to communicate uncertainty in river model output to decision makers in flood management.

To avoid misunderstandings about the objective, an elucidation of some terms in the context of this research is given.

Decision maker : a person who makes decisions on the measures, which have to be taken at certain expected water levels.

Model output : the water level at rivers or surface water that is calculated in river models / DSS.

Presentation form : a method of one-way communication to decision makers.

1.2.2 Research questions & research approach

In order to support the accomplishment of the objective stated in section 1.2.1 three research questions are formulated. These questions are:

- Which presentation forms are appropriate for communication of uncertainty in model output to non-technical decision makers?
- Which of the designed presentation forms is the best to communicate uncertainty towards decision makers in flood management?
- What determines the ranking of the presentation forms for the decision makers in flood management?

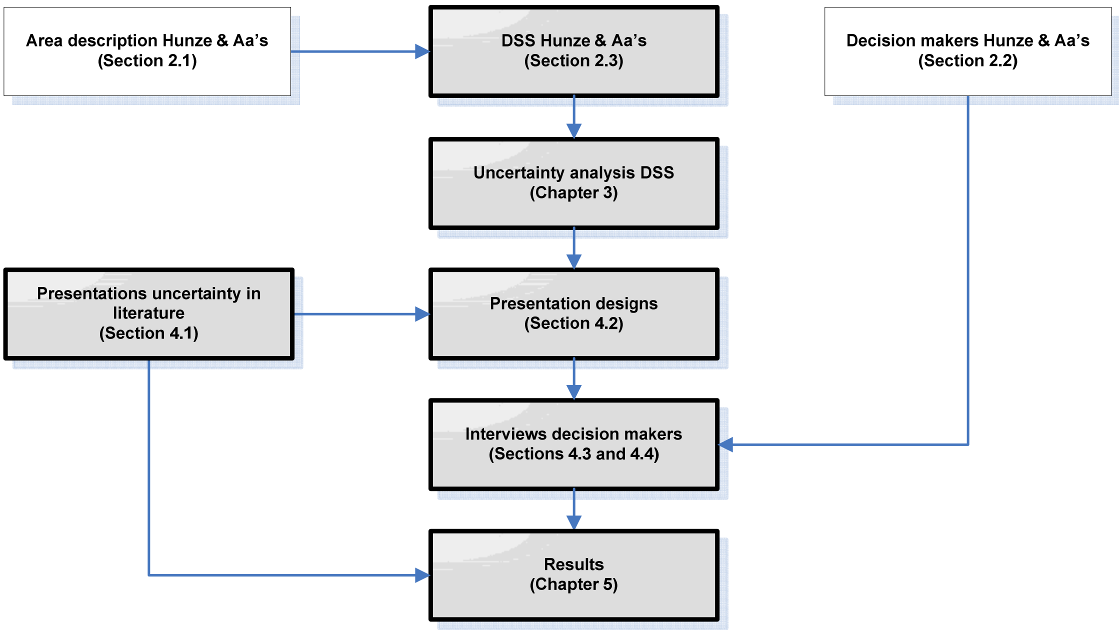


Figure 1.1. Research approach

The research questions have to be answered by means of the research approach in figure 1.1

Hunze & Aa's is the starting point of this research and the area is modeled in the Decision Support System (DSS) of the Water Board Hunze & Aa's. The data of the most extreme high water wave since 2004 is used during this research. These data is used to determine the uncertainty in the DSS model output by means of a sensitivity analysis and a Monte Carlo analysis.

The uncertainty in the DSS model output is presented in several presentation forms. These presentation forms are drawn up on the basis of scientific literature for policy making, because there is no literature found on presentation forms for water level management or flood management. Finally, the designed presentation forms are used as input for the interviews, which will be held with ten decision makers in water level management. During the interviews, the decision makers are asked to rank the presentation forms and give comments about the designed presentation forms.

1.3 Report outline

Chapters 2 and 3 provide the inside knowledge that is necessary to understand the framework of the research. Chapter 2 gives an outline of the area, the decision makers and the Decision Support System (DSS) of Hunze & Aa's. The uncertainty in DSS model output is determined in chapter 3, by means of a sensitivity analysis and a Monte Carlo analysis.

Chapter 4 contains the method that is used to designed presentation forms, the interview setup and the interview analysis will be discussed. Chapter 5 shows the presentation forms found in scientific literature and the best presentation forms for presentation of uncertainty to decision makers in flood management. These results will be discussed in chapter 6, followed by the conclusion and recommendations given in chapter 7.

Chapter 2 Study area Hunze & Aa's

A recent extreme event for the area Hunze & Aa's will be used as starting point for this research. Therefore this chapter describes the area, the decision makers and the DSS of the Water Board Hunze & Aa's. Advantage of using a recent event instead of a fictional one is that the model already exists and that all the predictions for the input are available. Furthermore, using a recent event provides a more realistic situation and that results in more commitment by the decision makers.
Due to the 1998 flooding and the expectation of more intense rainfall in the future, the Water Board Hunze & Aa's had decided to develop a DSS in 2004. More intense rainfall and the limited capacity of the water systems has lead to higher demands to the operational water management. The DSS could predict water levels and indicate the most optimal use of measures, in both regular and crisis situations. The DSS helps the decision makers to understand the seriousness of the situation.

The Water Board of Hunze & Aa's uses the DSS in everyday situations, for example to decide the optimal use of controllable structures like sluices and weirs. The DSS could also be used in crisis situations, for example to decide which emergency flooding areas to use. When the emergency flooding area is flooded too early, this could signify that the measure has no effect and cannot be used later again. On the other hand when the emergency flooding area is put into work too late, the damage already occurred. So the question of when to take which measure becomes more important at high water situations (Loos et al., 2008).

This chapter provides shows the area of Hunze & Aa's in section 2.1. The decision makers are discussed in section 2.2. Section 2.3 contains the different layers of the DSS. Section 2.4 shows the event that is used in the uncertainty analysis and the interviews with decision makers.

2.1 Area description

The control area of the Water Board of Hunze & Aa's is situated in the northeast of the Netherlands and its surface covers 207.000 hectares with in total 3.525 km water courses. Figure 2.1 shows a general map of the area with multiple water courses, the Eems-Dollard estuary, the largest cities and the most important structures of the area.

The map in figure 2.2 shows that the area is subjected to height differences and it even contains a large area where people live under sea level. According to this map the cities of Groningen, Hoogezand, Winschoten and Delfzijl are below sea level. This is approximately 25% of the area of the water board. The area of the water board of Hunze & Aa's counts 420.000 inhabitants and almost 300.000 of them live under sea level.

The water courses in the area of Hunze & Aa's are divided into four main systems: Eemskanaal-Dollard, Duurswold, Oldambt and Flemel boezem. A boezem is a network of water bodies in which excess water in case of extreme rainfall is temporarily stored. The boezem exists of lakes, canals and bigger ditches before it can be drained into sea. The largest part of the water in the area of Hunze &

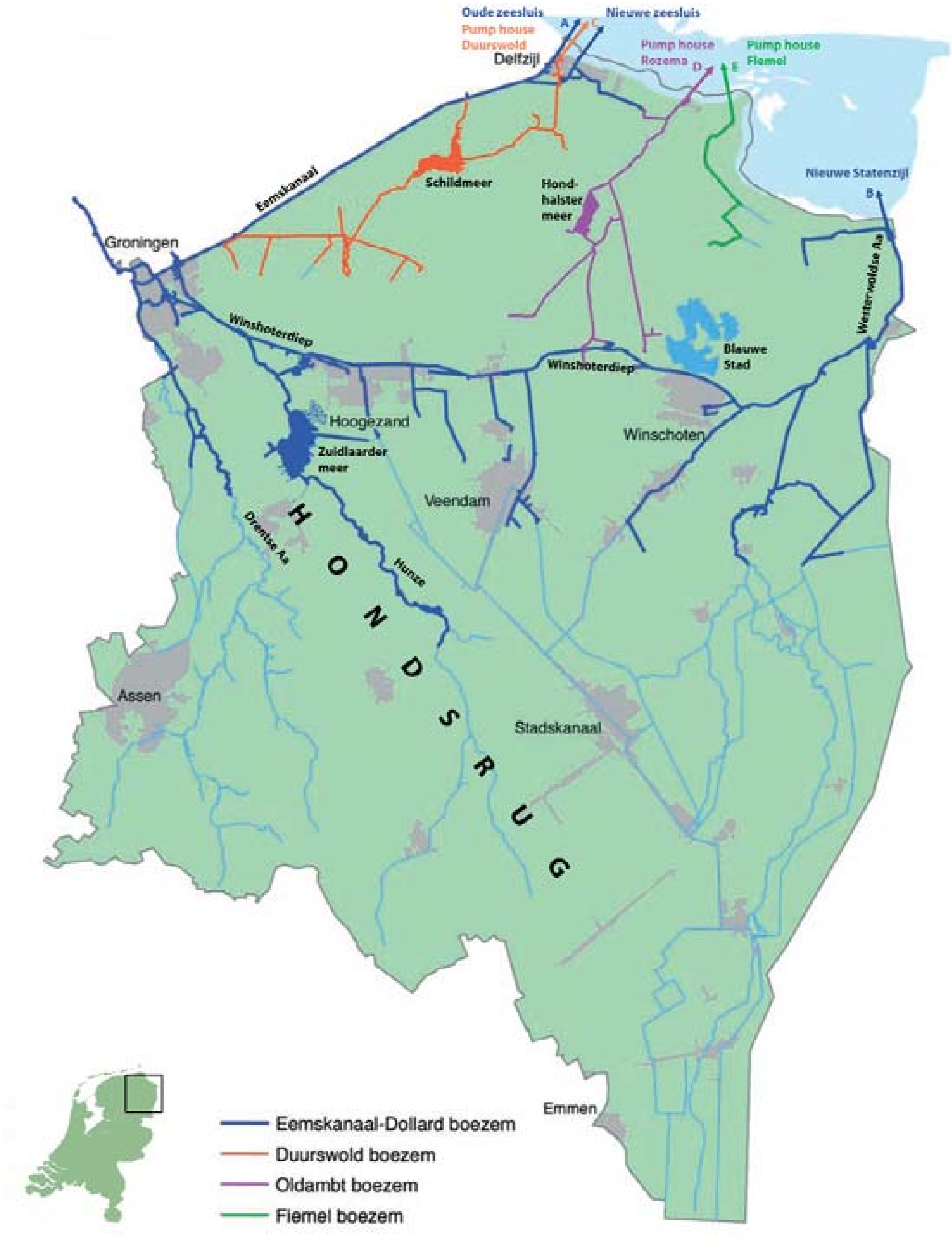


Figure 2.1. General map of Hunze & Aa's
Source: adapted from (Hunze & Aa's, n.d.).

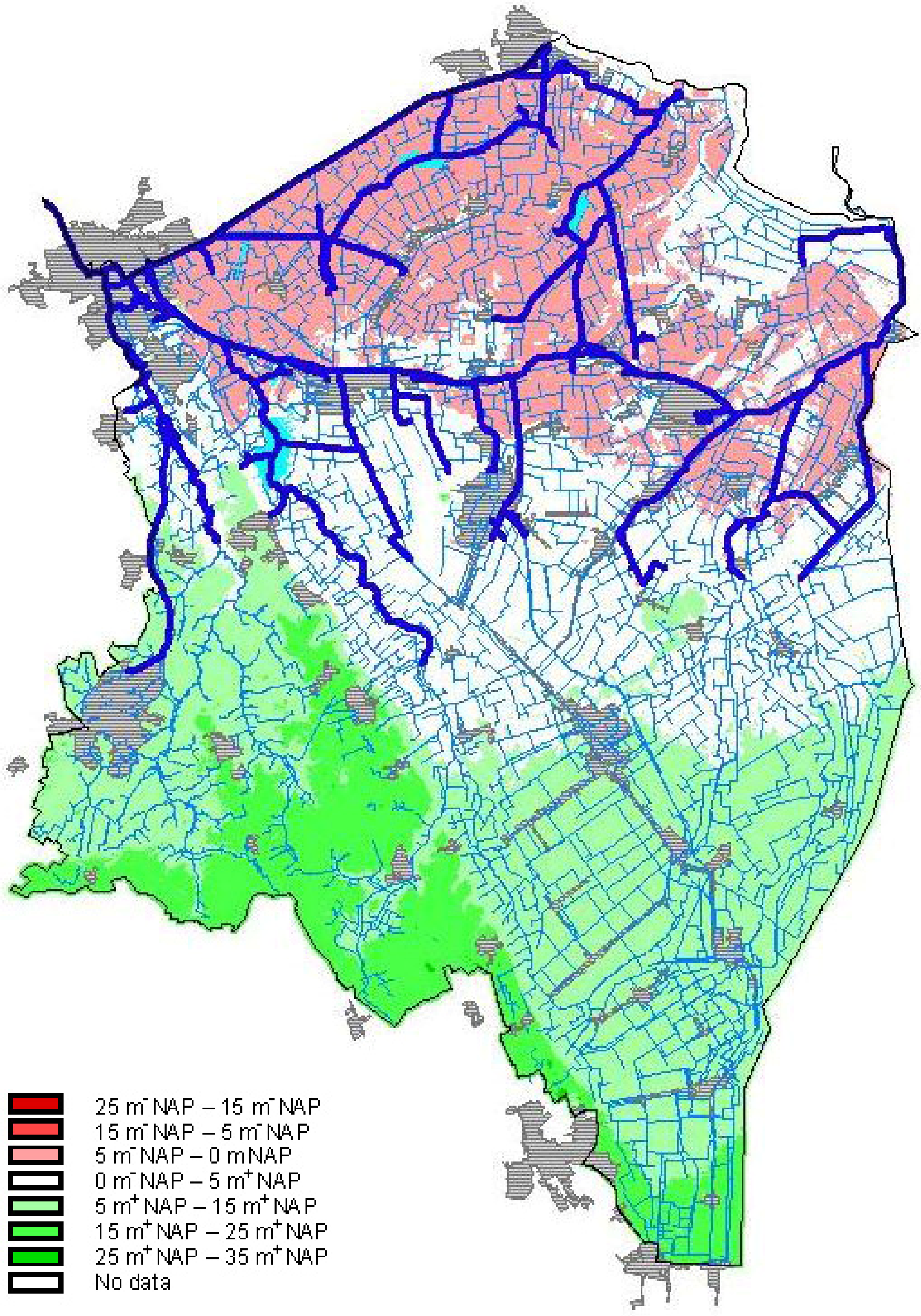


Figure 2.2 Height map Hunze & Aa's

The water courses are displayed in blue.

The grey area reflects the areas where the population density is large.

Aa's is discharged by the Eemskanaal-Dollard boezem. The water flows through the Eemskanaal or Westerwoldse Aa and is sluiced into the Eems or Dollard respectively. The water of the Duurswold boezem is pumped into the Eems and the water of the Oldambt and Flemel boezem is pumped into the Dollard.

The water system has a restricted capacity. If the sea water level is higher than the water level in the area, there is no possibility to sluice the superfluous water and the water has to be stored in the area of Hunze & Aa's. If there would be sluiced, the sea water flows into the area of Hunze & Aa's and the water level in the area would increase even more. Therefore sluicing cannot be used if the sea water level is higher than the water level in the area of Hunze & Aa's. Figure 2.3 shows that particularly the red areas in figure 2.2 are sensitive to flooding. In case of large rainfall and high sea water levels, the situation in the red areas can become critical.

To protect these low situated areas against flooding the Water Board has build 500 km polder dikes and 28 km sea dikes. However, the Water Board is prepared for situations in which meteorological circumstances, failure of controllable structures and dike breakthroughs can still lead to flooding. These scenarios are recorded in the emergency response plan of the Water Board Hunze & Aa's. Due to abundant rainfall in October 1998, the area of Hunze & Aa's was saturated. Extreme precipitation upstream at the 27th and 28th of that month caused more stress on the water system. This water could not be drained into the Eems or Dollard, because of the high sea water level due to wind from the northeast and slack water. The combination of abundant rainfall, saturated soils and restricted drainage possibilities caused extreme high water levels in the boezems. To prevent the area from flooding, measures had to be taken. Parts of the Onnerpolder and the Zuidlaardermeer were flooded and a dike had to be destroyed to prevent the city of Groningen from flooding. This has lead to more attention for flooding and new policies. Flood studies for the Province of Groningen have been carried out between 1999 and 2003 (Vegter, 2007) to investigate the possibility to install emergency flooding areas, to raise the dikes and remeander the streams.

Especially the emergency flooding areas were criticized by the inhabitants. Nevertheless, the Water Board has pointed out some areas that have to serve as emergency flooding areas as indicated in figure 2.3.

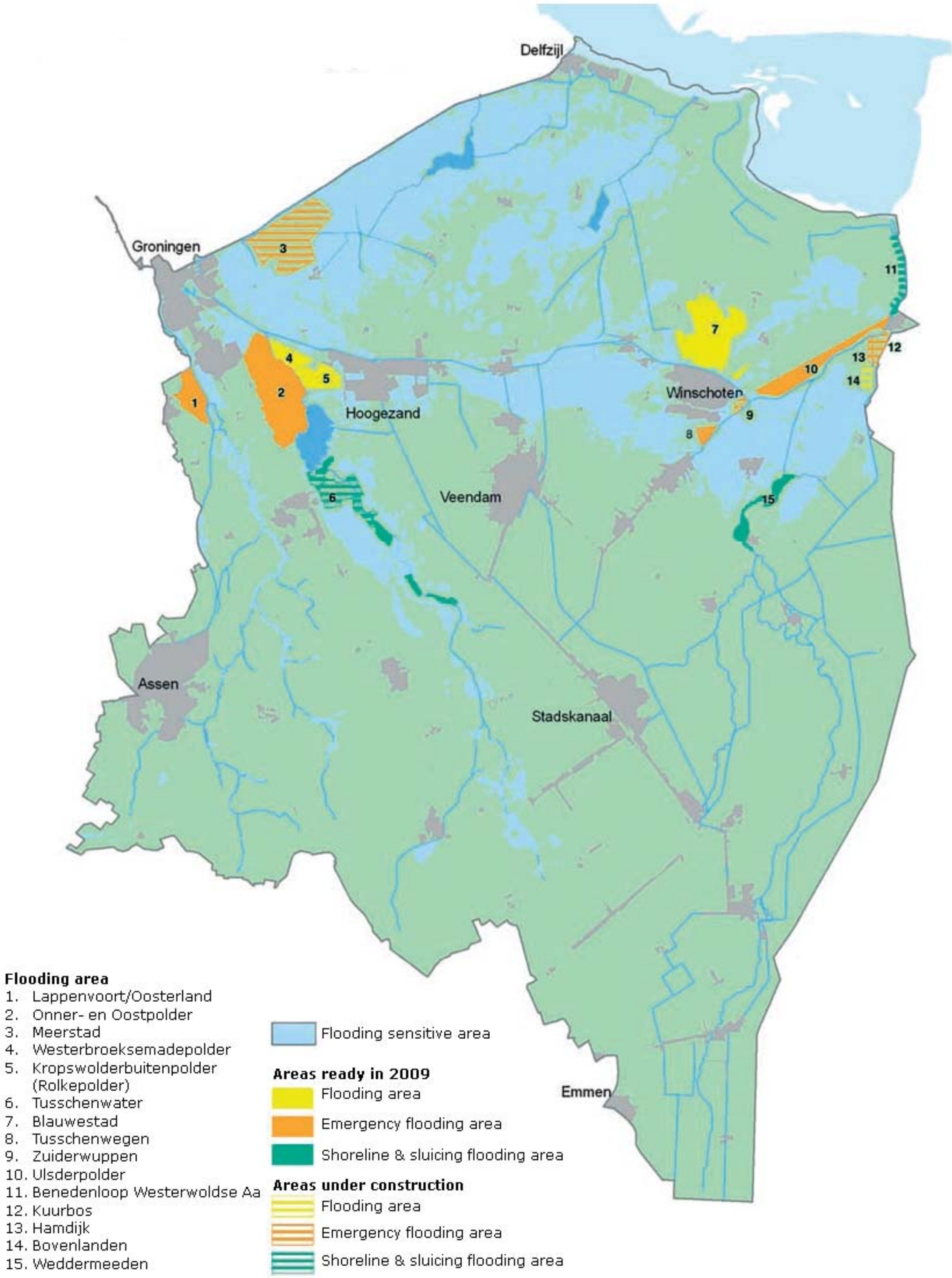


Figure 2.3 Flooding sensitive areas & (emergency) flooding areas
Source: edited from (Hunze & Aa's, n.d.)

2.2 Decision makers

One of the responsibilities of a Water Board is 'safety'. The area has to be protected from flooding. So every Water Board should have an emergency response plan according to article 69 of the Dutch Water management law 1900. The content of the plan is partly up to the Water Boards themselves. The Water Board of Hunze & Aa's has an emergency response plan called the 'Beheersplan Hunze & Aa's 2010-2015'. This plan contains instructions for what to do at a certain water level and which decision makers are responsible for a specific phase. Figure 2.4 shows the different calamity phases for different water levels. The water level is indicated from normal to extreme high water levels, because it is impossible to assign numbers to it. The area of Hunze & Aa's is subjected to height differences, which results in different water levels for several locations. So the water levels have to be evaluated per location for that reason. If the water level exceeds a critical value, a higher calamity phase is entered and other people are responsible for the decisions.

Water level	Calamity phase	Decision makers
Extreme high water	3	Safety Region
	2	WBT, WOT & WAT
	1	WAT
Normal	0	-none-

Figure 2.4 Water levels with accompanying phases and decision makers for the Water Board Hunze & Aa's. WBT, WOT & WAT are teams specified by and part of the Water Board Hunze & Aa's. The Safety Region is an umbrella organization for the Province of Groningen, which the Water Board takes part in.

The Water Board of Hunze & Aa's is fully responsible for the water level management up to and including phase 2. This is done in three different teams, specified with WBT, WOT and WAT. When phase 3 is reached, the Safety Region becomes responsible for all the actions that have to be taken, including water level management. The different teams and the Safety Region are defined below:

Water Board Action Team (WAT)

This team consists of people in the field who implement the actions and informs the rest of the Water Board about the situation in the field. This team guides the actions in phase 1.

Water Board Operational Team (WOT)

The Water Board Operational Team (WOT) consists of the department managers inside the Water Board and investigates the effect of measures from calamity phase 2 and up. The WOT assesses the seriousness of the situation; is there more rain coming, are the dikes strong enough etc. The WOT establishes their tactics to overcome the calamity on basis of these data. The WOT is advised by the hydrologists of the Water Board, who make calculations of the expected water levels in different scenarios and examine the effects of the measures. In case of extreme high water levels the WOT advises the WBT.

Water Board Policy Team (in Dutch Waterschap Beleid Team; WBT)

The WBT consists of the official board members of the Water Board Hunze & Aa's and a representative of the daily management. The WBT gives guidance to the internal calamity organization in phase 2 and 3, although they are informed by the WAT when calamity phase 1 starts to work. When the Safety Region is brought into being, a representative of the WBT takes place in the Safety Region.

Safety Region

A Safety Region normally consists of the mayor(s) and community services; police department, fire department and the Municipal Health Services. The Safety Region Groningen is quite unique in the Netherlands, because besides the earlier mentioned participants it also contains the army, the Water Boards, Province and the Public Prosecutor. The Safety Region deals with all sort of calamities. For example flooding, an airplane crash or an accident with dangerous substances. If one of the eight members of the Safety Region gets into a calamity phase, all the members meet and think about a solution.

At first, this seems questionable, because although almost all parties of the Safety Region has a limited knowledge of the behavior of the water system (Van Overloop et al., 2005), the Safety Region has to take the final decision in the highest calamity phase. On the other hand water issues are not the only decisions that have to be taken. Also issues like the need to evacuate and how to do that, have to be discussed.

The borders of Water Board and Safety Region are not the same. In case of a calamity concerning extreme high water levels and flooding a liaison of the Safety Region Drenthe is added to the Safety Region of Groningen. Although the Water Board of Hunze & Aa's is primarily located in the Safety Region of Groningen, there is also a part of the Water Board that is located in the Safety Region of Drenthe.

