Integration of Uncertainty into Emergency Procedures of Water Boards

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ABSTRACT

In the Netherlands, Royal Dutch Meteorological Institute warns water boards for extreme rainfall if per-specified thresholds are (expected to be) exceeded. When a water board receives a warning, certain response measures can be taken. In general, the thresholds are based on experience and intuition. Clear procedures, which describe decision-making under uncertainty in available information (e.g., forecasted rainfall), do not exist.

In this document, first results of the project "Extreme weather for water boards" are briefly described. The aim of this project is to study integration of the uncertainty into emergency procedures of the water boards. The current emergency procedures of two water boards are analyzed. Recommended adjustments to the procedures allow including the uncertainty by estimation of a probability of overload and cost-benefit analysis of response measures (benefit as avoided damage). A simple scheme that supports estimation of the probability is introduced.

Keywords

Uncertainty, emergency procedures, extreme rainfall, forecasts.

INTRODUCTION

The Netherlands is a country located on the delta of three rivers: the Rhine, the Meuse and the Scheldt. As a consequence of natural conditions and human interference over the past millennium, more than 50% of the country is potentially threatened by floods from the rivers or/and the sea (Voortman, 2003). The area has a long history of floods and works to control the water. Nowadays, with the population density of approximately 400/km^2 and the GPD of some $ 47,000 per capita, the Dutch land is protected by nearly 3,700 km of primary and 14,000 km of secondary or other water defences (Pilarczyk, 2007).

26 water boards are distinguished within the country (state on the 1st of January 2011). Water boards are local government organizations that are responsible for flood control, water quantity, water quality and treatment of urban wastewater in their respective regions. The water boards constitute one of the oldest forms of local government in the Netherlands; some of the water boards were founded in the 13th century (Lazaroms and Poos, 2004).

In August 2010, extreme rainfall caused material damage in the regions managed by Regge and Dinkel Water Board and Rhine and IJssel Water Board. Locally, 138 mm/m^2 of rainfall was measured within 24 hours and this was the highest observed rainfall amount since 1998, in the Netherlands. Royal Dutch Meteorological Institute[1] (KNMI) warns water boards of extreme rainfall if per-defined thresholds are (expected to be) exceeded (Kok *et al.*, 2011). The thresholds are described by the so-called rainfall risk profiles, which consist of several rainfall events and which differ per water board (within a water board differences with respect to season and forecast length are usually maintained). The rainfall events are, for example, "total rainfall in the period of the last 24 hours and the next 24 hours exceeds 40 mm", "rainfall within the next 24 hours exceeds 25 mm" or "rainfall within the next 4 days exceed 80 mm with probability 30%". To verify whether one or more of the rainfall events occur, the KNMI uses historical rainfall (up to 5 days back), forecasts produced by radar-forecast (up to 2 hours ahead), deterministic model HIRLAM[2] (from 2 to 36 hours ahead) and ECMWF EPS[3] (more than 36

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[1] KNMI is the national weather institute for weather, climate research and seismology. It disseminates weather information to the public at large, the government, the aviation and the shipping industry in the interest of safety, the economy and a sustainable environment (source: the KNMI website).

[2] HIRLAM – High Resolution Limited Area Model.

hours ahead). The latter is used to derive probability forecasts for rainfall (de Vries, 2009; Kok *et al*., 2011). When a water board receives a warning from the KNMI, certain response measures can be taken. Differences in the rainfall risk profiles, which are motivated by sensitivity of different areas on weather conditions, led that in August 2010, the Regge and Dinkel Water Board, which has a very complex rainfall risk profile, received dozens of warnings from the KNMI, whereas the Rhine and IJssel Water Board, which has a simpler profile, did not receive any official warnings.

In the rainfall risk profiles, uncertainty in available information is sometimes taken into account by means of, e.g., probability forecasts for rainfall. The profiles are, however, based on experience and intuition, and clear procedures, which describe decision-making under uncertainty, are still missing. In this document, preliminary results of the project “Extreme weather for water boards” are presented (van Ruiten *et al.*, 2011). The project is part of Flood Control 2015 innovation program that is being carried out in the Netherlands. The aim of the project is to study integration of the uncertainty into emergency procedures of the water boards. In the project, procedures, which define receiving, interpretation and response to the warnings from the KNMI, are analysed using Regge and Dinkel and Rhine and IJssel Water Boards as examples. Recommended adjustments to the procedures allow including (1) the uncertainty by estimation of a probability of overload and (2) cost-benefit analysis of response measures.

