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**121. Decision-making in the case of a flood-threat**

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INTRODUCTION

Design-criteria for flood-defences have a legal character in the Netherlands. Formerly, these flood protection standards were based on design-waterlevels, where a flood defence was implicitly supposed not to fail below this waterlevel. Since knowledge regarding dike-failure improved, a new risk approach has been developed based on a social cost-benefit analysis which addresses a monetary value to a (prevented) fatality. Also, loss of life is part of the risk analysis. The main improvement of the new approach is the explicit inclusion of failure probabilities in flood-risk calculations. A recent floodrisk study showed the risk of flooding for some regions in the Netherlands is larger than previously thought [Rijkswaterstaat 2015].

In the case of a flood-threat, safety protocols are conducted for crisis-managers and decision-makers. These protocols use design-waterlevels as up-scaling criteria to indicate a degree of alertness. The green scale represents a normal life situation, whereas scale red indicates the most extreme situation where evacuation is considered. Regarding evacuation, the measure has the opportunity to prevent loss of life but enormous costs are involved. Two problems can be noticed related to the evacuation-decision. First, the moment of up-scaling represents the start of communication. It does not indicate a moment to start the evacuation-process. Second, scales are developed by history and have a limited scientific substantion.

Because of high (economic) impact and uncertainties, decision-makers tend to wait to call for evacuation. Accordingly, decision-makers requested additional information to support this decision [Kolen, 2013]. Research question is whether an alarm waterlevel for evacuation can be developed, based on the risk-management approach as used to define the new flood protection standards.

**Decision-method**

The main objective is a decision-method to find an alarm-waterlevel to call for evacuation. The method uses a social cost-benefit analysis to support a decision on a rational basis. Additionally, waterlevel-forecasts and conditional dike-strength are required as input. The costs of evacuation are defined as:

- Loss of life (LoL): Expressed in monetary units as is done in the new safety standards. It relates to the percentage of evacuated people (a), a mortality rate (r ), the number of inhabitants (I ) and the value for loss of life (V ), after [Bockarjova et al. 2010, Bockarjova et al. 2012].

$F1 = r \times I \times$

$V$

Value of LoL if no evacuation called, given a flood. (1)

$F2 = r \times a \times I \times$

$V$

Value of LoL if evacuation called, given a

flood.

(2)

- Some loss of life can occur due to the evacuation-process itself [Kolen, 2013]. This value is expressed as a fraction b of the number of inhabitants.

     $F3 = b \times I \times V$          Value of LoL due to evacuation-

process.

          (3)

- Business interruption (B.I.): Due to evacuation, inhabitants are not able to contribute to economy for a while.

     C = m ×

GDP

Costs of B.I. if evacuation

called.

(4)

- Goods: Damage can be partly saved by moving goods. This factor is expressed as a fraction k of all damage D.

     M = k × D          Value of goods saved by evacuation, given a flood.

          (5)

Benefits of evacuation (prevented loss of life) are related to the uncertain event of flooding, since time is needed for decision-making, preparation and transportation [Barendregt and van Noortwijk

2004]. Accordingly, more people can be evacuated if more time is available until the critical event (Figure 13). If no flooding occurred, the measure evacuation only incurred costs.

Forecasts of waterlevels are used as indicator to call for evacuation. The method uses a representative waterlevel-development over time to mimic waterlevel-forecasting (Figure 14). For every day t = i, forecasts of waterlevels are made for days t = i+k. A maximum time-frame of four days k = [1 : 4] is considered as enough time to evacuate all inhabitants from the threatened area. Every day in the design-wave an evacuation-decision will be made based on forecasts of that day.

Figure 15 presents a decision-tree for day t = i. Seven cost-scenarios can be conducted when the evacuation- process is assumed to be irreversible. If one decides for no evacuation and no flooding occurred, the next day a new decision can be made with updated information. A decision for evacuation for day t = i is made if the expected costs of evacuation are smaller than the expected costs of no evacuation, i.e.:

$$P_{t=i,k=1} \times \text{Scenario } 1 + (1 - P_{t=i,k=1})P_{t=i,k=2} \times \text{Scenario } 2 + \ldots + (1 - P_{t=i,k=1})(1 - P_{t=i,k=2})(1 - P_{t=i,k=3})(1 - P_{t=i,k=4}) \times \text{Scenario } 5 < P_{t=i,k=1} \times \text{Scenario } 6 + (1 - P_{t=i,k=1}) \times \text{Scenario } 7$$
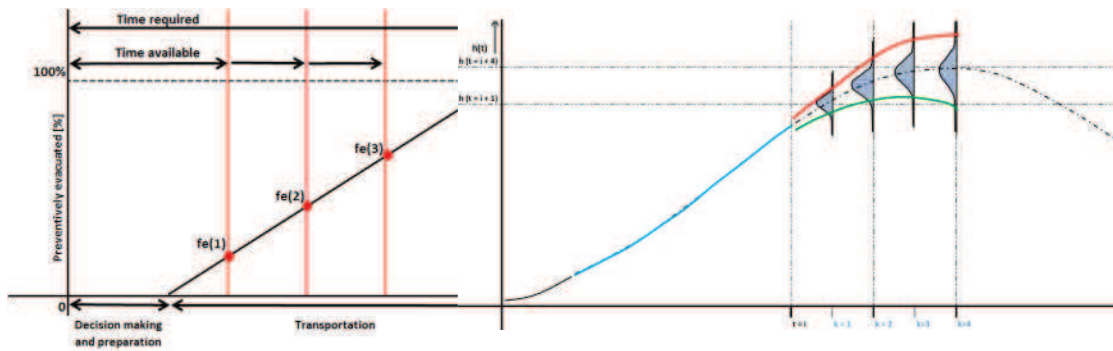
$$(6)$$