Concerning water levels, the members meet when the Water Board thinks that there is a real chance that the water level somewhere in the area is about to end up in calamity phase 3 and areas are threatened to be flooded. The Safety Region discusses about possible measures to reduce the water level, but they wait with the decision to bring an emergency flooding area into action for as long as possible. Before activation of the measure, the Safety Region has to decide, amongst other things, to evacuate the area and inform the companies. In the meantime, the Safety Region receives hourly updates about the situation in the field, new water level predictions and the most actual weather forecasts.

2.3 Decision Support System of Hunze & Aa's

The DSS of Hunze & Aa's could help the decision makers in a calamity phase to understand the seriousness of the situations if water level is concerned. The DSS predicts the water levels for the next three days and offers the possibility to calculate the effects of certain measures. The DSS also gives an indication if the situation is clear, alarming or critical according to the given critical values for the different phases at the specified locations. This is done by showing a clickable map, with colors that mimic the seriousness of the situation.

The DSS consists of three interacting layers: the data layer, model layer and presentation layer. These layers are discussed in the next sections.

2.3.1 Data layer

Data is gathered and stored in the data layer. The data is also exchanged with the model layer and presentation layer. The data layer uses actual hydrological and meteorological data as input.

Information about the actual water levels is gathered by several measurement points in the area and sent to the DSS data computer every 15 minutes. The water level on the boezem channels is determined by interpolation between the measurement points (HydroLogic, 2008a).

Precipitation

Precipitation has two subcategories: actual precipitation and the predicted precipitation.

The actual precipitation is measured at weather stations and by radar. Both are available every hour. The actual precipitation by radar is calibrated and adapted for precipitation per sector. All the information on precipitation is stored and a 90 day history of the precipitation is used to determine the soil conditions. When the soil is saturated the actual rain is directly transported to the water courses, otherwise it will infiltrate into the soil.

For this research the Ensemble Prediction System (EPS) of the European Centre for Medium-Range Weather Forecasts (ECMWF) model is used. Some characteristics of the model are shown in table 2.1.

Evaporation

The KNMI delivers the daily evaporation data

Table 2.1 EPS ECMWF

Sources: (HydroLogic, 2008b)

	EPS ECMWF
Area of the predictions	The total globe
Minimal grid size	50 x 50 kilometers
Prediction time	Up to 10 days
Model run	2 times a day 00:00 UT and 12:00 UT
Available	12 hours after the model run
Data delivery from the KNMI	Every 12 hours
Prediction value	50 values

Tide

For this research the WAQUA model is used. Some characteristics of the model are shown in table 2.2. The predictions for the tide are used as boundary conditions downstream at Delfzijl and Nieuwe Statenzijl.

Table 2.2 WAQUA

Sources: (HydroLogic, 2008b)

	WAQUA **on the basis of HIRLAM**
Prediction time	Up till 48 hours
Model run	4 times a day 00:00 UT, 06:00 UT, 12:00 UT and 18:00 UT
Available	4 hours after the model run
Data delivery from the KNMI	Every 6 hours

Wind

Wind predictions cannot be determined deterministic and therefore the wind direction and wind speed of the "Operational Run" is used. The "Operational Run" is the run of the weather predictions which starting values resembles the actual situation.

2.3.2 Model layer

The model layer prepares, calculates and fix the information for storage and presentation. In this layer the actual calculation of water level predictions is executed by a hydrological or hydraulic model that is used in the Dutch water management. In case of Hunze & Aa's the DSS works on a 1-D SOBEK-Rural model (further referred as SOBEK model).

The SOBEK model of Hunze & Aa's reflects all the relevant surface water, obstructing and controlling structures in the area. A schematization of the SOBEK-model for the Water Board Hunze & Aa's is shown in figure 2.5.

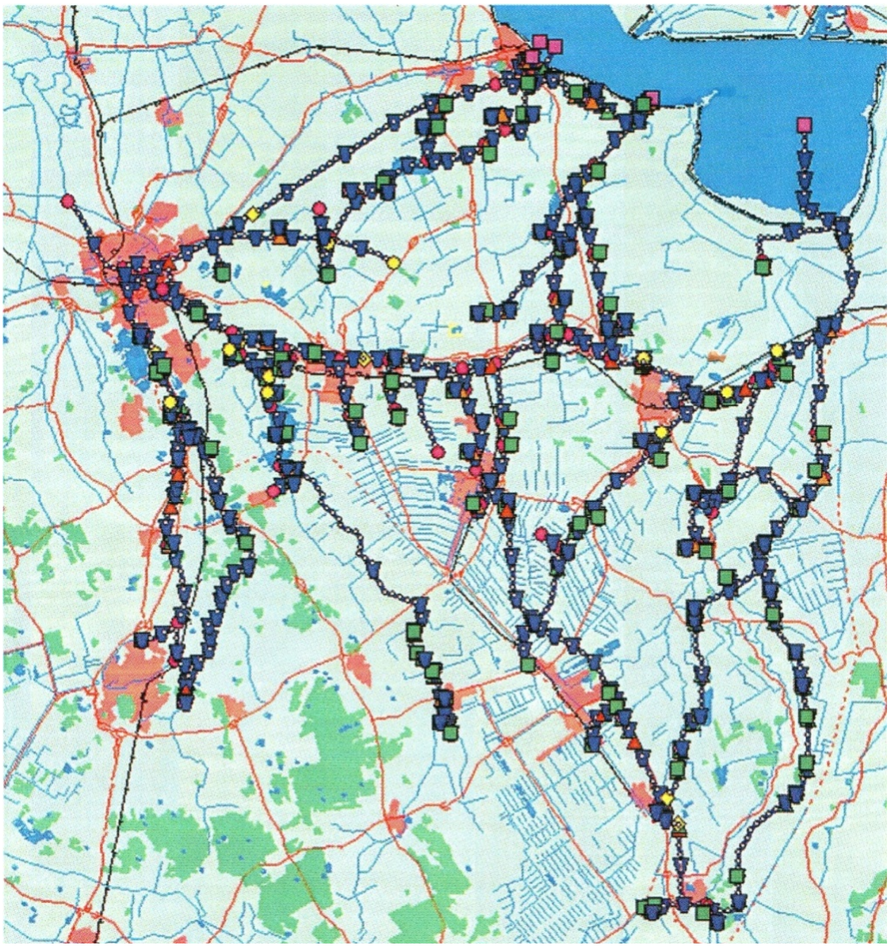


Figure 2.5 SOBEK-model for the Water Board Hunze & Aa's
Source: (Van Overloop et al., 2005)

By means of diverse input variables, parameters and boundary conditions it is possible for the SOBEK model of Hunze & Aa's to predict the water levels and discharges for various locations for the next three days.

Rainfall Runoff module

The RR is defined by the Sacramento concept. This means that the modeler explicitly indicates the impervious area. The concept distinguishes two reservoirs for the surface area (upper zone), and three for the groundwater levels (lower zone). Precipitation that falls at the impervious area, leads to a direct runoff. When the precipitation fall onto a pervious area, the water is transported to the lower zone and it leads to surface runoff, baseflow or subsurface outflow. For a more extensive explanation about the Sacramento concept is referred to Prinsen et al. (n.d.).

Flow module

The flow module deals with the dimensions of the transverse profiles of the watercourses as referred to in chapter 2.2, with its accompanying friction coefficients, the obstructing and controlling structures like sluices and pumps.

The next obstructing and controlling structures are embedded in the SOBEK model. The 'Oude Zeesluis' serves to sluice the superfluous water. The water is sluiced when the water levels near the measurement point Oostersluis exceeds a certain level (this is established in the SOBEK model as SP 0.51), and when the water levels in the area near the Oude Zeesluis are higher than the water levels at the Eems. The 'Kleine Zeesluis' is closed during regular situations, but can be put into action in periods with high water. It is only possible to sluice at low water moments. The 'stromingskokers' are closed in regular situations, but when the water levels in the area are high it is possible to sluice superfluous water towards Pump house Rozema. The 'weir De Bult' is also embedded in the SOBEK model.

The next formula's are used in the flow module; the continuity equation (1D-Flow): $\frac{\partial A_f}{\partial t} + \frac{\partial Q}{\partial x} = q_{lat}$ and the momentum equation (1D-Flow): $\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A_f}\right) + gA_f\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2RA_f} - w\frac{\tau_w}{\rho_w} = 0.$

<u>Boundary conditions</u>

The boundary conditions pointed out in the SOBEK model are downstream boundaries, which gives the tide at the sluices at Delfzijl and Nieuwe Statenzijl, and at Pump house Rozema. There are no upstream boundary conditions, because

2.3.3 Presentation layer

The presentation layer presents the information for the reports (tables, charts and texts), analysis and communication. In case of Hunze & Aa's the information is presented in ArcGis and Microsoft Excel. Examples of these are the presentation of a clickable map in figure 2.6 and the scenario chart in figure 2.7

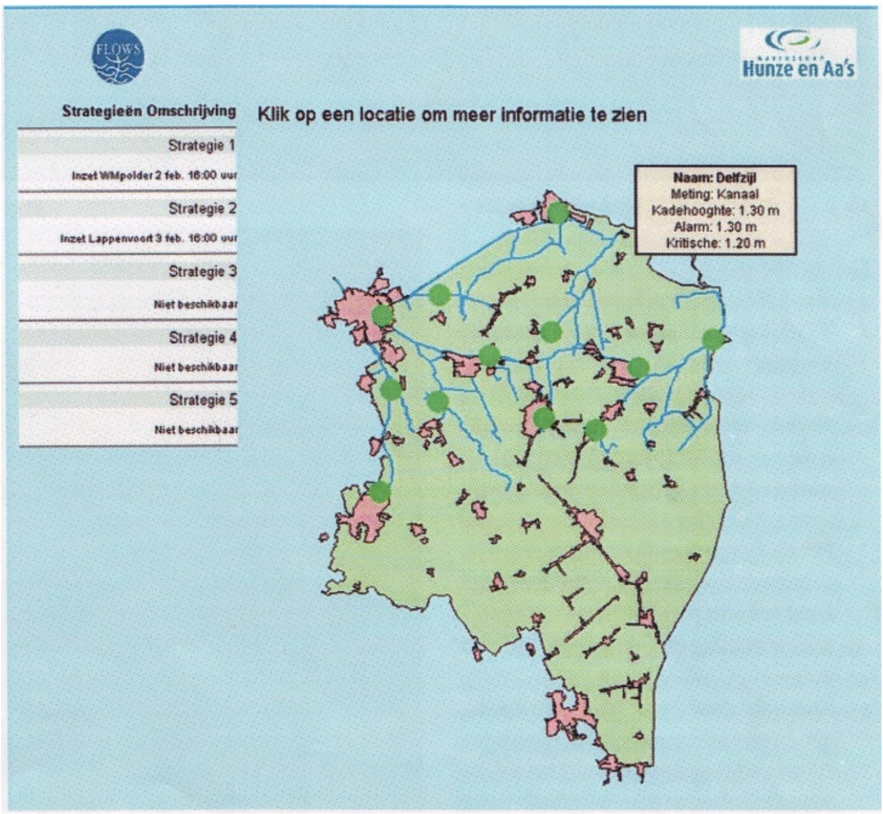


Figure 2.6 Example of a presentation of a clickable map.

The strategies that can be chosen can be found in the box on the left side

Source: (Van Overloop et al., 2005)

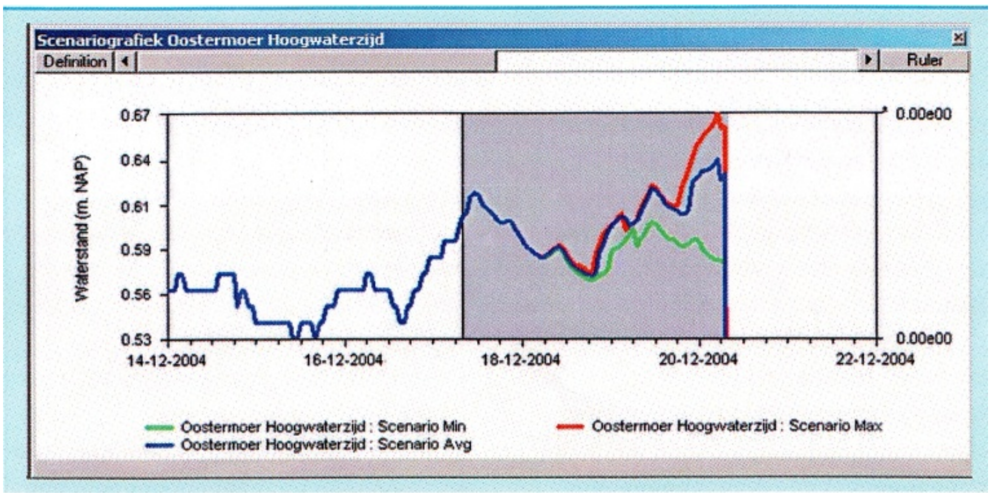


Figure 2.7 Example of a presentation of the DSS in Microsoft Excel

Source: (Van Overloop et al., 2005)

The locations in the clickable map of figure 2.6 indicate if the situation is clear, alarming or critical. The locations on the map color green, orange or red according to the critical values for the different phases at the specified locations.

Figure 2.7 presents the water levels as measured in Oostermoer, with in the grey area the expected water levels for the minimum, average and maximum precipitation scenarios.

2.4 The event

A specific event in the DSS model of Hunze & Aa's will be used as starting point for this report. This high water situation was chosen, because it is the most extreme situation the DSS of Hunze & Aa's has stored from the past. The advantage of using this event is that the SOBEK model already exists and that all the predictions for the input values are available.

The specific event has been used before, during a project of HydroLogic in 2008. In accordance with the research of HydroLogic (2008b) the same high water situation and specific locations in the area of Hunze & Aa's are used.

The Water Board of Hunze & Aa's specified three relevant moments in time for the high water of January 2008. These moments are based on the observations of the high water wave at the city Groningen.

Begin high water:	20 January 2008 00:00
Peak high water:	22 January 2008 17:00
End high water:	25 January 2008 00:00

Based on these data, two specific indications of time are presented:

'Peak moment'	22 January 2008 17:00
'Peak event'	the period of 20th of January 2008 00:00 till the 22nd of January 2008 23:59

The DSS is not able to predict longer than three days ahead. To give the decision makers a first indication that a high water situation would occur, it is decided to carry out the analyses in chapter 3 for the period of the 'peak event'. This is the first period that contains the peak of the high water and therefore the first moment decision makers can take action.

An assumption is made here; the water levels at the 'peak moment' contain the maximum values of water level for that high water wave, at all the locations.

The Water Board of Hunze & Aa's also specified eight representative locations, which are presented in figure 2.8. The addition (HWZ) means that the water level is taken at the high water side of a pump house or a weir. It is important to know the water level at a HWZ, because it indicates if the water runs over the crest of the structures or not.

The addition (Niv) means that the water levels are the water levels on all sides of the measurement point. It is important to know the water level in this point, because several water courses flow together in this point.

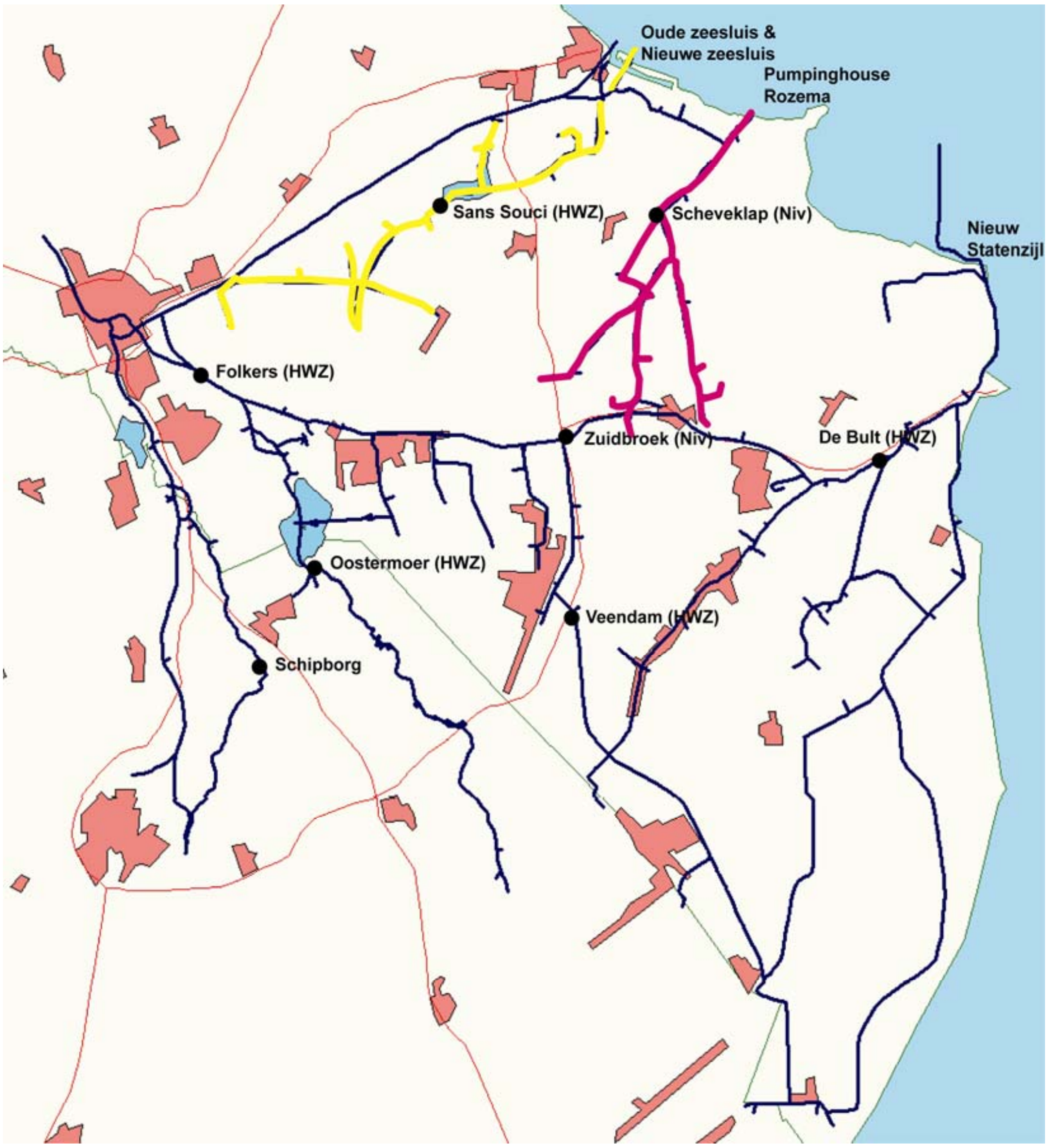


Figure 2.8. Map of the Hunze & Aa's area with the specific locations used in the event of 2008.

Chapter 3 Quantification of uncertainty in water level

This chapter determines the uncertainty in the water level for the 'peak event'. This uncertainty analysis of the DSS output serves as preparation for the presentation design in chapter 4. So the results of the uncertainty analysis have to be trustworthy, but it is not the goal of this report to do a full uncertainty analysis of the DSS.

There are several methods to analyze uncertainty in models. Refsgaard et al. (2007) mentioned several (partly complementary) methods to perform the uncertainty assessment. Only six of these methods can be used to determine statistical uncertainties in model output. The 'expert elicitation', 'Monte Carlo analysis' and the 'sensitivity analysis' can be used to determine the uncertainty caused by model input and parameters. The other three are not appropriate for this research while they determine the uncertainty elsewhere in the model. The 'multiple model simulation' is only appropriate to determine the uncertainty caused by model structure. The 'inverse modeling' is only appropriate to determine the uncertainty caused by parameters. The 'error propagation equations' is mainly suitable for screening analysis, because the underlying assumptions seldom hold (Refsgaard et al., 2007). For that reason the uncertainty analysis of the DSS Hunze & Aa's will be done in three steps: general sensitivity analysis by interviewing the experts, sensitivity analysis and Monte Carlo analysis.

Section 3.1 discusses the method used to execute the three analysisses. Section 3.2 shows the results of these analyses and section 3.3 contains a discussion about the results. The conclusion is discussed in section 3.4.

3.1 Method

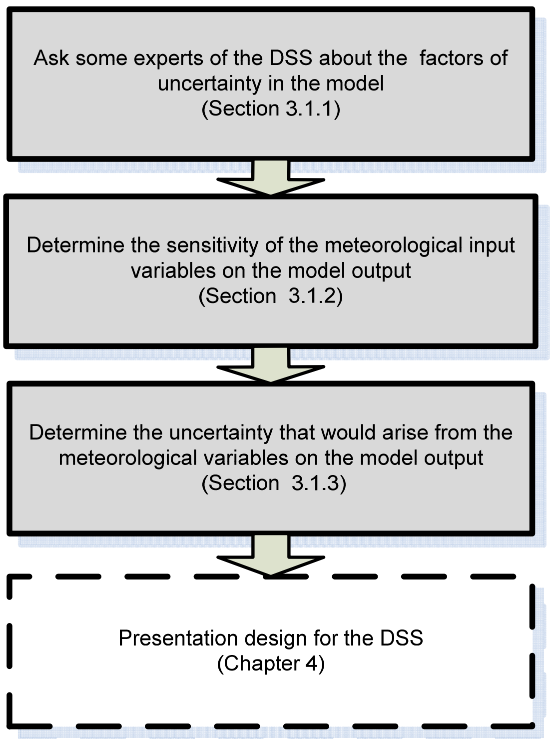


Figure 3.1 Method for determining uncertainty in the DSS model.

The uncertainty in the DSS model is quantified in three steps as shown in figure 3.1. Firstly, some experts are asked for the sources of uncertainty in the DSS to get a quick visualization of it. Subsequent to that, it was decided to restrict the uncertainty analysis to the meteorological input values. The experts ascribed precipitation and tide as prominent sources of uncertainty in model output. Advantage of this decision is that the combined data of all the meteorological input values is already available, which means that the relations between these input variables are already taken along. Secondly, the sensitivity analysis is used to check the influence of the meteorological input sources given by the experts. These meteorological input variables indeed influence the model output. Thirdly, the Monte Carlo analysis is used to determine the distribution of probability for the model output on basis of the meteorological input variables.

3.1.1 General sensitivity analysis

The goal of the general sensitivity analysis in this report is to get an indication of the most important sources of uncertainty in the DSS Hunze & Aa's. Therefore three experts are interviewed on the basis of the Uncertainty Matrix of Walker to gain more information about the uncertainties in the DSS Hunze & Aa's.

Source of uncertainty		Level				Nature	
		Statistical uncertainty	**Scenario uncertainty**	**Qualitative uncertainty**	**Recognized ignorance**	**Epistemic uncertainty**	**Stochastic uncertainty**
Context	**Natural, technological, economic, social, and political**						
Input	**System data**						
	Driving forces						
Model	**Model structure**						
	Technical						
	Parameters						
Model outputs							

Figure 3.2. The uncertainty matrix modified by Refsgaard et al. (2007)

Walker et al. (2003) provides a tool to get a systematic and graphical overview of the essential features of uncertainty in relation to the use of models in decision support activities; the uncertainty matrix. An adapted version of the uncertainty matrix (Refsgaard et al., 2007) is shown in figure 3.2. The idea of the matrix is to identify the location, level and nature of the uncertainty, so that model developers and users will become aware of and address all the relevant elements of uncertainty.

The following three persons were interviewed, because they have experience with the relevant model(s):

Expert 1
Worked at HydroLogic from 2005 till September 2009 and worked with the SOBEK model of the DSS Hunze & Aa's. The SOBEK model is the basis model for the DSS Hunze & Aa's as discussed in chapter 2.

Expert 2
Works at HydroLogic and was involved in the development of the DSS Hunze & Aa's for the Water Board of Hunze & Aa's. He has knowledge of the DSS Hunze & Aa's.