CASE STUDY WATER BOARDS

The project team organized and supervised meetings between employees of the KNMI and employees of the two water boards, who are familiar with the emergency procedures. Aims of the meetings were to clarify the procedures, to determine weak points of the procedures and to investigate possibilities for including the uncertainty in the procedures of the water boards. During the meetings, the employees of the KNMI explained an intern procedure leading to disseminating of weather alarms in the Netherlands. According to this procedure, probability of extreme weather is assumed equal to the average of probabilities (independently) estimated by three or four experts. The employees also described data that are used to assess whether one or more of the rainfall events occur. The data include probability forecasts for rainfall. Furthermore, the meetings have shown that both water boards share many features:

- The used rainfall risk profiles are based on experience and intuition, and the expected annual frequency of warnings is one of the criteria used to formulate the profiles. In the winter, when extreme rainfall is relatively easy to forecast, the profiles work well as early-warning means; intensive storms in the summer are difficult to predict hampering early-warnings;
- Rainfall in German provinces North Rhine Westphalia and Lower Saxony influences (ground) water levels in the areas managed by both water boards; observations and forecasts of rainfall in these provinces are not included in the procedures;
- Few employees of the water boards know the existing procedures on receiving and interpretation of the warnings; the warnings are received via an alert e-mail; one employee receives the warnings and judges whether the situation can be potentially dangerous for the managed region. Possible absence of the employee (e.g., night, holiday, disease) is not included in the procedures;
- When considering response measures (e.g., starting and management of a stand-by team, control inundation of an agricultural area), a present state of the managed area is taken into account. At the moment a warning has been received, the state of the threatened area is described by, e.g., a groundwater level and concentration of vegetation. No clear procedures exist on including of the state into the decision-making.
- Both water boards would like to receive information on uncertainty related to data provided by the KNMI and to establish clear procedures, in which the uncertainty is included. Such procedures can afterwards justify taken actions. None of the water boards considers a cost-benefit analysis as a plausible approach to choose an action; this is motivated by difficulties in expressing costs and benefits (i.e., avoided damage) of the measures in terms of money. Cost-benefit analyses can be used to argue and substantiate decisions and to compare different actions objectively. Such approach is commonly used in the Dutch water safety policy (Kind *et al.*, 2008).

As a consequence of the meetings, the two water boards have developed proposals of adjustments to the current receive-interpret-response procedures. In the case of Rhine and IJssel Water Board, the adjustments amount to involvement of three employees (a hydrologist, an expert on water management and an expert on maintenance) in interpretation of the warnings. In the new procedure, uncertainty is not taken into account explicitly. In the

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[3] ECMWF – European Centre for Medium-Range Weather Forecasts, EPS – Ensemble Prediction System.

case of Regge and Dinkel Water Board, the adjustments concern the receive and response procedures, and consist of: (1) the KNMI disseminates warnings via the Internet and/or telephone (several employees receive alert e-mails and/or a alarm service worker, who is available 24/7, receives warnings via telephone) and (2) a decision to scale up to the next coordination phase is made on the basis of emerging risks, which are estimated by the process manager using available information. The water board does not indicate clearly how the risks are derived and how the risks are used in the decision-making. The water board has also proposed a modification of the daily water management that realizes an idea of "from reactive to proactive". Namely, the water board would like to organize weekly meetings, during which qualitative and quantitative descriptions of current and future (water) situation in the area are made, and shared within the organization.

RECOMMENDED ADJUSTMENTS

The project team has recommended several adjustments to the current receive-interpret-response procedures of the water boards under constrains of relative consistency with the procedures and explicit inclusion of uncertainty in available information (e.g., forecasted rainfall). The new procedure, which holds for both water boards, is shown in Figure 1.

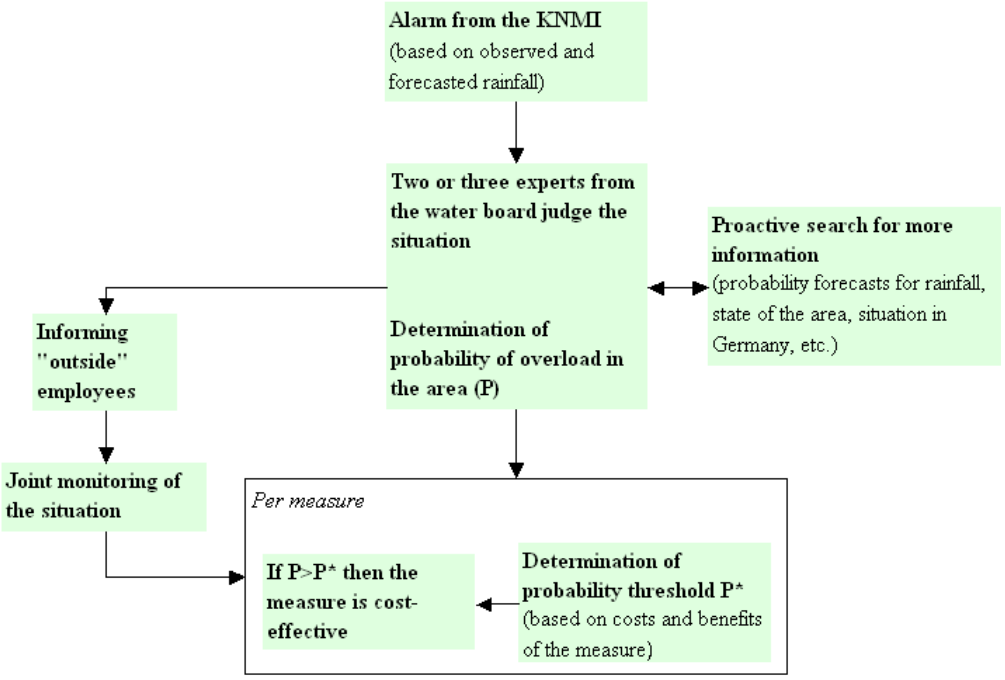

Figure 1. New receive-interpret-response procedure proposed by the project team.