Expert 3
Works as an area hydrologist for the Water Board of Hunze & Aa's. One of his tasks is to monitor the water levels in the area. He uses the DSS Hunze & Aa's in crisis situations to calculate the measures that could be taken to prevent the area from flooding.

Experts 1 and 2 were extensively interviewed on the basis of the Uncertainty Matrix, while expert 3 was consulted by e-mail. After reviewing his response no further inquiries were made, which resulted in little information from expert 3. In practice it appears that experts found it hard to answer according to the uncertainty matrix of Walker et al. (2003). Instead of adding uncertain factors to every cell of the uncertainty matrix, the expert mentioned and ranked all the sources of uncertainties they experience in the DSS. Afterwards, these sources of uncertainty were divided into the categories of the uncertainty matrix: input and model. The number '1' means that the expert recognizes this factor as most uncertain. All the successive numbers mean that the factor is less uncertain.

The experts were free to fill in all the uncertain factors they had noticed in the DSS, it resulted in a different amount of uncertainties per expert. The fact that the experts did not indicate the same amount of uncertain factors, mean that the expert did not mention the uncertain factor during the interview for any reason. However this does not mean that the expert thinks that the factor is not subjected to uncertainty. The expert could have forgotten to mention this during the interview. This is a disadvantage of giving the experts the opportunity to fill in the uncertain factors they recognize themselves. On the other side, this method gives the opportunity to discover more uncertain variables than could be thought of in advance.

The group of people with knowledge of the Hunze & Aa's water system is limited. Asking more people for the general sensitivity analysis will limit the number of people for future interviews about the presentation of uncertainty. The general sensitivity analysis gives useful and trustworthy information that can be used in the presentations of chapter 4 and chapter 5. It is not the goal to do a full uncertainty analysis of the DSS in this report. The choice to involve only three experts in the general sensitivity analysis seems sufficient.

3.1.2 Sensitivity analysis

The sensitivity analysis examines which variables and parameters have and do not have influence on the model output by varying the variables and parameters (Booij, 2010). Sensitivity analysis will not assess how likely it is that specific values of the variables and parameters will actually occur, but only if they have influence on the model results and how much this influence is. The strength of a sensitivity analysis is that it provides insight in the potential influence of all sorts of changes in input and it helps to distinguish which variables and parameters are important for the accuracy of the outcome (Refsgaard et al., 2007).

Only the mentioned meteorological variables of the general sensitivity analysis are taken into account at the sensitivity analysis. This is justified because it is not the objective of this research to determine the total uncertainty of the DSS. The sensitivity analysis gives useful and reliable information on the uncertain variables in the DSS, which can be used as input for the Monte Carlo analysis. Five input variables will be examined in the sensitivity analysis, because the experts state that these input variables are the most important. The variables are assumed to be independent and will be examined separately, according to the univariate sensitivity analysis.

The measured values of the meteorological variables of the event will be changed with -10%, -5%, +5% and +10% to discover which of the five variables have the largest influence on the water level. The range of these scenarios calculated in the sensitivity analysis seemed small, but in fact it is not realistic that the predictions for the meteorological variables differ more than 10% in critical situations. The predictions for precipitation, wind speed and tide contain high numbers already, so it is assumed that a deviation from that would not be more than 10%. The larger the change compared to the default situation, the more sensitive the water level is to changes of the input variable.

Exception on this would be the wind direction which will be changed with -25%,-12.5%, +12.5% and +25%, to cover half the scale of wind direction; which is $180°$..

3.1.3 Monte Carlo analysis

Monte Carlo analysis is a statistical technique for stochastic model calculations and analysis of error propagation in calculations (Refsgaard et al., 2007). The Monte Carlo analysis requires the specified probability distributions of all model input and parameters, and the correlations between them to trace out the structure of the distributions of model output. The advantage of a Monte Carlo analysis is that it provides a comprehensive insight in how specified uncertainty in the input propagates through a model (Refsgaard et al., 2007). A disadvantage is the large run time for computationally intensive models and the huge amount of outputs that are not always straightforward to analyze (Refsgaard et al., 2007).

The goal of the Monte Carlo analysis is to establish the distribution of probability in model output due to slight changes in the model input. The four most important meteorological input variables are used to obtain the distribution of probability of the model results. Those variables requires input, therefore the EPS of the ECMWF for the specific situation on the 20^{th} of January 2008, 00:00 is used.

An EPS plume of the ECMWF normally contains 52 forecasts or members as they are called by the KNMI; 1 member with based on measured data, 1 member with measured data but another grid, for control purposes and 50 members with slightly perturbed input values are imported into the computer for a run. The perturbations per member are established in advance; therefore member 1 always is perturbed with an imaginary layer of snow in the South of the Netherlands, while member 2 always has a too high humidity above France, and so on. In this case the 50 perturbed members are used in the Monte Carlo analysis.

EPS data for precipitation, temperature, tide, wind direction and wind speed are more or less correlated because of the same perturbation procedure. Due to this correlation a Monte Carlo analysis can be created, by importing these EPS data into the DSS and run the model with all the 50 perturbed forecasts. After the calculation, 50 predictions are given for the water levels in a specific location. This makes it possible to read the absolute peak value of the water levels and the moment of the peak predictions, when assumed that the EPS plume contains all the possible weather forecasts.

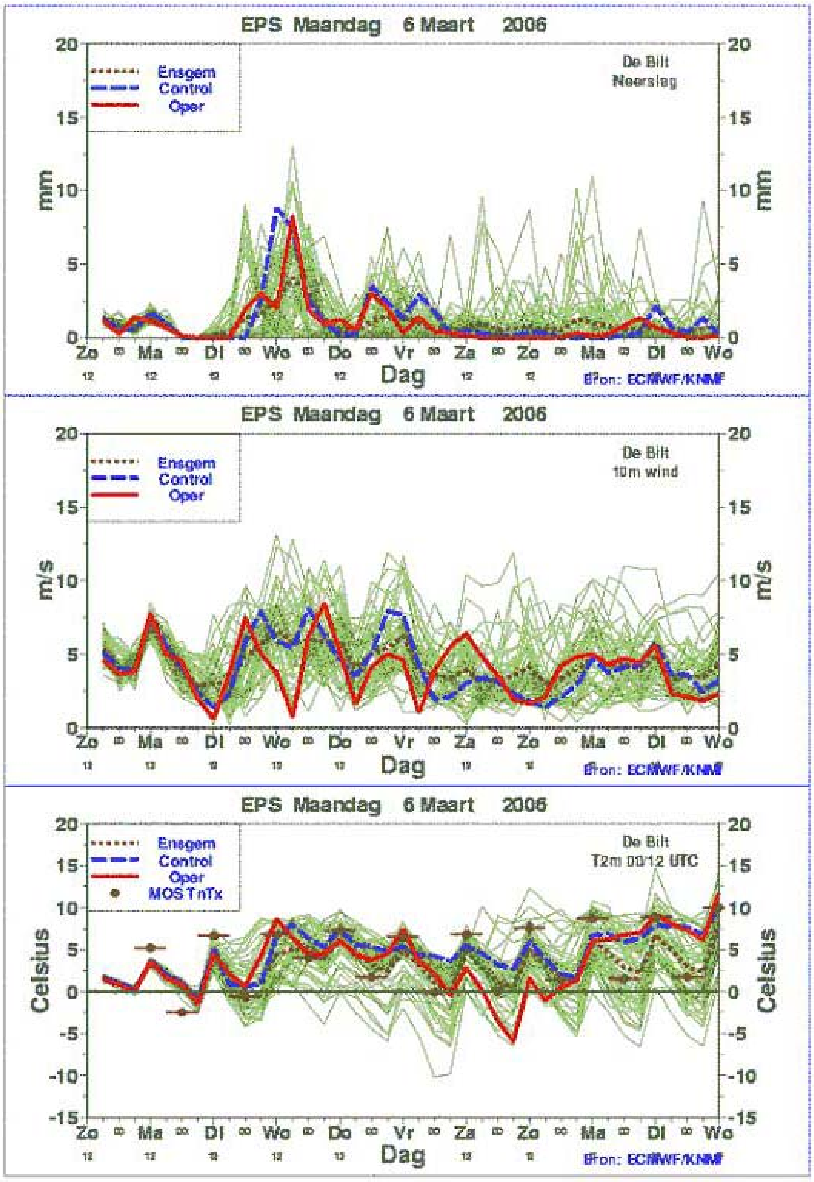


Figure 3.3 An example of an EPS plume for precipitation, wind and temperature for March 2006. Source: (KNMI, n.d.)

3.2 Results

Since the method is divided into three different analyses, the results are also presented in three separate sections. The results of the general sensitivity analysis, the sensitivity analysis and the Monte Carlo analysis are presented in section 3.2.1, section 3.2.2 and section 3.2.3, respectively.

3.2.1 Results general sensitivity analysis

The results of the general sensitivity analysis could be divided into the categories of the Walker matrix: input and model as shown in table 3.1 and table 3.2 respectively. Note that the experts were able to fill in all the uncertain factors they noticed, which explains the difference in amount of uncertain factors mentioned by the different experts.

Table 3.1 Results general sensitivity analysis concerning input. A number '1' means that the expert recognizes this factor as most uncertain.

INPUT		**Expert 1**	**Expert 2**	**Expert 3**
1.	Meteorological forecasts: uncertainty in the prediction of the expected • Tide • Precipitation • Wind • Evaporation	 2 1 4 5	 1 2 3 6	 1 1
2.	Possible measurement errors in the range finding network: • Incorrect measurements of the actual water level • Total missing water levels	 5 5	 5 4	

Table 3.2 Results general sensitivity analysis concerning model. A number '1' means that the expert recognizes this factor as most uncertain.

MODEL		**Expert 1**	**Expert 2**	**Expert 3**
3.	The choice for a 90 day history for precipitation and evaporation could possibly be too small.	3		
4.	The choice for "Sacramento" parameters in RR could be incorrect.	3		
5.	Uncertainty in the flow module section of SOBEK; calibration (at a high water event) is done in 2004. These values are still used nowadays and it is questionable if they are still correct .	3		
6.	Uncertainty in the dimensions of the: • Cross sections • Weirs • Locks • Pump houses	 3 3 3 3		

In total the experts indicated thirteen factors of uncertainty in the DSS divided into 6 categories, as is shown in table 3.1 and table 3.2. The experts considered the meteorological input variables precipitation and tide as most important sources of uncertainty for the model output.

There is chosen to examine only the meteorological input variables of table 3.1 in the following sensitivity analysis and the Monte Carlo analysis, because the data for these meteorological input variables is already available in the form of EPS predictions. This is especially favorable for the Monte Carlo analysis, because the relationships between the mutual meteorological input variables are already taken into account due to their perturbation.

3.2.2 Results sensitivity analysis

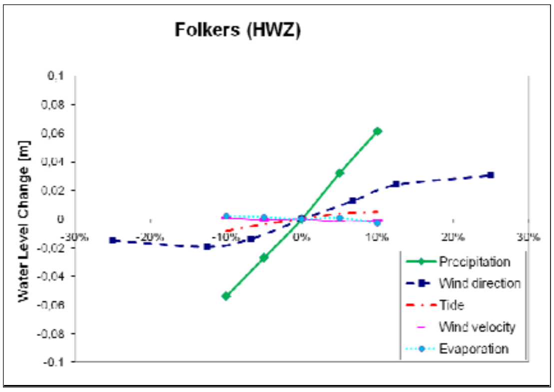
The expert analysis indicated the meteorological variables as the most influential. The weather variables tide and precipitation were appointed as most important uncertain variables in the general sensitivity analysis by all three experts. Wind and evaporation were ascribed less influence when uncertainty is concerned. This sensitivity analysis indicates how much influence these variables have on the water level.

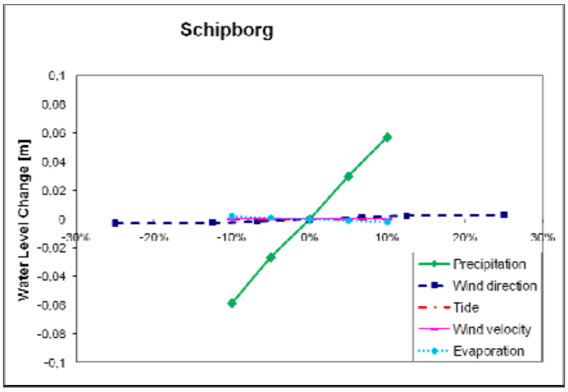
Figure 3.4 shows the results of the sensitivity analysis for the eight specific points which were discussed in section 2.4. Figure 3.4 the water level seems to be the most sensitive for precipitation and sometimes for wind direction, because the x-axis represents the change in % compared to the default value of the input variables at the original event. The y-axis represents the corresponding change in water level compared to the default value. If there is a steep slope compared to the x-axis this means that the water level is sensitive for change of the input variable.

The small influence of all the meteorological input variables on the water level change in location Veendam is caused by the presence of a weir, upstream and close to Veendam. The fixed weir has a crest height of 3.4m above datum.

Although the water level differs per location, the water level is the most sensitive for change in precipitation in all locations. Precipitation has the steepest slope and therefore the most influence on the water level in six out of eight locations. This seems to be a roughly linear development. Exceptions are the locations Sans Souci and Scheveklap, which are located in the Dollard boezem and Oldambt boezem. The effect of the pumps cause a difference in the relationship between the meteorological variables and the water level. For Sans Souci it is the Duurswoldpump 3 that starts to work at precipitation +10%. At Scheveklap the Termunterzeepumps 2 and 3 starts to sluice when the water level reach -1.26 m at a certain point just upstream of the pumps.

Wind direction has a big influence on the water level, as is shown in the locations Folkers, De Bult and Scheveklap. On the other hand, at the locations Schipborg, Sans Souci and Veendam the wind direction has nearly the same influence as the tide, wind speed and evaporation. Therefore, no unambiguous relationship between water level and wind direction exists. This relates to the fact that other variables, like wind velocity, also have a role in this.





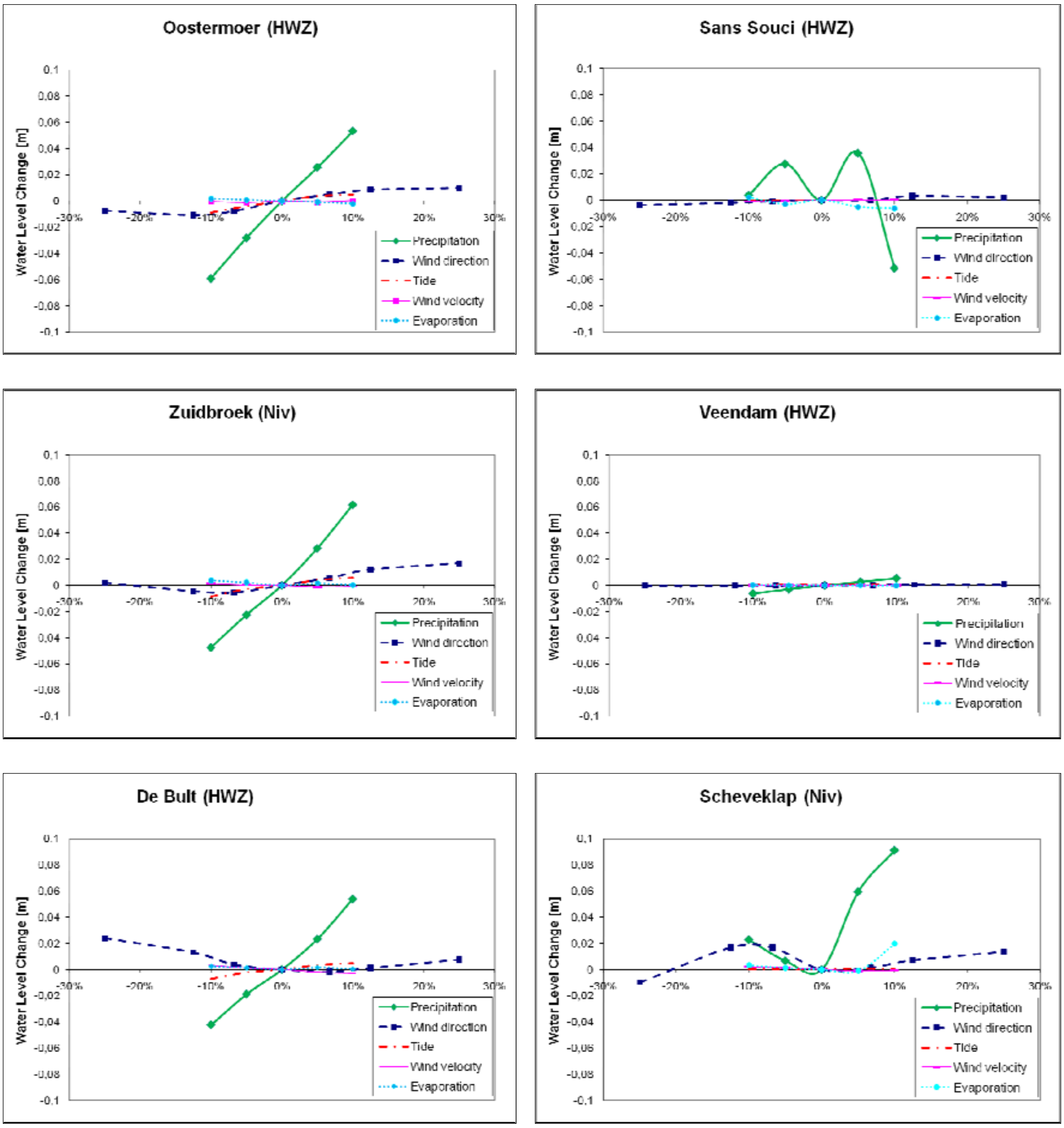


Figure 3.4 Sensitivity analysis for the eight locations at the "peak moment". Note the insensitivity of location Veendam.

Tide, wind velocity and evaporation have nearly as much influence at all locations. They are small in comparison to the precipitation and the wind direction. For evaporation this was expected, because the experts were convinced that evaporation has the least influence on the model output of all the sources mentioned.

On the other hand the experts assessed tide as an important uncertain factor, but the sensitivity analysis does not confirm this. Although there is a belief that the tide also has large influence, this is not justified in the sensitivity analysis. A possible cause for this could be that the critical tide is not reached yet. Therefore the extra water in the boezem still can be sluiced and no problems in the area of Hunze & Aa's are shown.

Despite the fact that wind speed is small, this variable is connected with the wind direction. Therefore it is impossible to exclude one of the variables, while the other is taken into account.

Both general sensitivity analysis and sensitivity analysis indicate that the uncertainty in water level due to evaporation is very small. Only at location Scheveklap the evaporation has a visible influence.

3.2.3 Results Monte Carlo analysis

After the sensitivity analysis is done, a Monte Carlo analysis is executed with the input variables precipitation, tide, wind direction and wind speed. Precipitation and wind direction seem to have a large influence on the water level according to the sensitivity analysis. The wind speed is small, but this variable is connected with the wind direction. Therefore it is impossible to separate these two variables, so wind velocity is included in the Monte Carlo analysis. Tide does not seem to have large influence on the water level according to the sensitivity analysis, but the experts appreciated the tide as one of the two most uncertain factors in the model. Therefore the tide is also examined in the uncertainty analysis.

Evaporation is left out of the Monte Carlo analysis, because both general sensitivity analysis and sensitivity analysis indicate that the uncertainty in water level due to evaporation is small.

Figure 3.5 and table 3.3 show the results of the Monte Carlo analysis for the eight specific points discussed in section 2.4.

There is a noticeable wave motion in figure 3.5 that is influenced by the tide. The wave motion is caused by pumps in the area of Hunze & Aa's. The pumps only work when the water level in the area of Hunze & Aa's is lower than the water level at sea and the water level. The pumps at Delfzijl have a supplementary demand; the water level at the measurement station Oostersluis has to be higher than 0.57 m^+ NAP. A consequence of the wave motion is that the peaks and valleys do not take place on the same time for all the locations due to the time the water wave has to travel.

In section 2.4 is assumed that the 'peak moment' of 22th of January at 17:00 hour, is the moment in time that represents all the peaks in the water system of Hunze & Aa's. The vertical red line in figure 3.5 indicates this peak moment; however the chart does not show a crossing with a peak in the water wave for any of the eight locations. So the assumption is incorrect. The 'peak moment' reflects the highest water level in Groningen city, but not in the other locations.

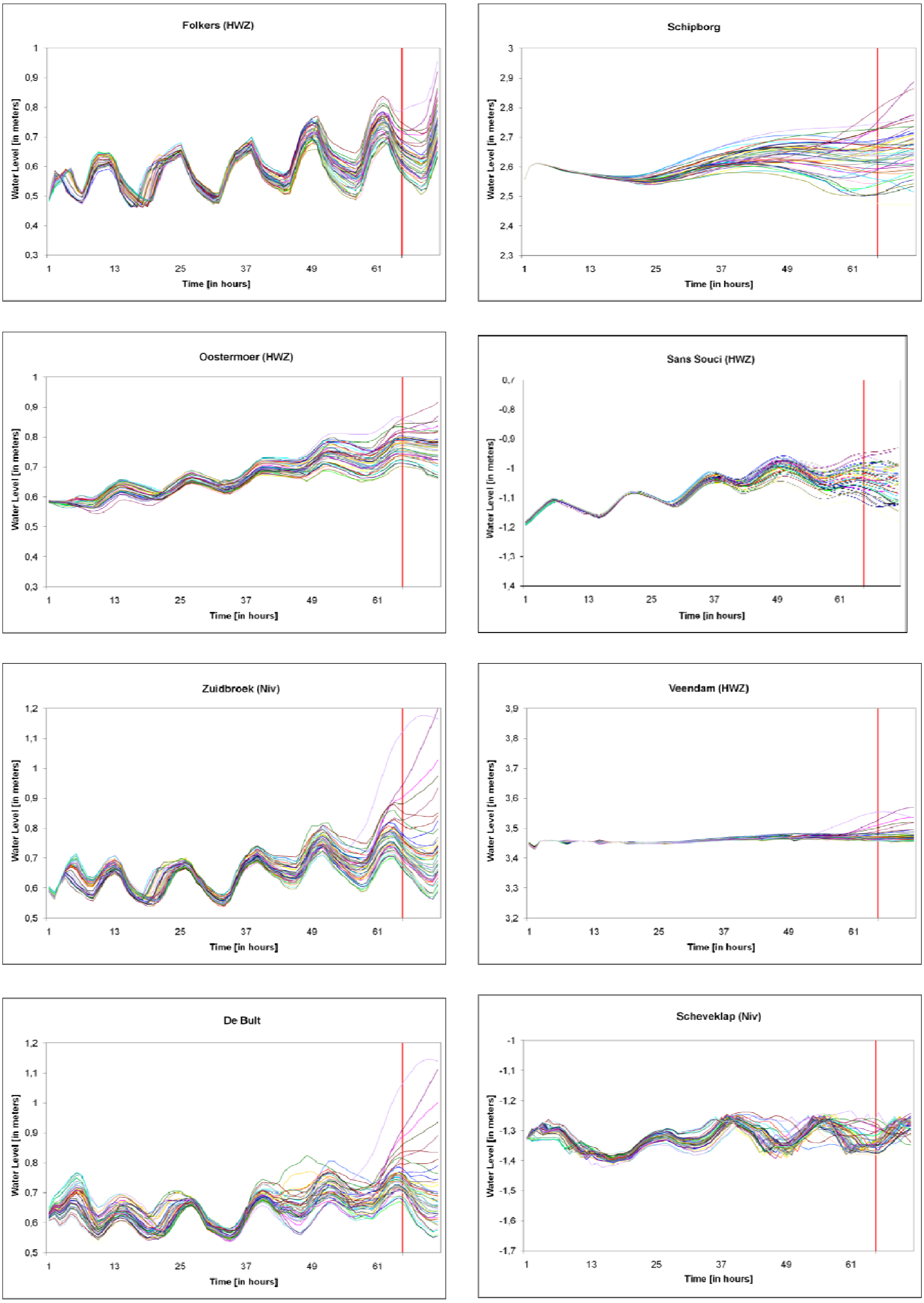


Figure 3.5 Monte Carlo analysis of January 20th, 2008: 00.00 hours. This is done for the eight locations defined in chapter 2.4 The red vertical line represents the peak moment; 22th of January 2008; 17:00 hours.

The range of the prediction for the water level at one point in time expresses the uncertainty per location. The range, as presented in table 3.3, is defined as the maximum range of predictions: the absolute maximum minus the absolute minimum predicted water level. This range increases over time, as can be seen for example at location Schipborg in figure 3.5. In the beginning the prediction is accurate and the range is small, but after a day or so the range becomes bigger. Location Scheveklap (Niv) is an exception, because there the influence of the pumps is dominant and the uncertainty slightly increases. This results in a quite accurate prediction in the beginning and it still flares out after one and a half days. Table 3.3 shows that the uncertainty per location varies from 0.10 m till 0.48 m at the defined 'peak moment'.

Table 3.3. Uncertainty (absolute maximum minus absolute minimum predicted water level) per location at the "peak moment".

Location	**Uncertainty**	**Location**	**Uncertainty**
Folkers (HWZ)	0.23 m	Zuidbroek (Niv)	0.48 m
Schipborg	0.33 m	Veendam (HWZ)	0.10 m
Oostermoer (HWZ)	0.16 m	De Bult (HWZ)	0.42 m
Sans Souci (HWZ)	0.18 m	Scheveklap (Niv)	0.14 m

3.3 Discussion

The experts answered and assessed the uncertainties in the DSS during the interviews of the general sensitivity analysis. It is possible that they forgot or did not mention a factor of uncertainty in the DSS. Since three experts were asked and they all agree that the meteorological variables are uncertain factors in the DSS, it did not seem to have a negative influence on the results of the uncertainty analysis.

The choice to involve only three experts in the general sensitivity analysis did not cause problems for the results of the general sensitivity analysis, because the experts all were convinced that precipitation and tide have the most influence on the model output. The sensitivity analysis verifies indeed that for precipitation and for several cases of tide by showing a relatively large change compared to the default values.

The assumption made in section 2.4, that the peak of the tide always occurs at the same moment is incorrect. Therefore, assuming that the 'peak moment' contains all the peaks of the 50 members is incorrect. This influences the results of the sensitivity and Monte Carlo analysis, because table 3.4 and table 3.5 only contain the 50 predicted water levels per location at the 'peak moment'. Figure 3.5 shows that not all the peaks occur at the assumed 'peak moment' and some higher water levels could be expected. This means for the presentations in chapter 4 that the shown uncertainty range is too small compared to all the predictions for the water levels during the high water event, but that is not a problem for this research while the higher water levels only will be the extremes. Therefore it is fair to conclude that the Monte Carlo analysis gives a trustworthy picture of the uncertainty in water levels for the event.

The event of January 20th 2008, 00:00 was the event with the highest water levels available since the development of the DSS Hunze & Aa's in 2004. On basis of the results of the Monte Carlo analysis, it has to be said that this event is not ideal for using in the interviews, because no critical values are exceeded. Presentations with a predicted water level that exceeds the critical value are more suitable for the interviews, since the decision making is enclosed into the frame of a high water event.

Although the event of January 2008 is not directly usable for the presentation forms for the interviews it is better to use an event from the past than using a fictitious event, because it is more realistic. There could be chosen between two approaches to create a more expressive situation for decision makers in flood management: lowering the critical values or heightening the predicted water levels. When the critical values are lowered, the uncertainty range stays realistic. While heightening the predicted water levels, probably creates a situation with an unrealistic uncertainty range. Therefore it is better to lower the critical values and notify the decision makers during the interview about this alteration.

3.4 Conclusion

The high water event of January 2008 was not even high enough to cross the critical value to enter calamity phase 1. Therefore, the critical values should be lowered to retain a representative uncertainty band for the predicted water levels. Although the event is not ideal, it is representative with some alterations.

The Monte Carlo analysis for location Zuidbroek contains a broadest range of predictions for the water levels, which resulted in a 0.48 m uncertainty range for the peak moment. That makes it an interesting location for the presentation forms in chapter 4.

Chapter 4 Method

This chapter presents the method to determine the best presentation form to communicate uncertainty in model results to decision makers in flood management. This method results in the best uncertainty presentation form and will collect the criteria for the presentation of uncertainty in model output to decision makers in flood management, as shown in figure 4.1.

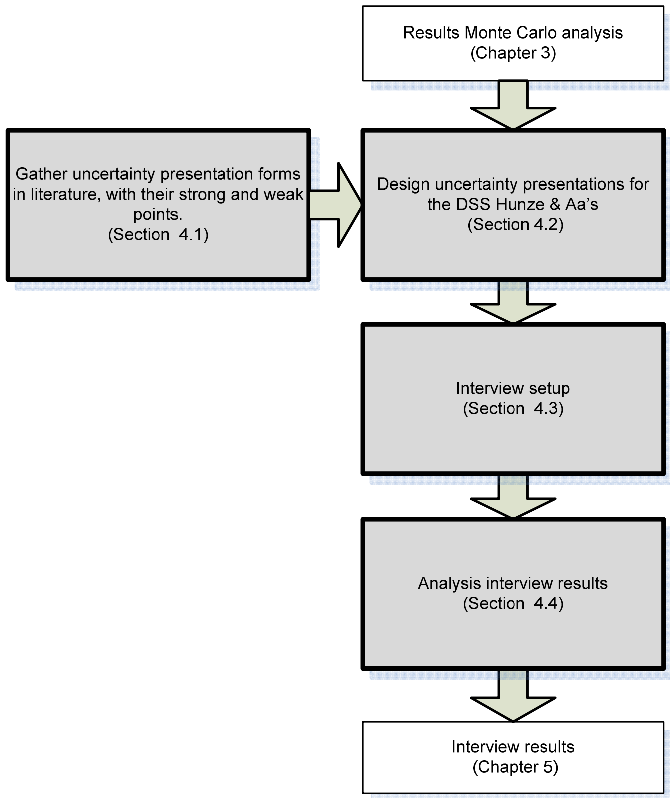


Figure 4.1 Method to gain the best uncertainty presentation, by collecting the strong and weak points of uncertainty presentations.

Firstly, information is gathered about uncertainty presentation forms in literature, including their strong and weak points. There are several ways to present uncertainty; linguistic, graphical, numeric or a combination of these (Kloprogge et al., 2007; Beckers, 2007).

The best presentation forms found in the literature are combined with the results of the Monte Carlo analysis from chapter 3, this result in nine uncertainty presentation forms that are suitable to present to decision makers during the interviews. Seven of them only show the predicted water levels at the 'peak moment' and are referred to as 'time independent presentation forms'. Two of the presentation forms show the water levels for the 'peak event' and are referred to as 'time dependent presentation forms'. The decision makers have to comment the presentation forms and decide which presentation form is the best for communication to decision makers in flood management. The comments on the nine presentation forms, will be used to determine the criteria decision makers in water level management have for uncertainty presentation.

Throughout the interview setup, questions and presentations have to be formulated. The critical levels have to be lowered to create a possible crisis situation. And the decision makers have to be selected, who could supply useful information about the presentation of uncertainty.

During the interviews with the decision makers, the seven time independent presentation forms will be explained and the decision makers will be told what the presentations show. Besides that, the decision makers will be asked to comment on the presentation form. Next, the decision makers will be asked to rank the presentation forms by placing the best presentation form on top of the pile and the least at the bottom of the pile.

Also the two time dependent presentation forms are explained and the decision makers are told what is shown in the presentation. The decision makers will be asked to comment on and rank the presentation forms. The two time dependent presentation forms should be put up/into/under the pile with the seven time independent presentation forms, according to their usefulness for communication to decision makers in flood management.

After the interviews, the outcome of the interview is send to the decision maker, with the question to read and reflect upon it. All the decision makers have answered this request.

In the interview analysis, the presentation forms are compared to each other. The median of the ranks per presentation forms are determined. The lower the median of the specific presentation form, the better that presentation form is for communication of uncertainty to decision makers in flood management. With this a distinction is made between time independent presentation forms and time dependent presentation forms. These two sorts of presentation forms will be examined separately, because the basis of the uncertainty information is different.

Next, the Mann-Whitney U test has to provide information about the presence of a significant difference between the presentation forms. The same is done for the two time dependent presentation forms.

Subsequently, the comments of the decision makers on the presentation forms are applied to determine the criteria for improvement in the communication of uncertainty to decision makers in flood management.

The results of the interview are presented in chapter 5.

Section 4.1 discusses the background information on communicating uncertainty and which presentation forms are mentioned in literature. This will be mainly scientific literature on policy making, because of the lack of scientific literature about the presentation of uncertainty in flood management. Section 4.2 presents the presentation forms design. Next, the interview setup and interview analysis in sections 4.3 and 4.4, respectively.

4.1 Background information on communicating uncertainty

When uncertainty information is presented, the ideal situation would be that every reader interprets the uncertainty information in the same way as the writer intended. However, interpreting uncertainties is difficult (Kloprogge et al., 2007). The brain tends to manipulate uncertainties and probabilities in order to reduce difficult mental tasks. Simplified ways of managing information (heuristics) are used, which could be technical or formulated interpretation issues. Although they are valid and useful in most situations, they can lead to large and persistent biases with serious implications (Department of Health (UK), 1997; Slovic et al., 1981).

The most relevant technical heuristics and biases are: availability, confirmation bias, and overconfidence effect (Kahneman et al., 1982; as cited in Kloprogge et al., 2007). The availability heuristic is a phenomenon in which people predict the frequency of an event based on how easily an example can be brought to mind. For example, after a high water event, people are rather inclined to mention it due to the availability. By the confirmation bias, people tend to select and interpret information in order to support their existing worldview. Whether or not the main conclusion of a report is in line with the readers' view, it may therefore influence the processing of uncertainty information. The overconfidence effect is a well-established bias in which someone's subjective confidence in their judgments is reliably greater than their objective accuracy, especially when confidence is relatively high.

Besides these 'technical' interpretation issues, interpretation can also be influenced by how the information is formulated: 'framing' (Kloprogge et al., 2007). For example 'the glass is half full' sounds more positive than 'the glass is half empty'. Although the information is the same, people are inclined to take other decisions because of the formulation.

Vaessen (2003) concludes: 'By far not all information in a report is read, and also important information on uncertainties that is needed to assess the strength of the conclusions is often not read.' Wardekker & Van der Sluijs (2006a) state that too much emphasis on uncertainty can however give rise to unnecessary discussion and therefore uncertainty information needs to be as limited and relevant as possible.

Kloprogge et al. (2007) state that the writers cannot determine and control which information is read by the target audiences, how it is processed, how it is interpreted, or how it is used. However, the locations where uncertainty information is presented should be chosen carefully. A clear and consistent way of describing the uncertainties will be beneficial to a correct interpretation of this information by the target audiences.

Nevertheless Kloprogge et al. (2007) gathered some general good-practice advise for adequate uncertainty communication that ideally should be met. Although these advise is drawn up for reports and formulating policies, the following advise might be useful for presentation design to decision makers:

- *Uncertainty communication deals with information on uncertainty that is required by good scientific practice and that readers and users need to be aware of;*
- *The information on uncertainty is clear to the readers and minimizes misinterpretation, bias and differences in interpretation between individuals;*
- *The information on uncertainty is not too difficult to process by the readers;*
    - *not too much effort and not too much effort time should be required to understand the method of representation and to retrieve the information itself;*
- *Uncertainty communication meets the information needs of the target audiences, and therefore is context dependent and customized to the audiences.*

There are several ways to present uncertainty (Kloprogge et al., 2007; Beckers, 2007). Therefore these presentation forms are discussed separately in the next sections. Section 4.1.1 deal with the linguistic, section 4.1.2 the numeric and section 4.1.3 the graphical presentation forms. These three sorts of presentation forms are referred to as ‘single presentation forms’ and can be combined as discussed in section 4.1.4.

4.1.1 Linguistic

Kloprogge et al. (2007) and Wardekker & Van der Sluijs (2005) both state that most readers are better at hearing, using and remembering uncertainty information in words than in numbers. Additionally the information could be adapted to the level of understanding of lay audiences, because there are many levels of simplification available.

However, in the simplification, nuances of uncertainty information may get lost and the information may be oversimplified. Words have different meanings for different people and in different settings. People do not separate probability and magnitude of an effect and thus tend to take the magnitude of effects into account when translating probability language into numbers and vice versa. This results in a broad range of estimated chances. An example of oversimplification is the word ‘possible’ which results in an estimated range between 0 and 100% chance (Kloprogge et al., 2007).

The loss of precision could be tackled by using the uncertainty terms as fixed intervals; as done in fixed scales. A consistent use of language makes it easier to remember and consistent messages are perceived as more credible (Kloprogge et al., 2007; Wardekker & Van der Sluijs, 2005). An example of such a scale is the IPCC 7 point probability scale as presented in table 4.1. This enables readers to make comparisons between topics.

Table 4.1. IPCC 7 point likelihood scale (Patt and Schrag, 2003)

Likelihood **of the occurrence/outcome**	**Terminology**
< 1% probability	**Exceptionally unlikely**
< 10% probability	**Very unlikely**
< 33% probability	**Unlikely**
33 to 66% probability	**About as likely as not**
> 66% probability	**Likely**
> 90% probability	**Very likely**
> 99% probability of occurrence	**Virtually certain**

Disadvantage of a fixed scale is, that it does not match people's intuitive use of probability language. People translate such language by taking the event magnitude (severity of effects) into account, which may result in an overestimation of the probability of low magnitude events and an underestimation of the probability of high magnitude events, when a fixed scale is used for communication (Kloprogge et al., 2007). Problems appear to be most pronounced when dealing with predictions of rare events, where probability estimates result from a lack of complete confidence in the predictive models. In general the context of an issue influences the interpretation and choice of uncertainty terms (Patt & Schrag, 2003; Patt &Dessai, 2005).

Halffman (as cited at the Expert Meeting in Wardekker & Van der Sluijs, 2005) notes that the standardization would be for the specific context only, which limits its usefulness of the scale (there is no universality). Therefore it is important to clarify which fixed scale is used, because there are several scales that use the same expression for different purposes. One example is given by the Schinzer scale (Weiss, 2003 and 2006) and the IPCC7 point probability scale (Patt & Schrag, 2003). The Schinzer scale uses the expression 'very unlikely' for a probability of 9-18%,while the IPCC7 point probability scale uses the same expression for a likelihood of the outcome <10% probability.

The advantages and disadvantages of linguistics are summarized in table 4.2.

Table 4.2. Summary of the advantages and disadvantages of linguistics.

Linguistics	
Advantages	**Disadvantages**
• Most readers are better at hearing, using and remembering uncertainty information in words than in numbers. • The information could be adapted to the level of understanding of lay audiences.	• In simplification, nuances of uncertainty information may get lost. • Words have different meanings for different people and settings (biases). • Less specific than numbers. • Text alone is boring and tedious.

4.1.2 Numeric expressions

Kloprogge et al. (2007) state that numbers are more specific than words. At least, if they are used in the correct manner. Assuming that the readers understand the way in which the numeric information is presented, interpretation differences between individuals will be smaller than the information was conveyed in a linguistic manner. However, when the information is only presented in numbers, some of the readers will translate this information into verbal expressions. The reader translate it for themselves or when communicating the information to other people. If this 'translation' is done incorrectly, this will lead to miscommunication. For example; an area could be unnecessarily evacuated, because someone translated the numbers as a risk. This causes a lot of public agitation and a waste of money.

Presenting uncertainty by numbers is a more statistical approach, and terms like confidence intervals are well known. Therefore, this presentation form is more appropriate for people that are familiar with statistics. The advantages and disadvantages of numeric expressions are summarized in table 4.3

Table 4.3. Summary of the advantages and disadvantages of numeric expressions.

Numeric expressions	
Advantages	**Disadvantages**
• More specific than words, because it presents absolute values. • Interpretation differences between individuals will be smaller than if the information is conveyed in a linguistic manner (less biased).	• Most readers are worse at hearing, using and remembering uncertainty information in numbers than in words. • People have to translate the numbers into verbal expressions themselves. • Incorrect translation leads to miscommunication.

4.1.3 Graphical expressions

Graphics summarize significant amounts of uncertainty information, although many graphical expressions of uncertainty are not straightforward to understand (Wardekker & Van der Sluijs, 2005). Kloprogge et al. (2007) state that graphical expressions have more disadvantages, which are listed in the remaining part of this paragraph. The reader is required to spend time in retrieving the uncertainty information in the figure, and –if the method is new to him or her– has to spend time in understanding the method of the presentation. Since conclusions are not stated explicitly in figures (they may be stated in the main text), figures are inviting the readers to draw conclusions on what they see. If they do not adequately study the figure or if they lack the ability to interpret the information in the figure, they may draw incorrect conclusions or even extract information from the figure that is not displayed.

Ibrekk and Morgan (1987) studied the ability of nine different pictorial displays for communicating quantitative information about the value of an uncertain quantity, *x,* as can be seen in figure 4.2. The different methods were presented to the respondents with and without explanation. The respondents were asked to approximate the best estimate, the chance of crossing a threshold (more than 2 inches of snow), the chance of being between two thresholds (between 2 and 12 inches of snow), how sure the respondents felt about their answer, and if they have ever seen this method before. (Wardekker & Van der Sluijs, 2005). There was not one display that performed best for every application, but different displays performed best in different applications as shown in table 4.4. They concluded that the displays that explicitly contained the information people needed, show the best performance.

Kloprogge et al. (2007) discussed some other figures as shown in figure 4.3. They concluded that uncertainty bands and tukey boxes are commonly-used graphical forms that show uncertainty ranges. They are easy and suitable for a non-technical public.

Table 4.4 Results of the research by Ibrekk & Morgan (1987).

	Before explanation	**After explanation**
‘Best estimate’	* Point estimate *Tukey boxes	
‘Over the threshold’	*Pie chart *PDF	*PDF
‘Between the threshold’	*Pie chart	*CDF

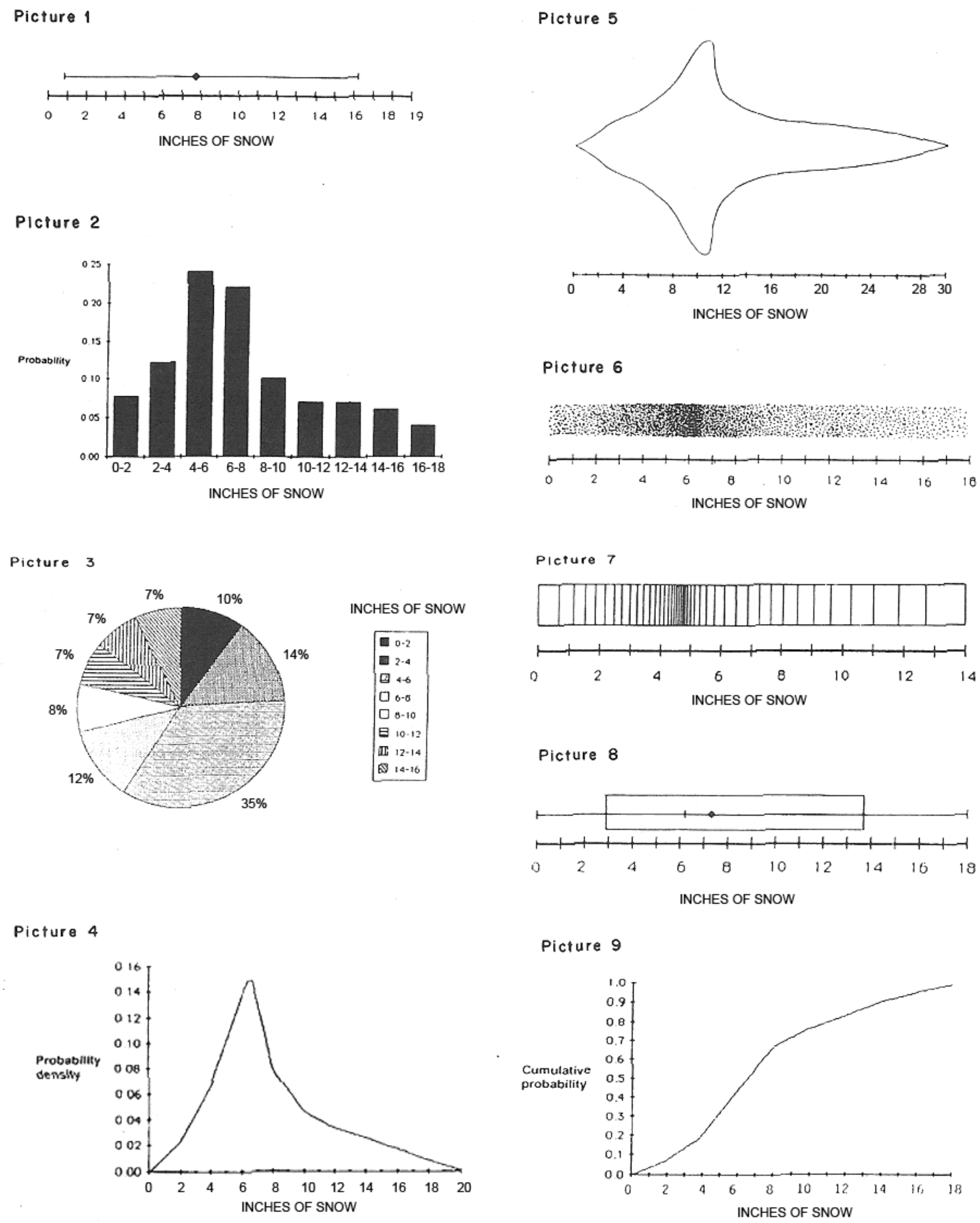


Figure 4.2. The examples of graphical presentations of uncertainty used in the experiments of Ibrekk & Morgan (1987). All nine displays are generated with the same computer graphics system, to make their realizations as similar in style and quality as possible.