The procedure starts with receiving a warning message from the KNMI via the agreed communication channel (e-mail, telephone, etc). The warning can be based on observed and forecasted rainfall in the area. Two or three experts from the water board judge severity of the warning taking into account, e.g., probability forecasts for rainfall, current state of the area and present and future situation in Germany (i.e., a proactive search for more information). Probability of overload P, which depends on the aforementioned factors, constitutes a direct result of this judgement. This probability is derived using uncertainty in available information and it is compared with a probability threshold P*, which depends on a considered response measure and which is defined as a ratio of costs to benefits (i.e., avoided damage) of the measure (both expressed in terms of money) also referred to as "the cost-loss ratio". When the probability of overload (P) exceeds (>) the cost-loss ratio (P*) then the measure is cost-effective and should be applied from a rational point of view (Murphy, 1977). Simultaneously, according to this procedure, informing of "outside" employees and joint monitoring of the situation take place.

Example: "the towing away of cars from the quays in the Dutch city Dordrecht in the face of flooding". The cost of removing one car (towing and storage) is € 200. The expected loss in case of flooding (average loss per car) is € 5,000. The cost-loss ratio is 0.04 (i.e., 200/5000) and it suggests that the quays should be cleared as soon as the flooding probability exceeds 4%.

The project team has proposed a scheme to estimate the probability of overload (P). The scheme is explained here using an example, in which three possible rainfall scenarios are considered (Table 1). The scenarios can be produced by the KNMI. Furthermore, it is assumed that the probability of overload is related to a score for overload as given in Table 2. Estimation of the score for overload is presented in the following paragraphs.

Rainfall scenario (rainfall within the next 24 hours)	Probability of scenario
A (10-20 mm)	$P_A = 25\%$
B (20-30 mm)	$P_B = 60\%$
C (30-40 mm)	$P_C = 15\%$

Table 1. Exemplary rainfall scenarios.

Score for overload ($S_{overload}$)	Probability of overload (P)
$1.0 < S_{overload} < 1.5$	$0 < P < 25\%$
$1.5 < S_{overload} < 2.0$	$25\% < P < 50\%$
$2.0 < S_{overload} < 2.5$	$50\% < P < 75\%$
$2.5 < S_{overload} < 3.0$	$75\% < P < 100\%$

Table 2. Exemplary relation between the score for overload and the probability of overload.

State of the area is described by a groundwater level and vegetation. Each of these factors receives score S (equal to 1, 2 or 3) depending on condition of the factor (1 = favorable, 2 = in-between, 3 = adverse). In this example, $S_{groundwater} = 3$ and $S_{vegetation} = 1$. The factors also receive weights W. Here, $W_{groudwater} = 0.65$ and $W_{vegetation} = 0.35$. The weighted sum of these scores constitutes the score for the state of the area 2.3 ($S_{area} = W_{groudwater} \cdot S_{groundwater} + W_{vegetation} \cdot S_{vegetation}$).

This score is combined with the rainfall scenarios yielding three conditional scores for overload (Table 3). Given rainfall scenario A and $S_{area} = 2.3$, the conditional score for overload is 1 (safe). Given scenario B and $S_{area} = 2.3$, the conditional score for overload is 2 (normal); whereas given scenario C and $S_{area} = 2.3$, the conditional score for overload is 3 (dangerous). Combining the conditional scores for overload with the probabilities of the scenarios entails the score for overload 1.9 ($S_{overload} = 1 \cdot P_A + 2 \cdot P_B + 3 \cdot P_C$). Then, from Table 2 follows that the probability of overload P is between 25% and 50%.

		$1 < S_{area} < 2$	$2 < S_{area} < 3$
Rainfall scenario	A	1 (safe)	1 (safe)
	B	1 (safe)	2 (normal)
	C	2 (normal)	3 (dangerous)

Table 3. Exemplary conditional scores for overload.

CONCLUSIONS

The adjustments, proposed by the project team, require some specifications in a future research:

- It is not clear whether the rainfall risk profiles should be used to initiate the new receive-interpret-response procedure; the extreme rainfall in August 2011 has shown that reliability of the profiles differ per water board. The profiles could be improved by experts from the KNMI and the water boards;
- Definition of the probability of overload needs to be more concrete (e.g., what is exactly being meant by “overload”?, which part of the managed area and what period of time are considered when estimating this probability?);
- According to the new procedure, the probability thresholds should be determined based on costs and benefits of a response measure, both expressed in terms of money. This assumption does not agree with the opinion of the two water boards, which claim that the costs-benefit analysis of the measures is too difficult;
- The proposed scheme for estimation of the probability of overload can be extended in several ways, e.g., additional factors that influence current state of the area, more variation in the values of the scores (1-5 instead of 1-3), including rainfall in Germany.

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