1. *Traditional point estimate with an 'error bar' that spans a 95% confidence interval*
2. *Bar chart (discretised version of the density function)*
3. *Pie chart (discretised version of the density function)*
4. *Conventional probability density function (PDF)*
5. *Probability density function of half its regular height together with its mirror image*

6. *Horizontal bars of constant width that have been shaded to display probability density using dots*
7. *Horizontal bars of constant width that have been shaded to display probability density using vertical lines*
8. *Tukey box modified to indicate the mean with a solid point*
9. *Conventional cumulative distribution function (CDF), the integral of the PDF*

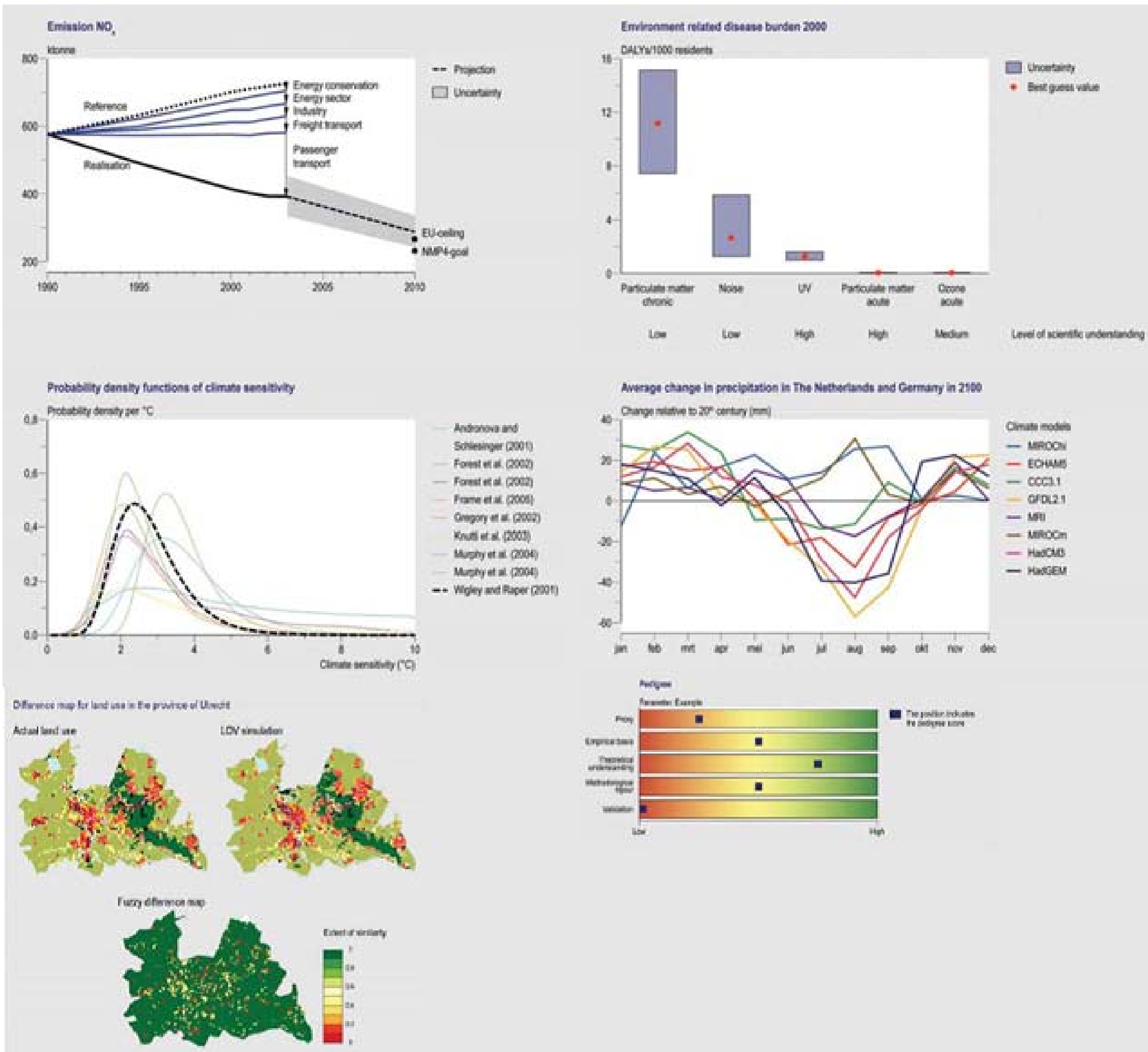


Figure 4.3.Several presentation forms shown in Kloprogge (2007).
Clockwise are presented, starting at the left upper corner: uncertainty bands, box plot, multi-model ensemble, pedigree chart, difference map and Probability Density Functions (PDF).

Probability Density Functions (PDF) and multi-model ensembles on the other hand are more difficult to understand. Additional information is required about the meaning of the figure and about the implications of the differences between model results. Specialized figures such as a difference map and pedigree chart are not necessarily complex, but they do require additional information about what the figure actually represents.

The advantages and disadvantages of all the graphics discussed in section 4.2.3 are summarized in table 4.5.

Table 4.5. Summary of the advantages and disadvantages of graphics.

Graphics	
Advantages	**Disadvantages**
• Significant amounts of uncertainty information can be summarized. Thus resulting in a shorter report. • If the presentation form is familiar, the information is obvious in a second.	• Many graphical expressions of uncertainty are not straightforward to understand. • Time has to be spent in retrieving the uncertainty information out of the figure and in understanding the method of the presentation. • Figures are inviting the readers to draw conclusions on what they see.

4.1.4 Combined forms of presentation

A combination of linguistic, numeric and graphical information is often seen in reports as the form of uncertainty presentation. The text of a specific section describes the uncertainties by using language, but also includes numbers and the section contains a figure in which the uncertainties are graphically displayed. Text alone in a report may come across as boring and tedious to the readers. Readers will appreciate a variety in forms of presentation. Moreover the users have preferences for a specific form of presentation. Nevertheless, to keep the uncertainty message convincing, one should take care that the implied messages are consistent. Besides that, the repetition may result in a better understanding of the uncertainty, since the uncertainty is explained in different ways.

An advantage of combining these forms is that it may result in a better understanding of the uncertainty, since it is explained in different ways and the reader can choose the presentation form of his preference (Kloprogge et al., 2007). While a description of the uncertainties occurs at several locations in a specific section of the report, chances are higher that the reader will notice this information. A disadvantage is that presenting the uncertainty information in several presentation forms will require more space in the report and specific attention must be paid to the consistency of the messages displayed.

The advantages and disadvantages of the combined forms are summarized in table 4.6.

Table 4.6. Summary of the advantages and disadvantages of combined forms., these could not be compared to the tables of the single presentation forms.

Combined forms	
Advantages	**Disadvantages**
• It is possible for readers to choose the presentation form they like. • Repetition may result in a better understanding of the uncertainty. • Less boring and tedious, than the single presentation forms.	• More space is required than for a single presentation form. • Chance of inconsistency.

4.2 Designing presentation forms

For the interviews, presentation forms have to be designed by means of the results of the Monte Carlo analysis presented in section 3.2.3. The decision makers that are interviewed should give comments on these presentation forms and rank them, to determine the best presentation form to communicate uncertainty to decision makers in flood management.

Before the designing could take place a general remark has to be made. The height of the critical values have to be brought to attention, because the water levels predicted in the Monte Carlo analysis were too low to exceed a critical value in location Zuidbroek. To create a more expressive situation for decision makers, the critical values are lowered, as suggested in section 3.3. The adapted values are presented in table 4.7.

These adapted critical values are used during the design of the presentation forms and during the interviews. Therefore, it is necessary to inform the decision makers that are going to be interviewed about the adaptation. Furthermore, a table with the adapted values has to be provided to decision makers, to prevent the decision makers to answer with the original values in mind.

Table 4.7. Critical values for the location Zuidbroek.

Critical value between:	Original value	Adapted value
phase 2 and phase 3	+1.45 m NAP	+0.80 m NAP
phase 1 and phase 2	+1.25 m NAP	+0.70 m NAP
phase 0 and phase 1	+1.05 m NAP	+0.60 m NAP

During the presentation form design, the next matters are taken account of:

First, the presentation forms are ordered so that every successive presentation form contains more information about the uncertainty than the one before. This way the decision makers first get the presentation form with the least uncertainty information and the more presentation forms they see, the more uncertainty information they get. The decision maker is forced to use his knowledge from simple to more complex forms. This probably will result in answers that are less contaminated with information of the uncertainty which is not presented in the shown presentation form.

Second, single presentation forms are used. The most suitable single presentation forms that were discussed in section 4.1 are used, with a possibility to add other single presentation forms. By omitting the combined presentation form, comparison of the effect of the presentation forms has been simplified.

Third, the presentation forms only show one location, to make it easier to compare the presentation forms with each other. There is chosen to use location Zuidbroek, because of its importance for the Water Board and the large uncertainty in water level according to table 3.3.

Fourth, the determination of the best presentation form is divided into presentations with and without the development of water levels in time. For the first one, the results of the 'peak event' are used. For the second one, the results of the 'peak moment'.

Fifth, the most suitable presentation forms of section 4.1 are used.

The chosen presentation forms are listed below, in the same order as they are going to be presented during the interviews. All the presentation forms are composed by the same data of Zuidbroek, with the same uncertainty range of the 'peak moment' and 'peak event', respectively if they are time independent or time dependent.

Time dependent presentation forms:

- Values. The point estimate graphical presentation form is transformed into a numeric one. This presentation form contains the least information on uncertainty, as it represents the minimal, most appropriate and maximum water level.
- Color. The form is inspired on the clickable maps used in the DSS. This presentation form is used to discover if the decision makers prefer the translation of the predicted values into a color, which is representative for the calamity phase the value the predicted water level is in.
- Linguistics (linguistic). The IPPC7 scale is used to determine if the decision makers prefer the use of linguistics as a presentation of uncertainty in model output.
- Statistics (numeric). The numeric presentation forms are strongly connected with statistical presentations, therefore an EDA presentation is chosen. The EDA presentation presents the number of observations, the median, the lowest 25%, the highest 25%, the absolute minimum and absolute maximum. This presentation form is used to determine the preference of decision makers in flood management for numeric presentation forms.
- Box plot (graphical). Which is also known as Tukey box. This presentation form contains exact the same uncertainty information as the 'Statistics' presentation form, but now in a

graphical manner. This presentation form is used to determine the preference of decision makers for graphical presentation forms.

- Histogram. Also referred as bar chart in the research of Ibrekk & Morgan, 1987). This presentation form is added to create a more progressive transition from box plot to PDF & CDF.
- PDF & CDF (graphical). Plotting a CDF with a PDF directly above it (with the same horizontal scale and with the location of the mean clearly indicated on both curves) seems to be a good approach for displaying probability information (Ibrekk and Morgan, 1987). This presentation form is shown to test if this is also correct for decision makers in flood management.

Time independent presentation forms:

- Bandwidth (graphical). The presentation form is also referred to as uncertainty bands. This presentation form is shown to determine the influence of development of the water levels in time on the uncertainty communication to decision makers in flood management.
- Whole prediction. This presentation form is added to determine the influence of showing all the predictions.

An overview of the results of the presentation form design is shown in Appendix A.

4.3 Interview setup

This section presents the goal of the interviews, how the decision makers are selected, which decision makers participated in the interviews, which questions were asked and which presentation forms were shown.

The goal of the interviews is to determine the best designed presentation form for presentation of uncertainty to decision makers in flood management by presenting the designed presentation forms, ask the decision makers to rank them and make comments on the presentation forms.

There are two selection criteria for the decision makers. One is that the decision maker should have knowledge about the water system of Hunze & Aa's. Second is that the decision maker should be concerned with water level management or water policy making. This means that the decision makers have to work at the Water Board Hunze & Aa's, the neighbor Water Board Noorderzijlvest or at the Province of Groningen. These authorities were approached and ten decision makers were willing to participate in the interviews. Five decision makers work at the Water Board Hunze & Aa's, three at the neighbor Water Board of Noorderzijlvest and two at the Province of Groningen. Within this group of ten decision makers, three people are concerned with policy making and seven people have a role during operational high water management. Those seven can be divided into three people who influence the WAT-phase, two the WOT-phase and two have influence on both the WOT- and WBT-phase.

All the interviews were taken in the period of June 2009 up to February 2010 at the offices of the Water Boards and the Province of Groningen, so the decision makers would only have to spend an hour and a half of their time on the interview.

During the interview a short introduction is given about the cause, the goal of the interview and the importance of comments on the presentation forms is emphasized toward the decision makers. Besides that, the decision makers were asked if they agree that the interview is recorded to provide better information for the interview analysis. The decision makers are questioned according to the presentation forms and the question list. (As can be found in Appendix A and Appendix B respectively.)

Subsequently, the framework for the designed presentation forms is told to the decision makers. That the choice was made to show presentation forms for the maximum DSS prediction period, because of the following two assumptions. First assumption is that the sooner a possible high water situation is mentioned, the faster decision makers can take action. Second assumption is that uncertainty is crucial to indicate the risks of a certain decision.

Thereafter it is explained to the decision makers that a Monte Carlo analysis is executed by means of weather variables, because weather variables cause uncertainty to the DSS. The weather variables are then changed according to the Ensemble Prediction System of the ECMWF, which consists of 52 predictions. 50 of them are perturbed. These 50 perturbed predictions for precipitation, wind, and tide are used in the Monte Carlo analysis of the DSS Hunze & Aa's. The Monte Carlo analysis of the DSS Hunze & Aa's show that different weather predictions can lead to different water level predictions.

Then the decision makers were told about the next assumption; the range of predicted water levels given at the Monte Carlo analysis is the total range of possible water levels that could occur.

Followed by, the decision makers were told that examination turns out that the critical values for the location Zuidbroek are much higher than the water levels presented in the DSS results of the 'peak event'. Therefore the critical values had to be lowered, for the purpose of this research, to create a more excessive situation which probably needs decisions. The decision makers have to keep in mind the fictitious critical values of table 4.8 when they answer the questions.

Table 4.8. Fictitious critical values location Zuidbroek, adopted in the interviews.

Critical value peak water level	Situation
< 0.60 m	Safe
0.60-0.70 m	First calamity phase
0.70-0.80 m	Second calamity phase
> 0.80 m	Serious threat high water

After the explanation of the framework: the decision makers answered the next questions about the desired uncertainty presentation forms. Which information should the presentation forms contain, regardless of the format of the presentation? Is there secondary information that is needed for the decision making? This is done to determine which information an uncertainty presentation has to contain. The information given by decision makers can be used to improve future presentation design.

The first seven uncertainty presentation forms of Appendix A are shown to the decision makers, one by one. With each presentation an explanation is given. These explanations were:

- Values: the values show three water levels. Minimal water level, the most plausible water level and the maximum water level. The most plausible is the water level which is at 50% of all the water level predictions. So 50% of the predicted water levels are lower, and 50% higher.
- Color: the values of the three water levels are replaced by colors. The legend tells us that the minimal water level is in the range of 0.70-0.80 m^+ NAP, just like the most plausible water level. Remembering the decision makers that it is the second calamity phase, according to the fictitious critical values of table 4.6. The maximum water level is colored red, which is a serious threat of high water with a predicted water level above 0.80 m^+ NAP.
- Linguistics: this presentation is made on the basis of a fixed scale. The terms used in the sentences are explained in the legend, with their accompanying probabilities.
- Statistics: on the basis of the 50 EPS predictions, the absolute minimum and maximum, 25%, 75% and the most appropriate water level are shown with help of statistical terms.
- Box plot: the graphic shows the water level on the y-axis. The box also represents the absolute minimum and maximum, 25% water level, 75% water level and the most appropriate water level. Behind the description of the water level, the exact prediction is given in numbers.
- Histogram: with on the x-axis the peak water levels in m^+ NAP and on the y-axis the number of predictions of that specific water level. Based upon the 50 predicted water level from the EPS.
- PDF & CDF: the PDF represents the same as the histogram, but then with a smooth line instead of all the bars. The CDF represents a value between 0 and 1. 'Zero' means that

all the predicted water levels are higher than the given value on the x-axis. 'One' means that all the predicted are lower than the given value on the x-axis.

After the explanation, the decision makers were asked about their opinion according to the understandability, surveyability and the clearness of uncertainty shown in the presentation form. With this the decision makers were asked if the presentation form is suitable for decision making according to the amount of information they provided. Next, the decision makers were asked to rank the presentations forms, by putting the most useable presentation form on top and the presentation form that is least useable at the bottom.

Then the last two uncertainty presentation forms of Appendix A are shown, one by one. And an explanation of the presentation form is given. These explanations were:

- Bandwidth: this presentation form shows the development in time on the x-axis and the predicted water level on the y-axis. The five lines represent the minimal water level, 10% line, 50% line, 90% line and the maximum water level. With the 50% line as resemblance of the most appropriate water level.
- Whole prediction: also this presentation form shows the development in time on the x-axis and the predicted water level on the y-axis, but this time all 50 predictions are shown.

The method for the last two uncertainty presentation forms is the same as the method explained above for the seven time independent uncertainty predictions. First the best uncertainty presentation and the strong and weak points were determined. Second, the decision makers were asked to rank the two presentations by putting them under/into/up the pile of all the presentation forms of Appendix A.

All the decision makers did agree to give feedback. When the interviews were worked out, these were send to the decision makers. When the feedback of all interviews was received, the analysis of the interview results began as described in section 4.4.

4.4 Interview analysis

This section contains information on how the interview results are analyzed to answer the second and third research questions "Which of the designed presentation forms is the best to communicate uncertainty towards decision makers in flood management?" and "What determines the ranking of the presentation forms for the decision makers in flood management?".

4.4.1 Determine the best designed presentation form

The decision makers ascribed the presentation forms with a rank. Number 1 means that the presentation form is best useable for communication to decision makers. Number 7 means that the presentation form is least useable. It is possible that the decision maker considered a presentation form as unusable or equally less useful. In that case all the missing ranks for the specific decision maker are averaged. This averaged rank is handled for all the presentation forms with missing ranks for that specific decision maker.

For example when a decision maker ranked four presentation forms and left three presentation forms open, because he is of the opinion that they are not usable. Then the missing ranks are replaced by the average rank of the remaining ranks 5, 6 and 7. So the average rank becomes 6.

All the ranks for the time dependent presentation forms are entered in table 4.7 and a similar table is made for the time independent presentation forms. These tables show the decision makers in the top row. To guarantee the anonymity of the decision makers, the name of the decision maker is replaced by a number between 1 and 10. The first column shows the presentation forms of Appendix A and the last column the median of the presentation form. The table is filled in with the rank the decision maker gave to the uncertainty presentation form on basis of appropriateness for communication to decision makers in flood management.

According to Wonnacott & Wonnacott (1969) numerical operations such as calculating an average are not possible for data that comes originally in ranked form. Therefore all the ranks per presentation form are observed and the median is determined. The presentation form with the lowest median is best useable and the presentation with the highest median the least.

To determine if the development of water level in time is a deciding factor for ranking, a short comparison is made. All the ascribed ranks by the decision makers are compared. If all the time independent presentations have better ranks than the time dependent presentation forms, the development in time is a deciding factor in ranking. Otherwise the development in time is not a deciding factor or it is not the only deciding factor.

Table 4.7 Ranking table time-independent uncertainty presentations

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Median**
Values											
Color											
Linguistics											
Statistics											
Box plot											
Histogram											
PDF &CDF											

To determine the best presentation form, the time independent and time dependent presentation forms are separately. So after the examination there will be two best presentation forms.

To show that there is a significant difference between the medians, the Mann-Whitney U test is used. If there is a significant difference between the presentations, the test proves that one presentation form is better than the other. The Mann-Whitney U test is a non parametric statistical test, which means that it is distribution free and does not have to answer the demand of normality. The test determines if the samples are part of the same distribution and is suitable for samples that consist of independent variables, which do not have a normal distribution and do have an ordinal scale. The interview results answer these demands, because the different ranks per presentation form come from different decision makers, so they are independent. The sample size is too small to consider it as a normal distribution. The order in ranking is clear, but the differences between the ranks have no meaning.

The Mann-Whitney U test is explained in this paragraph. All the ranks that the decision makers gave to the 'first presentation form' are added to the ranks that the decision makers gave to the 'second presentation form'. These are placed in order from low till high. The lowest rank receives the value 1 and the highest value 20, because there are ten ranks ascribed per presentation form and we have two presentation forms. When there are more observations with the same rank, all these observations receive the same value which is equal to: $LV + \frac{(HV-LV)}{2}$, with *LV*= '*the lowest value with the same rank'* and *HV*= '*the highest value with the same rank'*. The sum of all ranks in the first presentation form are defined as R_1 and the sum of all ranks in second presentation form is defined as R_2. Also the sample sizes of both presentation forms are determined as n_1 and n_2. With this information U_1 and U_2 could be determined. The formulas for U_1 and U_2 are $U_1 = n_1 n_2 + \left[{n_1(n_1+1)}/{2}\right] - R_1$ and $U_2 = n_1 n_2 + \left[{n_2(n_2+1)}/{2}\right] - R_2$. The total sample size of the two combined samples exceeds the table of Mann-Whitney. The total sample size is equal to 20 and could therefore be assumed to mimic normality, according to the Central Limit theorem. The U statistic is converted to a Z-score, according to the next formula

$Z = \frac{(largest\ U\ value) - \left({[n_1 n_2]}/{2}\right)}{\sqrt{{(n_1 n_2 (n_1+n_2+1))}/{12}}}$ (Kallenberg, 2000).

Interpretation of the Z-value is as follows. Two hypothesis are made and the α is determined as α = 0.05. The first hypothesis is $H_0 = there\ is\ no\ difference\ between\ \ the\ presentation\ forms$ and the second $H_1 = there\ is\ a\ difference\ between\ \ the\ presentation\ forms$. If $Z \leq 1.96$ than $P \geq 0.05$, than H_0 is valid. And if $Z > 1.96$ than $P < 0.05$, than H_1 is valid.

4.4.2 Criteria for ranking the presentation forms

To determine if there is an explanation for the ranking of the designed presentation forms, an analysis is done means of the concepts that were used in the interviews; 'comprehensibility', 'surveyability', 'uncertainty clear', 'usability' and 'decision possible'. When the decision maker was positive that the presentation form showed the meaning of the concept, the presentation form gets a '1'. When the decision maker was negative, the presentation form gets a '0'. All the ones and zeros were added and that gave the appreciation for that presentation form about that concept. The concepts are compared and examined for correspondence between ranking and appreciation.

Furthermore, the comments of the decision makers on specific presentation forms are analyzed and the criteria's of showing the model output to decision makers were filtered. These criteria's are used to examine the possibility for recommendations on the presentation of uncertainty to decision makers in flood management.

Chapter 5 Results

Chapter 5 presents the answers to the three research questions offered in section 1.2. The presentation forms for the presentation of uncertainty in model output are discussed in section 5.1. The best designed presentation form is discussed in section 5.2 and the criteria for ranking are discussed in section 5.3.

5.1 Presentation forms appropriate for communication

Section 5.1 answers the first research question: ‘Which presentation forms are appropriate for communication of uncertainty in model output to non-technical decision makers?’.

Ibrekk & Morgan (1987) and Kloprogge et al. (2007) examined some presentation forms from a policy making angle. These results are already presented in section 4.1, but shall be summarized below per presentation form, with their strong and weak points:

- The point estimate scores best as ‘best estimate’ before explanation, in the research of Ibrekk & Morgan (1987).
- The box-plot or Tukey box is commonly used, easy and suitable for non-technical people (Kloprogge et al., 2007). Ibrekk & Morgan (1987) state that this presentation form is best for determining the ‘best estimate’.
- The probability density function (PDF) is the best to determine if there is a chance that a critical value is exceeded (Ibrekk & Morgan, 1987), but Kloprogge et al (2007) state that this presentation form is more difficult to understand.
- The conventional probability density function (CDF) is the best to determine the chance that an event occurs. However, Ibrekk & Morgan (1987) also state that a CDF used alone is not a reliable way to communicate the mean. Therefore they bring up an approach for correctly showing the probability information by plotting a PDF directly above the CDF, with the same horizontal scale and location of the mean clearly indicated on both curves.
- The bandwidth or uncertainty band is commonly used, easy and suitable for non-technical people (Kloprogge et al., 2007).
- Fixed scales could be used in reports to create a consistent use of language, which makes it easier to remember and consistent messages are perceived as more credible (Kloprogge et al., 2007; Wardekker & Van der Sluijs, 2005). However, the fixed scales does not match people’s intuitive use of probability language (Kloprogge et al., 2007) and are for the specific text only.

5.2 The best designed presentation form

Section 5.2 answers the second research question: 'Which presentation form is the best, when it involves communication of uncertainty to decision makers in flood management?' With this a distinction is made between time independent and time dependent presentation forms, because section 5.2.1 shows that it is not proven that one is unanimous better than the other. Therefore are the results of the time independent presentation forms presented in section 5.2.2 and the results of the time dependent presentation forms in section 5.2.3.

5.2.1 Time independent versus time dependent

Table 5.1 shows the ranking of the presentation forms per decision maker, according to the usefulness for communication of uncertainty to decision makers in flood management. This is the original table, without the addition of the average ranks as explained in section 4.4.

Due to the extreme differences in ranking for time dependent presentation forms, it is not proven that the time dependent forms are better or worse than the time independent presentation forms.

Table 5.1 The presentation forms with their ranks as ascribed by the decision makers. The time dependent presentation forms are highlighted in grey. The remaining presentation forms are time independent.

	1	2	3	4	5	6	7	8	9	10
Bandwidth	**3**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**
Whole prediction	**-**	**9**	**9**	**2**	**2**	**2**	**9**	**9**	**9**	**-**
Values	*2*	*5*	*2*	*6*	-	*4*	*2*	*4*	*8*	*3*
Histogram	-	*2*	*4*	*8*	*4*	-	*4*	*2*	*2*	-
Box plot	*1*	*8*	*7*	*5*	*3*	-	*7*	*5*	*4*	*1*
Linguistics	-	*3*	*5*	*3*	-	*5*	*3*	*7*	*6*	-
Color	-	*6*	*3*	*4*	-	*3*	*5*	*6*	*7*	-
PDF & CDF	-	*4*	*8*	*9*	-	-	*6*	*3*	*3*	-
Statistics	-	*7*	*6*	*7*	-	-	*8*	*8*	*6*	-

5.2.2 Time independent

Table 5.2 shows the ranks are already arranged from low to high, which makes it easier to determine the median. The blue ranks are the ones determined by the decision maker. The red ranks are the ones that are assigned averaged ranks. Median 1 represents the median for all the ranks, while median 2 represents only the blue ranks. Although the medians are realized in a different manner, they show the same order in presentation forms.

Table 5.3 shows that all the Z-scores are higher than 1.96, which means that the chance is smaller than 0.05 that the two presentation forms are from the same distribution. That means that

H_1 is valid, so there is a significant difference between the presentation forms. For that reason it can be concluded that the presentation form with the lowest median is the best appropriate for communication of uncertainty to decision makers in flood management and the one with the highest median the least. Therefore 'Values' is the best time independent presentation form, according to the experts for this specific case.

Table 5.2 Ranking of the time independent presentation forms by decision makers, with their median, in a more conveniently arranged manner. Median 1 is the median on the basis of the average ranks. Median 2 is on the basis of the ranking by the decision makers.

					*	*					**Median 1**	**Median 2**
Values	1	1	2	2	2	3	4	4	4	7	**2.5**	**2.0**
Histogram	1	1	1	3	3	4	4.5	4.5	5	6	**3.5**	**2.0**
Box plot	1	1	1	3	3	4	5	6	6	7	**3.5**	**3.0**
Linguistics	1	2	2	3	4	4	4.5	4.5	5	6	**4.0**	**3.0**
Color	1	2	2	4	4	4.5	4.5	5	5	6	**4.3**	**4.0**
PDF & CDF	2	2	3	4	4.5	4.5	5	5	7	7	**4.5**	**4.0**
Statistics	4	4.5	4.5	5	5	5	5	6	7	7	**5.0**	**6.5**

Table 5.3 Z-scores of the presentation forms (on the basis of all ranks in table 5.1).

	Values	**Histogram**	**Box plot**	**Linguistics**	**Color**	**PDF & CDF**	**Statistics**
Values		3.59	4.12	3.63	4.38	4.91	6.05
Histogram	3.59		3.36	3.44	3.70	4.27	5.63
Box plot	4.12	3.36		3.10	3.40	4.04	5.59
Linguistics	3.63	3.44	3.10		3.14	3.74	4.80
Color	4.38	3.70	3.40	3.14		3.70	5.25
PDF & CDF	4.91	4.27	4.04	3.74	3.70		3.74
Statistics	6.05	5.63	5.59	4.8	5.25	3.74	

5.2.3 Time dependent

The decision makers also ranked the time independent presentation forms. Table 5.4 shows the ranks per presentation form with their median. The 'Bandwidth' is unanimous elected as number 1. The Z-score determined by the Mann-Whitney U test is 6.80, which proves that H_1 is valid. So there is a significant difference between the two time dependent presentation forms and the 'Bandwidth' is better for using than the 'Whole prediction'.

Table 5.4 Ranking of the time dependent presentation forms by decision makers, with their median.

					*	*					**Median**
Bandwidth	1	1	1	1	1	1	1	1	1	1	**1**
Whole prediction	2	2	2	2	2	2	2	2	2	2	**2**

5.3 Criteria for ranking the presentation forms

Section 5.3 answers the third research question: ‘What determines the ranking of the presentation forms for the decision makers in flood management?’ Section 5.3.1 discusses the appreciation of the decision makers for the presentation forms on the basis of six, in advance formulated, criteria. The appreciation of the criteria is compared with the ranking in section 5.2 to determine if there is a connection between those two. Next in section 5.3.2, the comments decision makers gave per presentation form are examined to find more criteria for ranking the presentation forms.

5.3.1 Appreciation of the criteria

Table 5.5 shows a comparison between the ranking and the positive appreciation of the presentation forms for ‘usability’. The higher the appreciation for ‘usability’, the more appropriate the presentation is for communication of uncertainty to decision makers in flood management. Striking is that the presentation form ‘Bandwidth’ gets maximum appreciation and has by far the best score.

The comparison between the ranking in section 5.2 and the order determined by ‘usability’ show a similarity for the time dependent presentation forms. However, this similarity is not shown for the time independent presentation forms. The presentation forms ‘Linguistics’ and ‘Color’ both score a ‘5’ on the ‘usability’, but are ranked place 4th and 5th, while the presentation form of the ‘Box plot’ is ranked 3rd place with a score ‘0’. There could be assumed that there is a discrepancy between the ranking in section 5.2, which was done at the end of the interviews, and the appreciation of the criteria ‘usability’ during the interviews.

Table 5.5 A comparison between the ranking and positive appreciation of the presentation forms, according to the usability of the presentation forms for communication of uncertainty to decision makers in flood management. The column with the ranking corresponds with the ranking determined in section 5.2. The time dependent presentation forms are highlighted in grey. The remaining presentation forms are time independent.

	Ranking	Usability
Bandwidth	*1*	*10*
Whole prediction	*2*	*4*
Values	*1*	*5*
Histogram	*2*	*3*
Box plot	*3*	*0*
Linguistics	*4*	*5*
Color	*5*	*5*
PDF & CDF	*6*	*2*
Statistics	*7*	*0*

Table 5.6 shows the positive appreciation of the presentation forms for the criteria: 'comprehensibility', 'surveyability' and 'uncertainty clear'.

The presentation forms 'histogram', 'PDF & CDF' and 'statistics' score low on 'comprehensibility', because the decision makers were scared off by the statistics and describe the presentation forms as too scientific.

The presentation forms 'histogram' and 'PDF & CDF' score low on 'surveyability', because the decision makers think that these presentation forms contain too much information and the indication of the most appropriate predicted water level is missing. Also 'linguistics' scores low on 'surveyability', because the decision makers had to read the large amount of text before they understood the situation. The decision makers state that it demands too much time to read it and that it takes too long to analyze it, certainly in a crisis situation.

The presentation forms 'values' and 'statistics' score low on 'decision clear', because the decision makers questioned the large 75%-100% range and they want to know where that large range of uncertainty comes from. Furthermore, the presentation forms 'histogram' and 'PDF & CDF' score low on 'decision clear', because the presentation form does not show the most appropriate predicted water level and the 75%-100% range is too large. Also the presentation form 'color' scored low on 'decision clear', because this presentation form does not show the absolute predicted values which are necessary for the decision which measure to use.

The time dependent presentation forms have the same order in appreciation as in ranking. Striking fact is that the presentation form 'Bandwidth' again gets maximum appreciation and the score is once more by far the best score of all the presentation forms. However, for the time independent presentation forms none of the criteria or the SUM of those criteria show the exact same order in appreciation as in ranking. Therefore, cannot be assumed that one of these criteria has an obvious connection with the ranking.

Table 5.6 Positive appreciation of the presentation forms. The time dependent presentation forms are highlighted in grey. The remaining presentation forms are time independent.

	Comprehensibility	**Surveyability**	**Uncertainty clear**	**SUM**
Bandwidth	*10*	*10*	*10*	**30**
Whole prediction	*7*	*0*	*6*	**13**
Values	*10*	*9*	*2*	**21**
Histogram	*5*	*4*	*5*	**14**
Box plot	*6*	*6*	*6*	**18**
Linguistics	*7*	*5*	*7*	**19**
Color	*7*	*7*	*1*	**15**
PDF & CDF	*2*	*3*	*3*	**8**
Statistics	*1*	*6*	*2*	**9**

Table 5.7 shows that all the presentation forms are not appropriate for decision making, except the time dependent presentation form 'Bandwidths'. The other presentation forms get a score of 4 or lower, which means that the decision makers believe that it is not possible to make a decision on basis of the information given in these presentation forms. The decision makers state that the presentation forms contained too little or just too much information, as showed in table 5.8. Just in a single case, the decision maker believes that the presentation form contains enough information.

Table 5.7 Appreciation of the presentation forms, according to the possibility of making decisions on the presentations. The column with the ranking corresponds with the ranking determined in section 5.2. The time dependent presentation forms are highlighted in grey. The remaining presentation forms are time independent.

	Ranking	**Decision possible**
Bandwidth	*1*	*9*
Whole prediction	*2*	*4*
Values	*1*	*3*
Histogram	*2*	*4*
Box plot	*3*	*3*
Linguistics	*4*	*3*
Color	*5*	*1*
PDF & CDF	*6*	*3*
Statistics	*7*	*0*

Table 5.8 Appreciation of the presentation forms, according to the amount of information it presents. The scores that end on '.5' are ascribed when the decision maker noticed that on the one side specific information was missing, but that on the other side there was also superfluous information presented.

	Amount of information		
	Too less	**Enough**	**Too much**
Bandwidth	*4*	*2*	*4*
Whole prediction	*-*	*1*	*9*
Values	*8*	*2*	*-*
Histogram	*5*	*-*	*5*
Box plot	*5.5*	*-*	*4.5*
Linguistics	*6.5*	*-*	*3.5*
Color	*8*	*1*	*1*
PDF & CDF	*4*	*3*	*3*
Statistics	*4.5*	*-*	*4.5*

5.3.2 The comments

This section gives a summary of the comments given by the decision makers. An overview of all the comments per presentation form is presented in Appendix C.

All the decision makers believe that uncertainty is important and prefer a situation without uncertainty, because uncertainty complicates the decision making process. Although when uncertainty occurs, the decision makers want to know how large it is and what caused it.

‘The crisis team needs some good, exact and simple information’. It must be useable everywhere and possible to understand the information quickly, since time is of the essence in most cases. Therefore, information has to be brief, concise and strictly to the point. The decision makers agree that the presentation form should be graphical and the development of the water levels and the accompanying uncertainties should be obvious in at a glance. To stimulate that, the information has to be shown in a presentation form that is already familiar to the decision maker. Only then is the information quickly available to the decision makers.

The use of statistics in the presentation forms is too difficult for the decision makers, because terms like sample and median scare the decision makers off. Besides that, the representation of the probability and percentages can cause a distortion in the perception of the seriousness of the situation towards decision makers. It raises too much questions and therefore, the probability and percentages should not be shown in the presentation.

The decision makers indicated three, for them very important, criteria that have to be shown in the presentation form:

- The peak in water level, including the uncertainty ranges.
- The development of the water levels in time.
- The critical values.

A presentation of three predictions for water level is enough to show the peak in water level with the uncertainty ranges: ‘minimal water level’, ‘most appropriate water level’ and ‘maximum water level’. Nowadays, the Water Board Hunze & Aa’s uses the 30%, 50% and the 90% lines of the DSS presentations to simulate these three predictions, for a matter of fact without mentioning the percentages to the decision makers. In practice, the Water Board Hunze & Aa’s decides to take measures upon the development of the ‘most appropriate water level’ and ‘maximum water level’. Therefore, this ‘maximum water level’ has to be apparently shown in the presentation form. The decision makers agree that it also could be another percentage, with the restriction that the extremes should not be told because they only cause confusion.

The presentation of the development of the water levels in time is essential, because the decision makers need to know how much time there is to prepare and take a measure and if it is necessary to take measures. They prefer a three day or, if possible, five day prediction term up to the appearance of the peak, to gain a better understanding of the situation; is the water level still raising or does it stagnate? Besides that, they need information about the actual water level and the measured water levels of the last two days. So, the decision makers are interested in the high water wave instead of a presentation of the peak situation.

The critical values have to be visually available in a graphical presentation. Only then is it clear to the decision makers if the situation is going to be threatening or not. If the critical values are only mentioned in the script, these values are forgotten or people experience it as annoying to search these information.

Some decision makers state that the next subjects also have to be presented: the cause of the peak in water level (abundance precipitation or high sea water levels), the effect of measures on the water level, the weather predictions, information about the surrounding area (strength of the dikes), the discharge and the risks of the upcoming situation.

Chapter 6 Discussion

All the appropriate presentation forms that were found in literature were time independent, except for the presentation form ‘bandwidth’. However, during the interviews it became clear that the development of water levels in time is important for the decision makers in flood management. Nevertheless, is decided to continue with the interviews, because there is a small number of decision makers and after improving the presentation forms the number of decision makers decreases even more. Therefore, the time independent presentation forms and the time dependent presentation forms have to be compared separately.

The decision makers work in different levels of the Water Board or at the Province. Three of the decision makers are policy makers and are not directly occupied with the crisis organization. This is not a problem for the interviews, because they worked a long time at the Water Board and the Province and have knowledge of the water system. So they satisfy the selection criteria for the interviews and are suitable to participate in the interviews.

The appreciations for the criteria per group are compared in a quick scan. The result is that the appreciation for a presentation form hardly depends on the position of the decision maker in the crisis organization, because the decision makers within a group are divided in their appreciation for the presentation form.

The predicted water levels are too low to create a crisis situation, therefore the critical water levels are lowered and communicated towards the decision makers. The decision makers had to keep that in mind and to make sure they will not forget that the adapted critical levels are used in the interview. The adapted critical values were written down on paper and provided to them. The effect of the critical level lowering on the interview results is not known, but an attempt was made to reduce that effect as much as possible by giving the adapted values on a separate piece of paper. The decision makers have the adapted values within reach when they answer questions about the provided presentation forms. The decision makers state that the critical values should be presented in the presentation form, not separately on a piece of paper or anywhere else.

By ranking the time dependent presentation forms the way as they were done, it could have caused misrepresentation in the ranking. The ranking happened at the end of the interview, so it is possible that the decision makers were inclined to put the time independent presentation forms up or under the pile since they were reviewed last. If the presentation forms were presented at random, then it is possible that the time dependent presentations were ranked differently.

A few decision makers had the opinion that some presentation forms are not suitable for using. During the analysis of the interview results these presentation forms received an averaged rank, to prevent groups of 6 presentation forms are compared with groups almost twice as large.

Table 6.1 shows the Z-scores on the basis of ranking of the decision maker, so without the averaged ranks. When this table is compared with table 5.3, which contained the Z-scores on the basis of all the ranks with the averaged ranks, the Z-scores are lower in the new situation. Nevertheless, all the Z-scores are larger than 1.96, so there is a significant difference between the presentation forms.

Table 6.1 Z-scores of the presentation forms (on the basis of the ranking of the decision makers in table 5.1).

	Values	Histogram	Box plot	Linguistics	Color	PDF & CDF	Statistics
Values		2.88	3.22	3.01	3.28	3.54	4.95
Histogram	2.88		3.18	2.93	3.07	3.36	4.40
Box plot	3.22	3.18		2.65	2.54	3.01	4.36
Linguistics	3.01	2.93	2.65		2.49	2.93	4.57
Color	3.28	3.07	2.54	2.49		2.79	4.43
PDF & CDF	3.54	3.36	3.01	2.93	2.79		3.20
Statistics	4.95	4.40	4.36	4.57	4.43	3.20	

The ‘Bandwidth’ had a high rank, with eight decision makers ranked it as number 1. The decision makers state that the development in time, presented in the ‘Bandwidth’ was crucial and the main reason to rank it as number 1. On the other hand ‘Whole prediction’ also included the development in time, but was ranked with the numbers 2 and 9. Three decision makers ranked it as number 2, because the development in time was included and the range of uncertainty could be read. While five other decision makers ranked it as number 9, because of the chaos in the presentation. Apparently the development in time is not the only criteria in ranking.

The presentation form ‘Bandwidth’ is the best time dependent presentation form, according to chapter 5. However, the presentation form looks like the actual presentation form and the decision makers might have answered by availability bias. The ‘Whole prediction’ also resembles the actual presentation form and scored changeable in ranking with 2 and 9. Furthermore the appreciation of the criteria in section 5.3.1 was comparable with the time dependent presentation forms. For that reason could be concluded that the resemblance of the presentation forms ‘Bandwidth’ and ‘Whole prediction’ does not influence the answers of the decision makers and availability bias can be excluded.

The actual presentation form of uncertainty to decision makers that is used by the Water Board Hunze & Aa’s is presented in figure 6.2 and should always be provided with an explanation of an expert. The graphical presentation shows the most appropriate predicted water level and the according bandwidth of 30%-90%. This bandwidth is always referred to as minimal and maximal water level. The percentages are deliberately left out of the presentation, because they only raise questions.

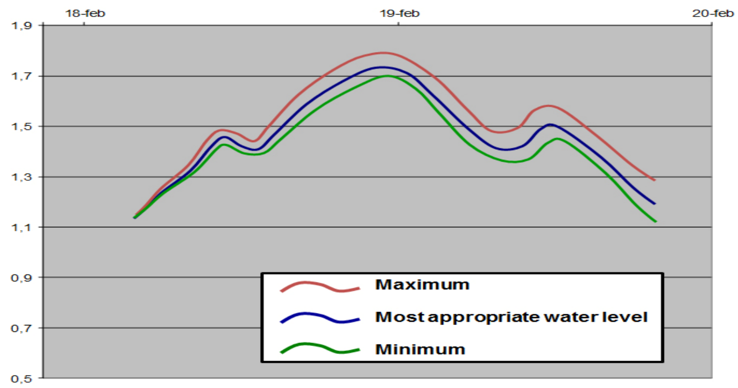


Figure 6.2 An example of the actual presentation form for the predicted water level, with its uncertainty range. Source: Water Board & Hunze & Aa's

The presentation form 'Values' is determined as best time independent presentation form, because it scores high on 'Comprehensibility' and 'Surveyability'. Nevertheless, the decision makers mentioned the lack of development of water levels in time and the lack of critical values in the presentation form.

Besides that it is quite remarkable that the 'Histogram' ended up as second, while four of the decision makers were of the opinion that it is not appropriate for communication to the crisis team.

The 'combined forms of presentation' are omitted in the interviews with decision makers, because the separate presentation forms used in the combined form are already presented by the single presentation forms. Therefore, only the single presentation forms (linguistic, numeric expressions or graphical expressions) are used for the interviews with decision makers, because isolating the single presentation form gives the opportunity to research the effect of that specific presentation form on the communication of uncertainty in model output to decision makers. However, the decision makers plead for an additional explanation by an expert. This explanation should provide more information about the cause of the large range of uncertainty in the predicted water levels and the condition of the surrounding area.

That means that it is not sufficient to show a single presentation form of uncertainty to the decision makers in flood management, this should always be accompanied by an explanation. This could be in textual form or given by an expert.

The decision makers state that a single prediction is not enough during crisis situations. New predictions have to be delivered every hour. So the decision makers get an advanced prediction of the water level and its uncertainty. The uncertainty is relatively large three days before an intended peak. When the time progresses and the moment of the intended peak the uncertainty gets closer, the predictions get more accurate and the uncertainty band gets smaller. This makes that at one day before the intended peak the uncertainty of the predictions becomes relatively small. This has the effect that decision makers wait as long as possible to take measures, because smaller uncertainties result in smaller risks. All the earlier prognoses are used to take preparations for the possible necessary measures.

Besides that, the decision makers always determine the need to activate a measure on basis of a mix between the measured values, the prognosis and expert judgment.

Chapter 7 Conclusions & Recommendations

In the interviews with ten decision makers of the Water Board Hunze & Aa's, the Water Board Noorderzijlvest, and the Province of Groningen information was gathered about the best manner to present uncertainty in water levels to decision makers. The conclusions will be discussed in section 7.1 and the recommendations are given in section 7.2.

7.1 Conclusions

The objective of this research was to determine the best presentation form to communicate uncertainty in model output to decision makers in flood management.

First, the comparison between the rankings of the time dependent and the time independent presentation forms gave no unchallenged evidence that one of these is better or worse than the other.

Second, the best presentation forms were determined for the categories 'time dependent' and 'time independent'. On the basis of the ranks ascribed by the decision makers, table 7.1 points out 'Values' and 'Bandwidth' as the best presentation forms. The Mann-Whitney U test verifies the significant differences between the presentation forms, so number 1 is better than number 2 and so on.

Table 7.1. The presentation forms in order of usability, according to the decision makers.

Time dependent		**Time independent**
'Values'	1.	'Bandwidth'
'Histogram'	2.	'Whole prediction'
'Box plot'	3.	
'Linguistics'	4.	
'Color'	5.	
'PDF & CDF'	6.	
'Statistics'	7.	

Third, the appreciation of the six criteria did not bring a clue about the consideration behind the ranking. The observed criteria were formulated in advance and cover the next matters: usability for communication, comprehensibility of the presentation form, surveyability of the presentation form, if the uncertainty is clear presented, if it is possible to make a decision on the basis of those information and if the presentation form contains too less, enough or too much information.

Fourth, the comments given on the presentation forms during the interviews indicate that three new criteria are very important for the decision makers. These criteria have to be shown in the presentation form when it is communicated to the flood managers:

- The peak in water level, including the uncertainty ranges.
- The development of the water levels in time.
- The critical values.

Fifth, the comments during the interviews and the high appreciation pointed out that the bandwidth is the best presentation form, because it easily could address the next three matters. First, the peak in the water level with the uncertainty range. The decision makers state that the 30%, 50% and 90% lines of the DSS presentations should be used to simulate the ‘minimal water level’, ‘most appropriate water level’ and maximum water level’. Second, the development of the water levels in time is essential, because the decision makers need to know how much time there is to prepare and take measures and if it is necessary to take measures. Information about the actual water level and the water levels of the last two days is preferred. Third, the critical values have to be visually available in the graphical presentation. It should be visible at a glance if a situation is going to be threatening or not.

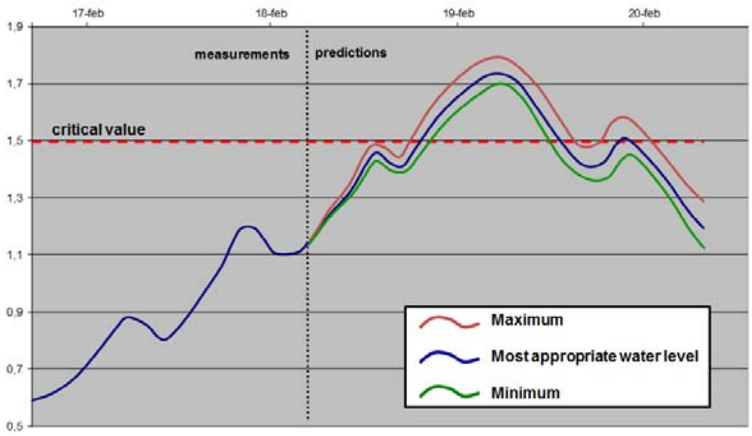


Figure 7.1The best presentation form to communicate uncertainty to decision makers in flood management.

7.2 Recommendations

When uncertainty in model output has to be presented to decision makers in flood management, the ‘Bandwidth’ as shown in figure 7.1 should be used. At least the peak in water level with its according uncertainty ranges, the development of the water levels in time and the critical values have to be presented.

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Appendix A: Presentation forms

This appendix A shows seven time independent and two time dependent presentation forms for the case Hunze & Aa's. Every page contains one presentation form in the following order:

Time independent presentation forms

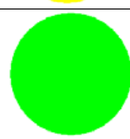
Time dependent presentation forms

Minimale waarde piekwaterstand = 0.72 m
Gemiddelde waarde piekwaterstand = 0.77 m
Maximale waarde piekwaterstand = 1.20 m

Minimale waarde piekwaterstand = 

Gemiddelde waarde piekwaterstand = 

Maximale waarde piekwaterstand = 

	Waterstand [m tov NAP]
	>0.80
	0.70-0.80
	0.60-0.70
	< 0.60 m

Verwachting

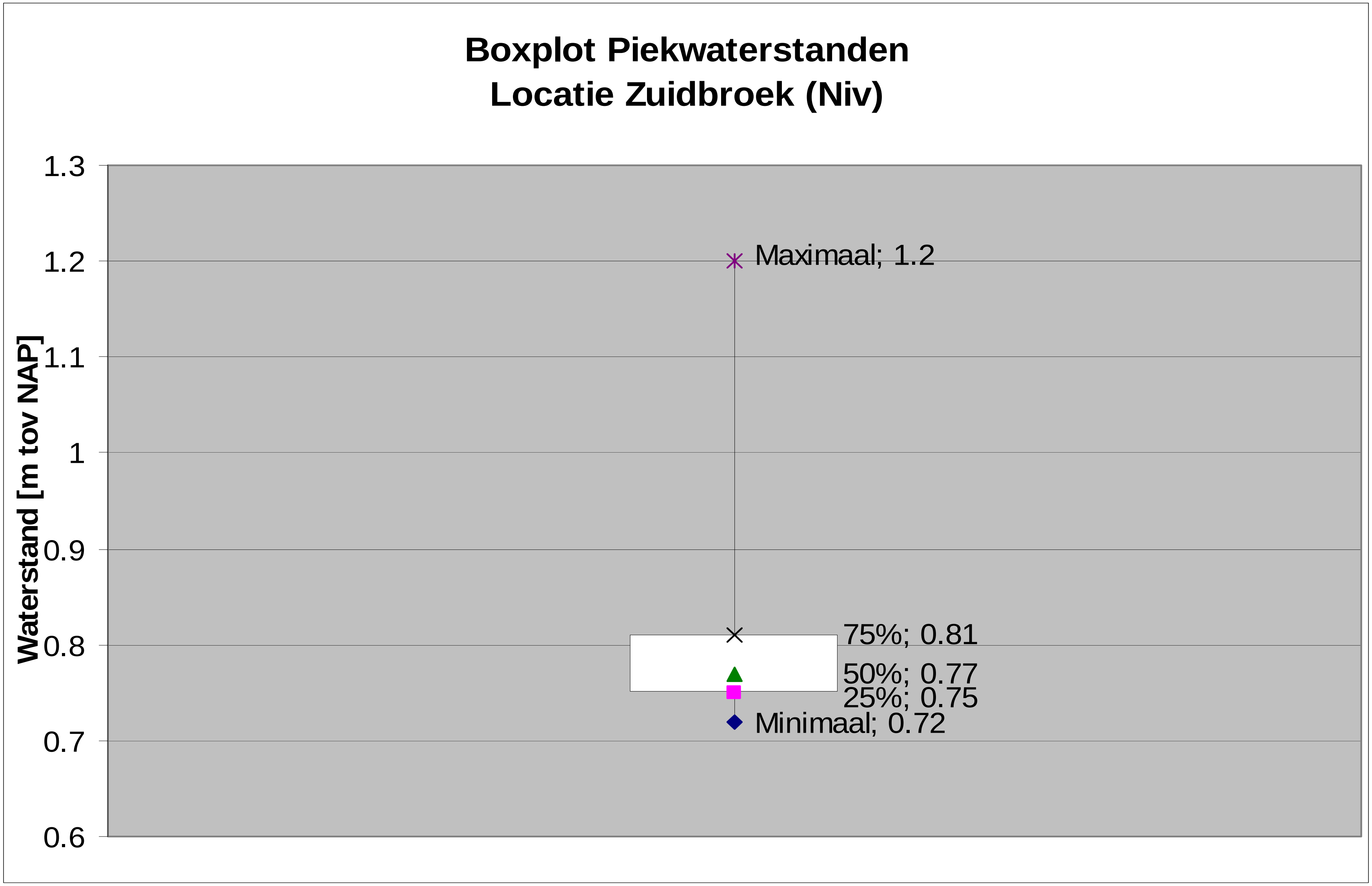
1. Het is vrijwel zeker dat een waterstand van 0.71 m wordt gehaald bij de locatie Zuidbroek (Niv).

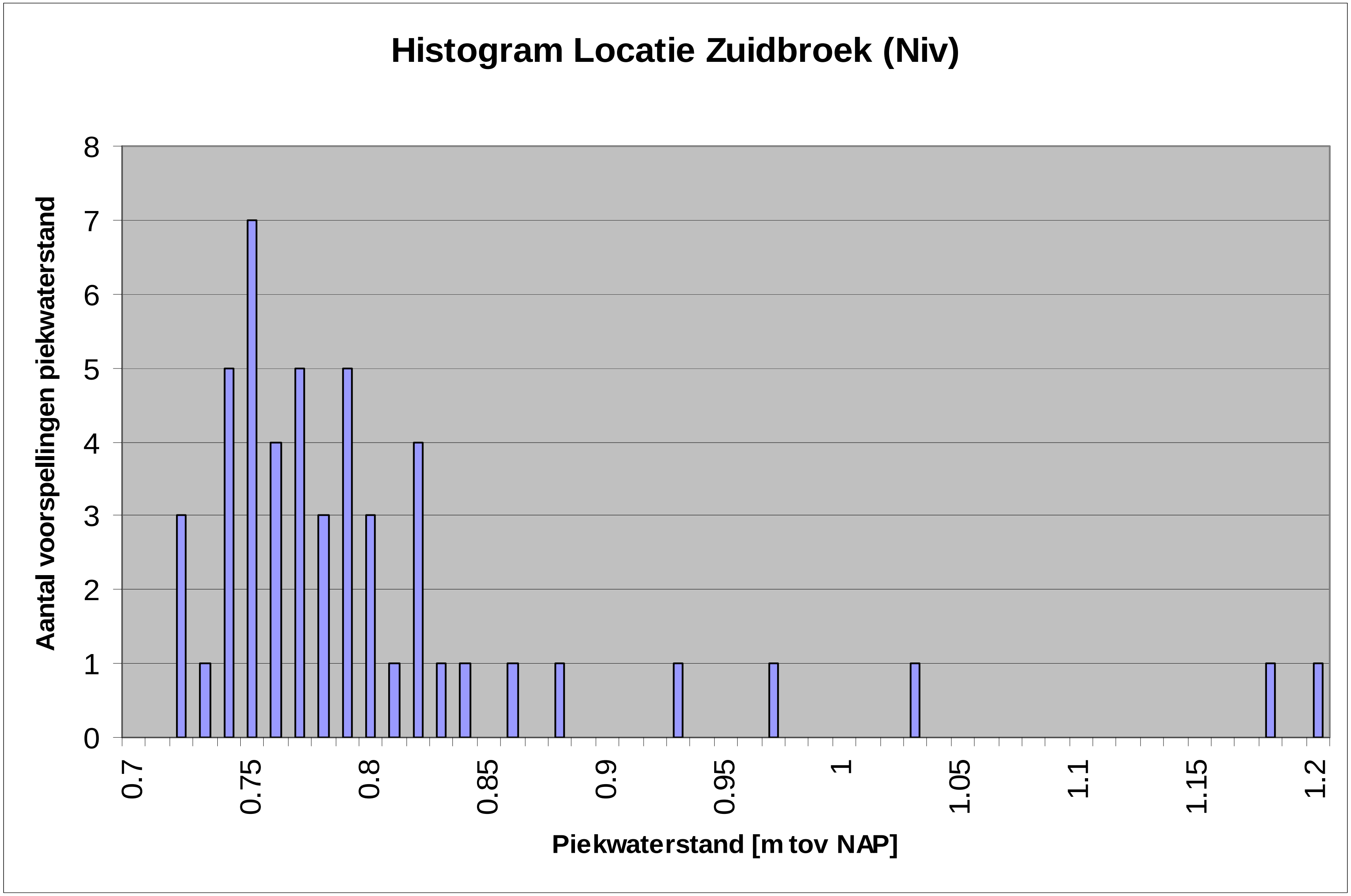
2. Het is erg onwaarschijnlijk er bij de locatie Zuidbroek (Niv) een waterstand op zal treden waarbij de waterstand hoger is dan 0.89 m.

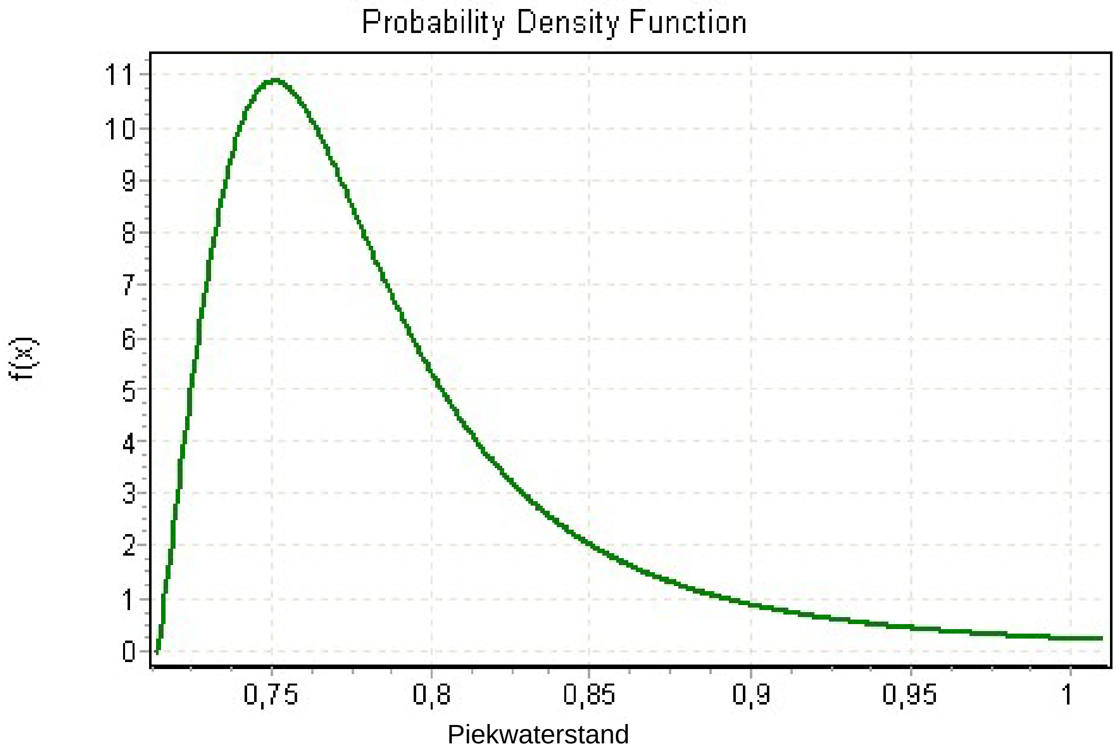
Gebruikte schaal

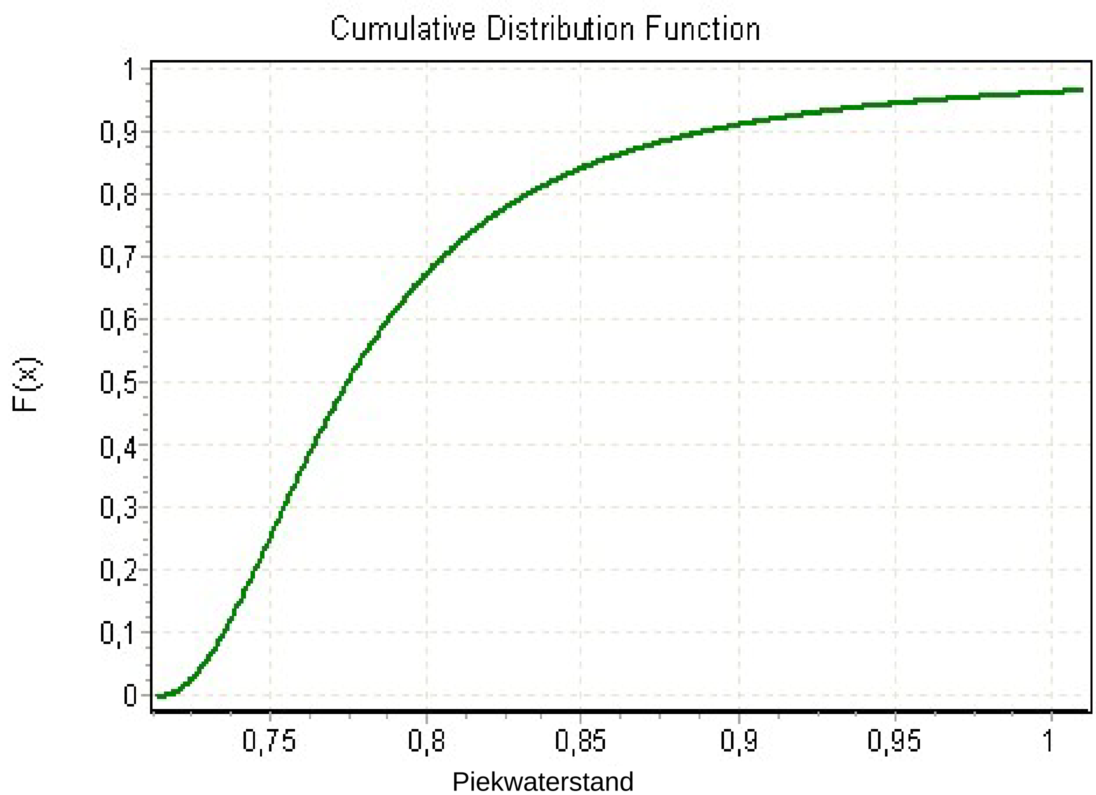
Term	**Kans**
Zeer onwaarschijnlijk	<1%
Erg onwaarschijnlijk	<10%
Onwaarschijnlijk	<33%
Niet onwaarschijnlijk, maar ook niet waarschijnlijk	33% tot 66%
Waarschijnlijk	>66%
Zeer waarschijnlijk	>90%
Vrijwel zeker	>99%

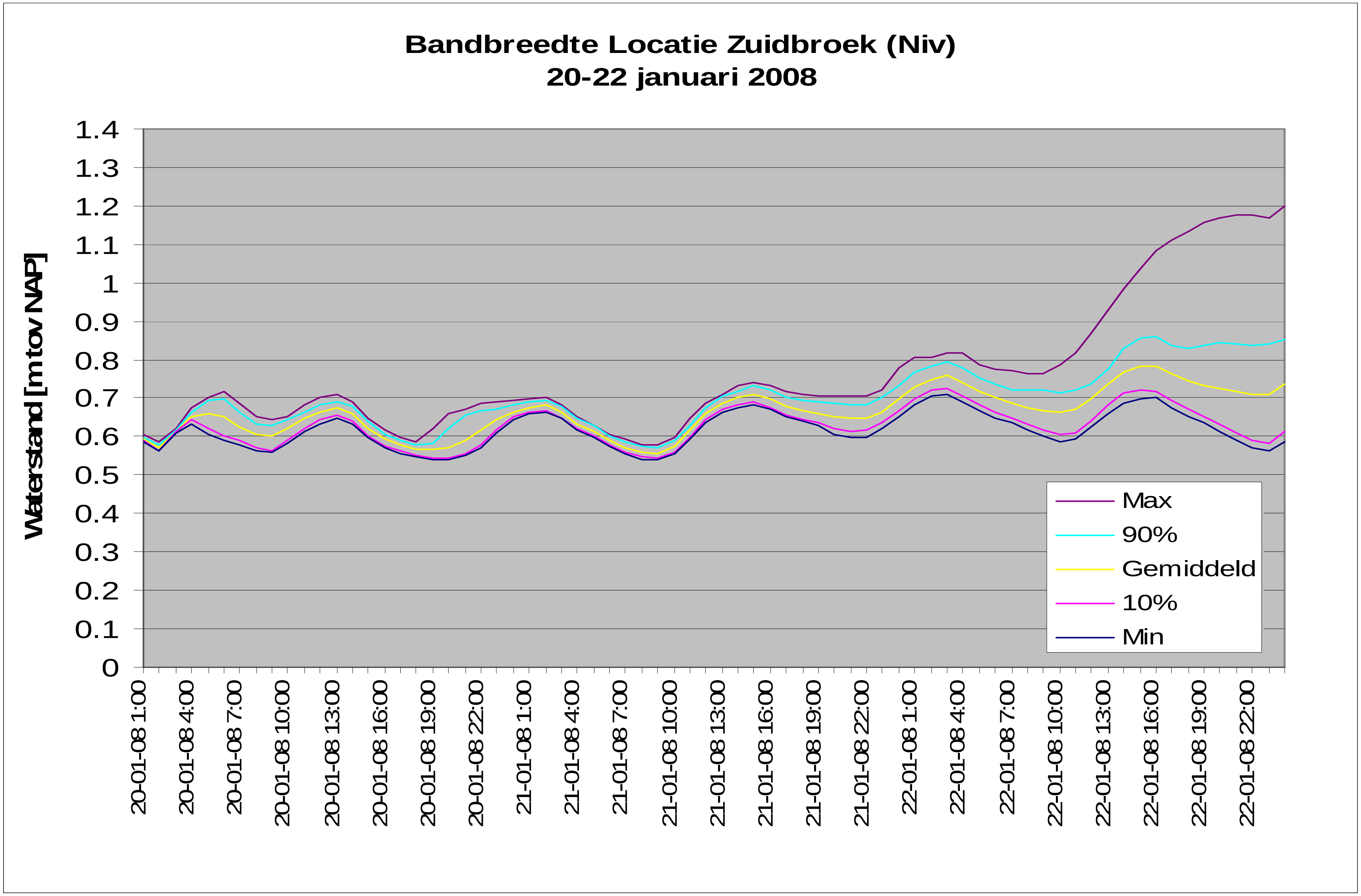
Steekproefgrootte	50
Steekproefmediaan	0.77
Steekproefkwartielen • Kleinste waarde • Grootste waarde	 0.75 0.81
Extremen • Laag • Hoog	 0.72 1.20

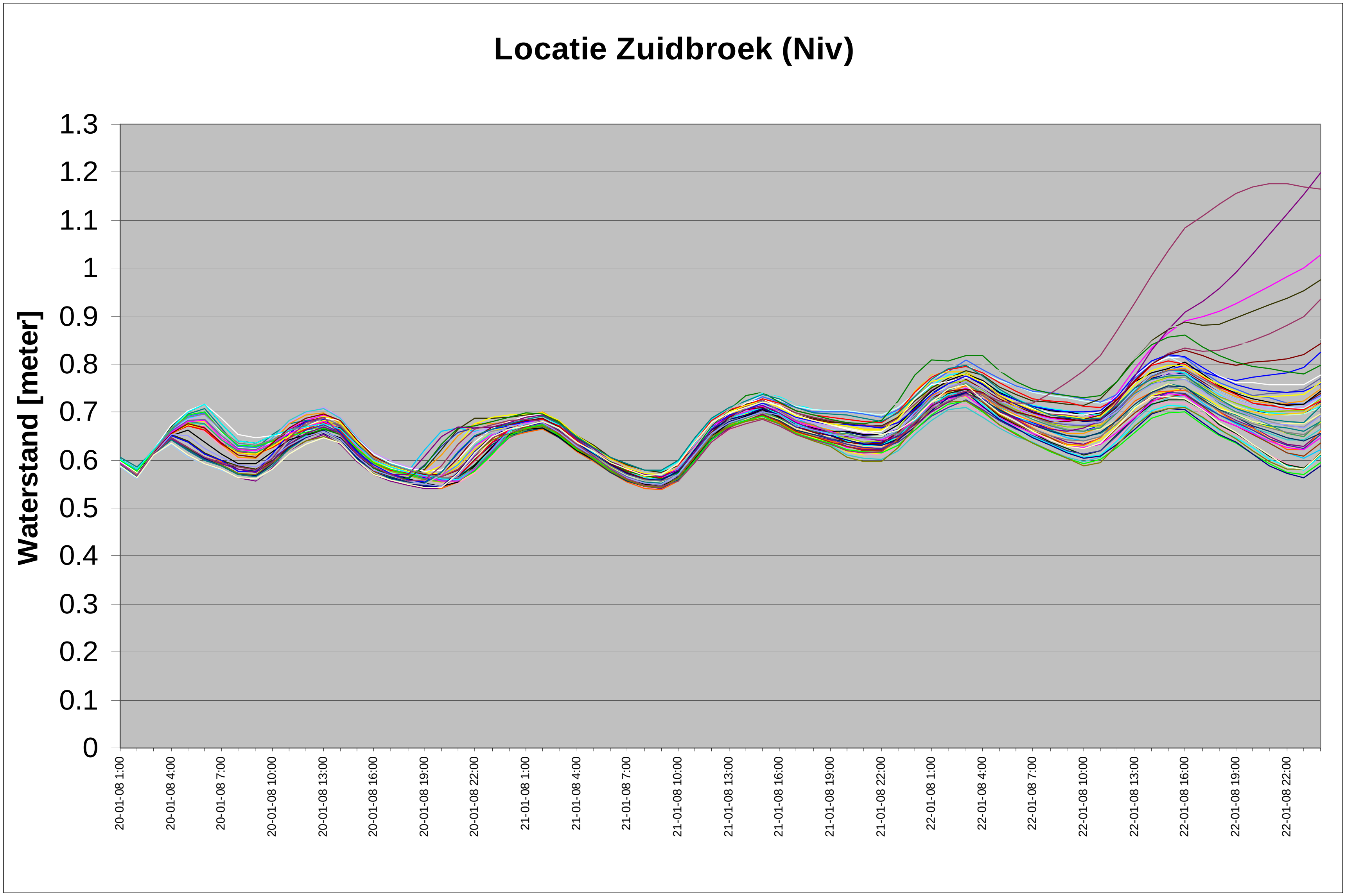

Boxplot Piekwaterstanden
Locatie Zuidbroek (Niv)
Waterstand [m tov NAP]
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
Maximaal; 1.2
75%; 0.81
50%; 0.77
25%; 0.75
Minimaal; 0.72


Histogram Locatie Zuidbroek (Niv)
Aantal voorspellingen piekwaterstand
0
1
2
3
4
5
6
7
8
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
Piekwaterstand [m tov NAP]


Probability Density Function
f(x)
11
10
9
8
7
6
5
4
3
2
1
0
0,75
0,8
0,85
0,9
0,95
1
Piekwaterstand


Cumulative Distribution Function
F(x)
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,75
0,8
0,85
0,9
0,95
1
Piekwaterstand


Bandbreedte Locatie Zuidbroek (Niv)
20-22 januari 2008
Waterstand [m tov NAP]
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20-01-08 1:00
20-01-08 4:00
20-01-08 7:00
20-01-08 10:00
20-01-08 13:00
20-01-08 16:00
20-01-08 19:00
20-01-08 22:00
21-01-08 1:00
21-01-08 4:00
21-01-08 7:00
21-01-08 10:00
21-01-08 13:00
21-01-08 16:00
21-01-08 19:00
21-01-08 22:00
22-01-08 1:00
22-01-08 4:00
22-01-08 7:00
22-01-08 10:00
22-01-08 13:00
22-01-08 16:00
22-01-08 19:00
22-01-08 22:00
Max
90%
Gemiddeld
10%
Min


Locatie Zuidbroek (Niv)
Waterstand [meter]
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20-01-08 1:00
20-01-08 4:00
20-01-08 7:00
20-01-08 10:00
20-01-08 13:00
20-01-08 16:00
20-01-08 19:00
20-01-08 22:00
21-01-08 1:00
21-01-08 4:00
21-01-08 7:00
21-01-08 10:00
21-01-08 13:00
21-01-08 16:00
21-01-08 19:00
21-01-08 22:00
22-01-08 1:00
22-01-08 4:00
22-01-08 7:00
22-01-08 10:00
22-01-08 13:00
22-01-08 16:00
22-01-08 19:00
22-01-08 22:00

Appendix B:

Interview questions ‘Presentation of uncertainty in model results’

The interview questions are presented in Dutch, because the interviews were performed in Dutch.

Interviewvragen "Presentatie van onzekerheden in modelresultaten"

INTRODUCTIE INTERVIEW

- Studente Civiele Techniek, Universiteit Twente
- Afstudeerstage Waterbeheer bij HydroLogic: onzekerheid in modellen
- Hiaat in de literatuur: er is nog relatief maar weinig bekend over hoe de gebruikers deze informatie zouden willen zien.
- Het doel van de interviews is het ontvouwen van de eisen die "decision makers" stellen aan onzekerheidsinformatie als het gaat om de presentatie van modelresultaten. Daarnaast is het de bedoeling meer inzicht te krijgen in de sterktes en zwaktes van verschillende presentatievormen en in welke context ze gebruikt kunnen worden.
- Een richtlijn opstellen voor de presentatie van onzekerheden.
- **Praktische informatie:**
  - Het interview duurt maximaal 1 uur
  - Toestemming vragen om het op te nemen op band.
  - Het is de bedoeling om de uitgewerkte interviewverslagen op te nemen in mijn eindrapport, indien u daar geen bezwaar tegen heeft. Voor citaten zal toestemming worden gevraagd.
  - Wanneer de gegeven informatie niet duidelijk is, moet je doorvragen!

DE VRAGEN:

<u>Besluitvormingsproces (huidige situatie)</u>

1. Ik heb begrepen dat u ……. bent. Kunt u mij misschien iets meer vertellen over wat uw rol is in het besluitvormingsproces bij het nemen van hoogwatermaatregelen?
   - ☐ Informatieverschaffende rol / Beslissende rol

2. Welk proces wordt er gevolgd in het nemen van maatregelen bij hoogwater?
   - ☐ Hoe wordt er met het draaiboek omgegaan?

3. Welke informatie krijgt u / verstrekt u nu wanneer er maatregelen genomen moeten worden?

4. Wordt er ook rekening gehouden met onzekerheid in de modelresultaten/ voorspelling?

5. Is onzekerheid belangrijk?

<u>Het kader voor de volgende presentatievormen</u>

- *Case Hoogwater Groningen: 22 januari 2008*
  - *Locatie Zuidbroek (Niv)*
  - *Uit de gevoeligheidsanalyse is gebleken dat verschillende weersvoorspellingen leiden tot verschillende waterstandsvoorspellingen.*
  - *BOS voorspelt 3 dagen: uitgangspunt. Daarom wordt er 3 dagen vooruit voorspeld met behulp van EPS gegevens.*
    - *Uitgangspunt / Aanname is dat het hele scala aan voorspellingen de hele range aan mogelijk optredende waterstanden omvat*
    - *Geïnteresseerd in de eerste voorspelling voor hoogwater.*
    - *Door een goede constatering van de onzekerheden & risico's, kunnen tijdig passende maatregelen worden genomen*

  - *De gebruikte drempelwaardes zijn **<u>fictief!</u>***
    - *Grenswaarden:*

Grenswaarde piekwaterstand	**Situatie**
< 0.60 m	Veilig
0.60-0.70 m	1e Alarmfase
0.70-0.80 m	2e Alarmfase
> 0.80 m	Serieuze dreiging hoogwater

<u>Informatie (gewenste situatie)</u>

6. Welke informatie is, ongeacht de inhoud en het format van de presentatie, voor u het meest van belang om uw besluit te kunnen nemen?
   - ☐ Zoals; Gemiddelde waterstand/Piekwaterstand/Maximale waterstand (hele golf/ tijdstip van optreden)/Anders: ……..
   - ☐ Waarom?

7. Is er naast deze informatie nog randinformatie die van belang kunnen zijn voor uw besluit?
   - ☐ Nee
   - ☐ Ja;
     i. De bronnen van onzekerheid die zijn meegenomen in de berekening
     ii. De onbenutte capaciteit van de kunstwerken, boezems en/of polders
     iii. Informatie over de mogelijke maatregelen
     iv. Overig: ……
   - ☐ Waarom?

8. Welke onzekerheid is maximaal acceptabel voor de maximale piekwaterstand?

Waterstandspieken

Eerst alle vormen op tafel leggen (algemene plaatjes zonder dat er zichtbare informatie wordt gegeven, dus met bijvoorbeeld xx als getal en geen cijfers langs de assen) → met als doel bepalen wat de voorkeur krijgt van de ondervraagden. Let op: dit wil niet zeggen dat ze ook daadwerkelijk goed gebruik maken van deze presentatievorm, maar spreekt wel het meeste aan!
(presentatievormen: doe dit op papier!, want via de PC wordt het erg onoverzichtelijk!)

- ☐ Heeft u voorkeur voor informatie in tekst, cijfers of grafieken?

*Nu aan de hand van de ontworpen presentatievormen (**zie bestand: Presentatievormen interview**).*

9. "Waardes van de piekwaterstanden"
10. "Kleur"
11. "Waarschijnlijkheids-schaal"
12. "EDA samenvatting"
13. "Box-plot"
14. "Histogram"
15. "PDF & CDF"

Vragen per vorm:

i. Is de gegeven informatie begrijpelijk?
ii. Is de gegeven informatie overzichtelijk?
iii. Is dit te weinig/voldoende/te veel informatie?
    - ☐ Aanpassingen: ………
iv. Is de gegeven informatie bruikbaar?
v. Is het duidelijk hoe groot de onzekerheid is?
vi. Heeft u genoeg informatie om een weloverwogen besluit te kunnen nemen?
    - ☐ Ja
    - ☐ Nee
    - ☐ Geen besluit mogelijk (meer informatie nodig)
        - ☐ Zijn er toevoegingen mogelijk zodat het wel aan uw eisen gaat voldoen? …………
        - ☐ Heeft dit consequenties voor uw beslissingen als deze informatie er wel bij zou staan? ………..

Als afsluiter nog een keer alle vormen laten zien, maar nu met de bedoeling dat ze deze rangschikken naar het gebruiksvriendelijkst.

Hoogwatergolf

*Nu aan de hand van de ontworpen presentatievormen (**zie bestand: Presentatievormen interview**).*

16. "Bandbreedte"
    - ☐ Verandert u na het zien van de 2[e] bandbreedte presentatie van mening over het nemen van maatregelen?
    - ☐ Bent u geïnteresseerd in de extremen of beschouwd u de kans dat ze optreden als zeer gering?
17. "Alle 50 voorspellingsreeksen in een grafiek"

Vragen per vorm:

- i. Is de gegeven informatie begrijpelijk?
- ii. Is de gegeven informatie overzichtelijk?
- iii. Is dit te weinig/voldoende/te veel informatie?
  - ☐ Aanpassingen: ………
- iv. Is de gegeven informatie bruikbaar?
- v. Is het duidelijk hoe groot de onzekerheid is?
- vi. Heeft u genoeg informatie om een weloverwogen besluit te kunnen nemen?
  - ☐ Ja
  - ☐ Nee
  - ☐ Geen besluit mogelijk (meer informatie nodig)
    - ☐ Zijn er toevoegingen mogelijk zodat het wel aan uw eisen gaat voldoen? …………
    - ☐ Heeft dit consequenties voor uw beslissingen als deze informatie er wel bij zou staan? ………..

Als afsluiter nog een keer alle vormen laten zien, maar nu met de bedoeling dat ze rangschikken naar het gebruikvriendelijkst/prettigst in gebruik. → Waar vallen nu deze laatste twee vormen in?

AFSLUITING

- Indien je voldoende informatie hebt verzameld over een onderwerp, stel je voor het interview op dit punt af te ronden.
  - o Samenvatten van de belangrijkste punten
  - o En zeg dat je feedback geeft & vraagt over dit interview
  - o Citaten worden gecheckt!
  - o Vragen of ze het fijn vinden om een eindrapport te ontvangen

Appendix C: Comments on the presentation forms

Appendix C shows the comments of the decision makers on the presentation forms mentioned in the interviews. These comments are divided into strong and weak points. The presentation forms are presented in the next order:

Note

An explanation for the relatively large amount of weak points is the fact that the presentation forms contained a inconsistent amount of information, which lead to much weak points. Table 5.7 shows that all the presentation forms contained too little or just too much information. Only in a single case the decision maker believes that the presentation form contains enough information.

1. 'Values'

Table C1 summarizes the strong and weak points of the presentation 'Values' mentioned during the interviews.

Table C1. Strong and weak points of 'Values'

'Values'	**Strong**	**Weak**
Comprehensibility	*** Minimal required info is presented.**	**-**
Surveyability	*** Brief and concise.**	**-**
Amount of information	*** The information given is very valuable.** *** Minimal required info is presented.**	*** Too little information.** *** An explanation about the seriousness of the situation is missing.** *** Critical values lack in the presentation.** *** Development in time lacks.**
Clearness of uncertainty	**-**	*** The uncertainty is very large; more information is needed about the cause of the uncertainty.** *** What is shown: 95%-interval or also the extremes?**
Decision possible	**-**	*** More explanation needed: why is the uncertainty so large.**
Usable	**-**	*** Critical values lack in the presentation.** *** The uncertainty is very large; more information is needed about the cause of the uncertainty.** *** Development in time lacks.**

Although the presentation is comprehensive and clarifying, the decision makers conclude that it is not clear how large the uncertainty is. In fact the three water levels shown in the presentation form are the minimal required information for a decision maker, in combination with the critical values, to reach to a decision. The representation of the minimal predicted water level is not that important, but has to be mentioned for the completeness. So the information is valuable and presented in a brief and concise manner, which is appreciated by the decision makers.

However this presentation form contains too little information. The uncertainty is very large and the decision makers want to know where it is coming from. Besides that, the decision makers want to know if the minimal-maximal range also represents the extremes or if it is the 95%-interval. Decision makers do not want to base their decisions on extreme predictions and prefer a situation without extremes. They would like to get an explanation from experts, about the cause of the large uncertainty range. And to determine the seriousness of the situation, they want to know If the extremes are taken along in the presentation. This explanation could be written down or told by an expert, but this information is necessary for decision making, otherwise it leads to wrong conclusions. Now there is no explanation, so the decision makers have to take into account a 1.20 m scenario.

The development of the predicted water levels in time is needed, including the weather predictions. Also the critical values have to be presented in the presentation form to make it more orderly. All this information clarifies the seriousness of the predicted situation.

2. 'Color'

Table C2 summarizes the strong and weak points of the presentation 'Color' mentioned during the interviews.

Table C2. Strong and weak points of 'Color'

' Color'	**Strong**	**Weak**
Comprehensibility	*** The critical test is already made by the colors.**	*** The colors do not give an explanation. * The color red is be seen as a problem, but that is not necessarily true. * The exact values get pushed aside. * The measure can not be derived from the presentation form.**
Surveyability	*** Colors deliver the seriousness of the situation.**	*** Colors cause a restless feeling.**
Amount of information	*** The critical test is already made by the colors.**	*** The absolute numbers are missing. * The measures that have to be taken are not clear, due to the missing absolute numbers. * An explanation of the seriousness of the situation lacks. * What is the water level at other locations? * 10 cm range for a color is too large. * History of the water level is missing. * Development in time lacks.**

Clearness of uncertainty	**-**	*** The range of especially the color red is too large. Is the exact value 0,81 m or 0,95 m? That is a significant difference, but the color makes no distinction.**
Decision possible	**-**	*** Danger is that the decisions are taken on basis of the color red, instead of exceeding the critical level.**
Usable	*** Ideal for communication, because the meaning of the water levels is also told.** *** Observation function**	*** Too little information.** *** It suggest something you do not want; the seriousness of the situation has to be explained by an expert instead of leaving that conclusion to the decision makers themselves.**

Although the presentation is comprehensive and clarifying for the most decision makers, they conclude that it is not clear how large the uncertainty is. However the colors give an indication of the seriousness of the situation, it is absolutely not clear how large the uncertainty is for the maximum predicted water level. It is known that it is higher than 0.80 m^+ NAP, but what is the exact value? For example it is a real difference if the maximum predicted water level is 0.81 m or if it is 0.95 m^+ NAP. Due to the linking of a calamity phase to a color, the difference in absolute value gets to the background. The most decision makers describe this as a lack of information. However, one decision maker defines the use of colors as too much information. Reason for that is that the absolute values are already translated to the seriousness of the situation. He is convinced that this is an undesirable situation, because the translation to the seriousness of the situation should not be done by lay people. An expert has to translate the uncertainty information into a message, because the color red could be misinterpreted easily. A 0.81 m^+ NAP water level situation needs other measures than a predicted water level of 0.95 m^+ NAP. So the color red does not mean that specific measures have to be taken, this differs to the seriousness of the situation. This has more phases than the legend shows.

The decision makers mention some points of improvement. The range of 10 cm for a color is too much, so they have to be made smaller and the color red should be divided into more phases according to the different measures. This presentation form of colors could be added to a map of the Water Board Hunze & Aa's, to get a presentation form like a clickable map. Then it is possible to see where problems would occur.

3. 'Linguistics'

Table C3 summarizes the strong and weak points of the presentation 'Linguistics' mentioned during the interviews.

Table C3. Strong and weak points of 'Linguistics'

'Linguistics'	Strong	Weak
Comprehensibility	**-**	*** Too hard to understand. * When do you have to evacuate? At 50% uncertainty or what?**
Surveyability	-	*** Takes too long to understand. This time is not available in a crisis situation. * This is too extended. * Too laborious.**
Amount of information	*** The percentage shows how large the uncertainty is.**	*** By adding the probabilities, people tend to get too much information. * Displaying probabilities does not contribute to the information . * Critical levels are missing * Only information about the water levels is given, this causes a distortion of the probability. * It raises too much questions. * Range of the uncertainty is unclear. * Development in time lacks.**
Clearness of uncertainty	**-**	*** Probability says something about the chance of appearance, but it is not sufficient.**

Decision possible	**-**	*** Critical values lack.** *** When does the peak occur?** *** An explanation about the uncertainty is required.**
Usable	*** Probability is available**	*** Too much text.** *** No clarity.** *** Raises too much questions.** *** Percentage creates a certainty that is not there, because of the restricted amount of sources observed.**

Although the comprehensibility and uncertainty are clear, the surveyability could be better. There is too much text and there is no clarity. It takes too much time from the reader to understand this, because the presentation form is too extended and laborious. However, time is not available in crisis situations.

Some decision makers state that the percentages show how large the uncertainty is and the percentages should be put in the text directly, without the fixed scale. Other decision makers state that adding the percentages give a false certainty, because the restricted amount of sources observed. The presentation only gives certainty about the water level, but not about all the other matters like the conditions of the dikes. Therefore the absolute values of the water levels have to be communicated, instead of the percentages.

The critical levels are missing, so it is not clear when the peak will occur. Thereby an explanation is required about the uncertainty and which measures should be necessary.

4. 'Statistics'

Table C4 summarizes the strong and weak points of the presentation 'Statistics' mentioned during the interviews.

Table C4. Strong and weak points of 'Statistics'

' Statistics'	Strong	Weak
Comprehensibility	**-**	*** Terms are unknown, too statistical or academical. * Too difficult. * More explanation required.**
Surveyability	**-**	**-**
Amount of information	*** Suit the needs of hydrologist.**	*** Too much information for the WBT. *Too much information for decision makers: leave the extremes out the presentation, because they make it more difficult. * Critical values are missing. * Worst case scenario (90%) is missing. * Development in time lacks.**
Clearness of uncertainty	**-**	*** There is the chance that people concentrate too much on the extremes. * Range of uncertainty is too large.**
Decision possible	**-**	*** Critical value is missing. * Too little information.**
Usable	**-**	*** It is more suitable for scientists than for decision makers. * Too much explanation needed * Too hard to understand.**

Although 6 decision makers appreciated the surveyability of the ‘statistical’ presentation positively, the decision makers agree that this presentation form is not suitable for communication towards decision makers. The statistical terms are too hard to understand and an explanation about the statistical terms is necessary. The presentation form might be suitable for hydrologists and the water level managers, but not for decision makers.

Besides that, it contains too much detail information for the decision makers in the WBT. For example: the extremes and the sample size should be left out. The focus on extremes can cause confusion. It is better to focus on a worst case scenario (for example 90%).

On the other hand the critical values and the development in time are missing. The decision makers also would like more information about the uncertainty sources that are taken along. And the range of the uncertainty also needs some explanation, because the uncertainty is almost 0.50 m.

5. 'Box plot'

Table C5 summarizes the strong and weak points of the presentation 'Box plot' mentioned during the interviews.

Table C5. Strong and weak points of 'Box plot'

'Box plot'	**Strong**	**Weak**
Comprehensibility	**-**	*** Too statistical.** *** The manner of presenting the information is too difficult.**
Surveyability	*** Minimal, most appropriate and maximal are present.** *** The range is present.** *** All the relevant information is shown in one glance.**	*** Difficult to read.** *** Too much information in percentage.** *** Too complex.**
Amount of information	*** Appropriate for hydrologists.**	*** Critical values are missing.** *** Percentages disturb.** *** Too much detail information for the decision makers.** *** Why is the range 75-100% so large?** *** Too complex.** *** Development in time lacks.**
Clearness of uncertainty		*** Why is the range 75-100% so large?** *** More information about the risks is needed.**
Decision possible		*** More information is needed about the range 75-100%.** *** Critical values are missing.** *** Development in time lacks.**
Usable	*** Minimal, most appropriate and maximal are present.**	*** Too complex.** *** Development in time** lacks**.**

A strong point of this form is that the most relevant information is shown in a glance. A clear presentation of the range; minimal, most appropriate and maximal predicted water level is provided. This is the opinion of 6 of the decision makers, although the other 4 did not agree. These decision makers did not understand the presentation form, because of the manner of presenting the information; too statistical and difficult to read.

The box plot scores low on usability, and it is hard to make a decision on basis of this presentation. Only three people believe that it is possible to make a decision. The rest of the decision makers need more information about the upper range, because the range is so large. Furthermore, the critical levels and a development of the uncertainty in time are missing. So the decision makers can not determine how worse the predicted situation is.

The percentages could be left out the presentation, because they disturb by giving a false certainty. This presentation gives too much detail information, by presenting all those percentages. Water level is just one of the factors, which is important in high water management. High water management also dependents on, for example, the strength of the dike and the weather predictions. Therefore it is necessary to leave the translation of a specific water level into a calamity phase up to an expert.

Suggestion for the uncertainty range is that other percentages could be used. In stead of 25%-75%, it is better to use 10%-90% to receive a better image of the extremes.

6. 'Histogram'

Table C6 summarizes the strong and weak points of the presentation 'Histogram' mentioned during the interviews.

Table C6. Strong and weak points 'Histogram'

' Histogram'	Strong	Weak
Comprehensibility	**-**	*** Too difficult for decision makers. * Too statistical. * Too much self interpretation. * The most appropriate water level is not shown.**
Surveyability	**-**	*** Too difficult. * Too statistical. * Too much self interpretation. * The peak water level is not shown. * Too much irrelevant info. * In thoughts already translated to a PDF. * Most appropriate water level is not clear in a glance.**
Amount of information	**-**	*** Critical values are missing. * The wrong information. * Too much detail information. * Too complex. * Uncertainty too large. * Development in time lacks.**
Clearness of uncertainty	*** Gives the probability. * The extremes are provided.**	*** The upper range is too large. * Too much irrelevant information. * Why do the extremes occur? * Are the extremes correct? * An explanation is needed; what are the risks?**

Decision possible	*** It is a good basis.**	*** Why the extremes?** *** Critical values are missing.** *** Development in time lacks.**
Usable	*** More for a scientist.**	*** Too much space for own interpretations, but the experts have to explain it.** *** Not suitable for decision makers**

This presentation form is not appropriate for communication to a crisis team. The information should be obvious and this presentation is not. It is too difficult and statistical. The decision maker has to interpret a lot themselves, because the most appropriate value is not clear at once. This leaves a lot of space for the decision makers to give the water level their own interpretation.

The presentation offers too much detail information and also the wrong information. The representation of the percentages is for some decision makers an advantage, while others believe that it is worse.

This presentation form is too statistical. Although the extremes are more visible, the range of uncertainty is too large. Especially the range of 0.85 m till 1.20 m needs an explanation, certainly the extremes at the 1.20 m. Why do they occur and what are the accompanying risks?

Furthermore, the critical levels and a development of the uncertainty in time are missing. So the decision makers can not determine how worse the predicted situation is.

Some decision makers translated the histogram into a PDF, because they have a more visual attitude and plotted a line into the presentation form.

7. 'PDF & CDF'

Table C7 summarizes the strong and weak points of the presentation 'PDF & CDF' mentioned during the interviews.

Table C7. Strong and weak points of 'PDF & CDF'

' PDF & CDF'	**Strong**	**Weak**
Comprehensibility	**-**	*** Too complicated.** *** Too much statistics.**
Surveyability	**-**	*** Too much interpretation time needed.** *** Too complicated.** *** More explanation needed.** *** The wrong information.**
Amount of information	**-**	*** Why the extremes?** *** Critical values are missing.** *** Development in time lacks.**
Clearness of uncertainty	*** It is clear where the development takes place.** *** More information about the peak values.**	*** Too much detail information.** *** Too academic.** *** Not relevant → uncertainty EPS prediction instead of water levels.**
Decision possible	**-**	*** Too academic.** *** The wrong information.** *** Development in time lacks.**
Usable	*** Background information for hydrologists.**	*** Too much detail information.** *** Too academic.**

The 'PDF & CDF' presentation form is too statistical, which means that the decision makers need too much time to translate the information into usable information. The decision makers are under time pressure, so the presentation form is not suitable for communication to decision makers. It contains too much detail information for a decision maker.

Furthermore, the critical levels and a development of the uncertainty in time are missing. So the decision makers can not determine how worse the predicted situation is.

8. 'Bandwiths'

Table C8 summarizes the strong and weak points of the presentation 'Bandwidths' mentioned during the interviews.

Table C8. Strong and weak points of 'Bandwidths'

' Bandwidths'	**Strong**	**Weak**
Comprehensibility	*** Legend is clear. * Easy and clear for the relevant values. * Most appropriate value is clearly present.**	*** An explanation for 90% is missing.**
Surveyability	*** Clear.**	*** Too much lines (show only low, medium and high).**
Amount of information	*** Development of time.**	*** Critical values are missing. * History water levels last two days. * Highest 10 % cause panic. * Leave the extremes out. * More information needed about the total picture of the situation.**
Clearness of uncertainty	**-**	*** What is the difference between 90% and max? What is the risk?**
Decision possible	**-**	*** Critical values are missing.**
Usable	*** Legend is clear.**	*** Highest 10 % cause panic, so do not show because they are extremes.**

The critical values are lacking; the critical values should be represented in the presentation itself, so that it becomes clear in one glance if the predicted water levels could cause problems or not.

The legend is clear, but a little explanation is needed for the percentages. What do they represent? The extremes or the upper 10 percentage should not be represented, because they cause unnecessary panic. Eventually the extremes could be presented as points.

The crisis team needs some good, exact and simple information. This presentation form is a good example of that. Furthermore it is advisable to enclose the measurements of the last two days. And the amount of line may be reduced till three. Use therefore the next distribution:

- Minimal water level / most appropriate minimal water level
- Median / most appropriate water level
- Maximum water level / most appropriate maximum water level

An explanation has to be given by an expert; what are the risks and so ever. Because there is more information needed for the total image of the situation. But for water levels, this is enough.

9. 'Whole prediction'

Table C9 summarizes the strong and weak points of the presentation 'Whole prediction' mentioned during the interviews.

Table C9 Strong and weak points of 'Whole prediction'

' Whole prediction'	**Strong**	**Weak**
Comprehensibility	**-**	*** Too much lines.**
Surveyability	**-**	*** Too much lines.** *** Illegible.** *** Chaos.**
Amount of information	*** Development of time.**	*** Too much information.** *** Too much self interpretation has to be done.** *** Critical values are missing.**
Clearness of uncertainty	*** Clear.**	*** Not clear.**
Decision possible	**-**	*** Critical values are missing.** *** Too much lines.**
Usable	*** The decision makers can get an image of the range of uncertainty.**	*** Too much self interpretation has to be done.** *** Too much lines.**

The critical test is lacking; the critical values should be represented in the presentation itself, so that it becomes clear in one glance if the predicted water levels could cause problems or not.

The decision makers concluded that this presentation is not suitable for communication. It contains too many lines for a quick conclusion. It gives a good image of the uncertainty range, but the decision maker has to spend a lot of time to understand which information is included in the presentation. The uncertainty is not clear yet.

A possible solution is to thicken the operational line. Then it is clearer what is predicted.