*Figure 13: Representation of available and required time for evacuation [Wojciechowska, 2015] after [Barendregt and van Noortwijk, 2004].*

*Figure 14: Representation of waterlevel forecasts for days t = i + k with k = [1 : 4], using a representative waterlevel-development over time.*

The decision-method uses fragility curves of dike-sections to calculate flooding-probabilities Pt,k using waterlevel-forecasts (Figure 16). These curves represent the conditional failure-probability for a given failure- mechanism as a function of the waterlevel.
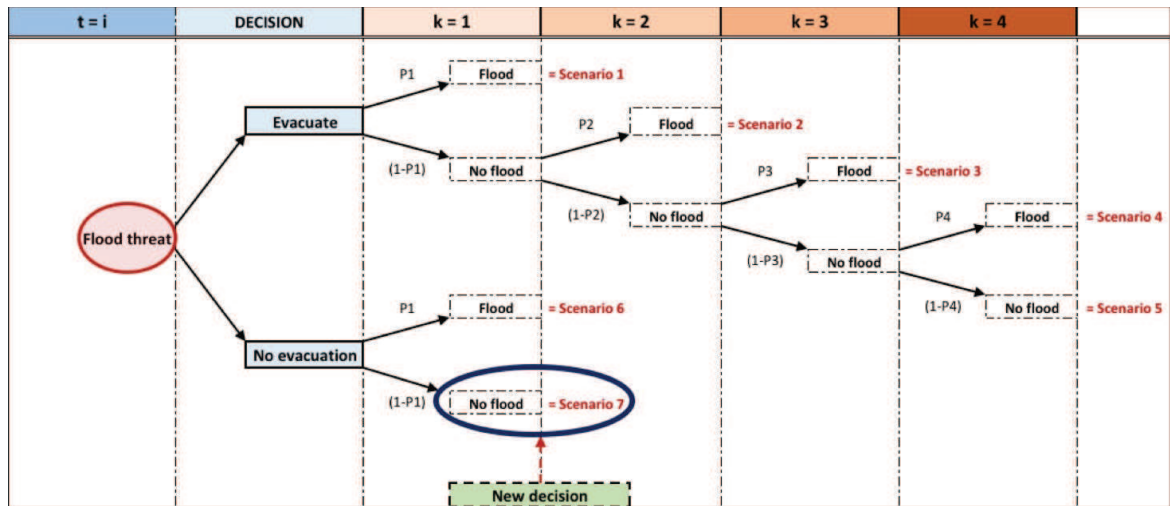
*Figure 15: Decision-tree for evacuation-decision on day t = i, using waterlevel-forecasts of days t = i + k with k = [1 : 4].*

Every day t = i according to the representative waterlevel-development over time, expected costs for the measures evacuation and no evacuation can be compared. If this ratio becomes smaller than one, deciding

for evacuation is satisfied. Figure 17 shows the development of $\frac{Expected\ costs\ Evacuation}{Expected\ costs\ No\ Evacuation}$ over time, relative to a given waterlevel-development over time. An alarm-waterlevel can be found using the corresponding failure-probability with given fragility-curve. This alarm-waterlevel can be compared with current emergency- protocols to check if the evacuation-decision is still considered in time.
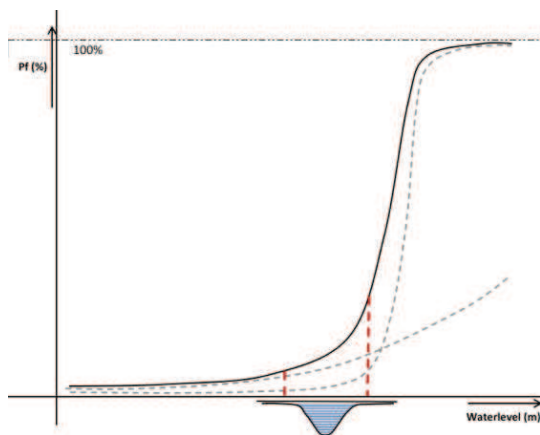


*Figure 16: Calculating flooding-probabilities: integrating forecast-distributions under the fragility-curve.*
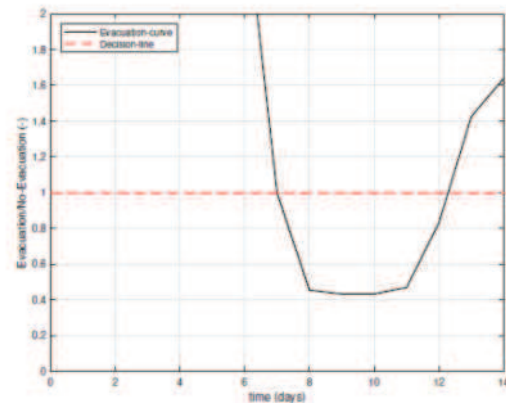
*Figure 17: Representation of the development of an evacuation-decision over time, relative to a representative waterlevel-development over time.*

**Results case-study**

The decision-method finally is applied to dikering-area 43 in the Netherlands, which is surrounded by branches of the river Rhine. The study focused on emergency-procedures on national and local level, using evacuation estimates of [Kolen et al., 2013] and actual dike-strength information of

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[Rijkswaterstaat VNK Project, 2015] to calculate a well-considered alarm-waterlevel to call for evacuation. Figure 18 shows a representative waterlevel-development over time for this region during an extreme high- water event. The colours represent scales as stated in the national emergency-protocol.
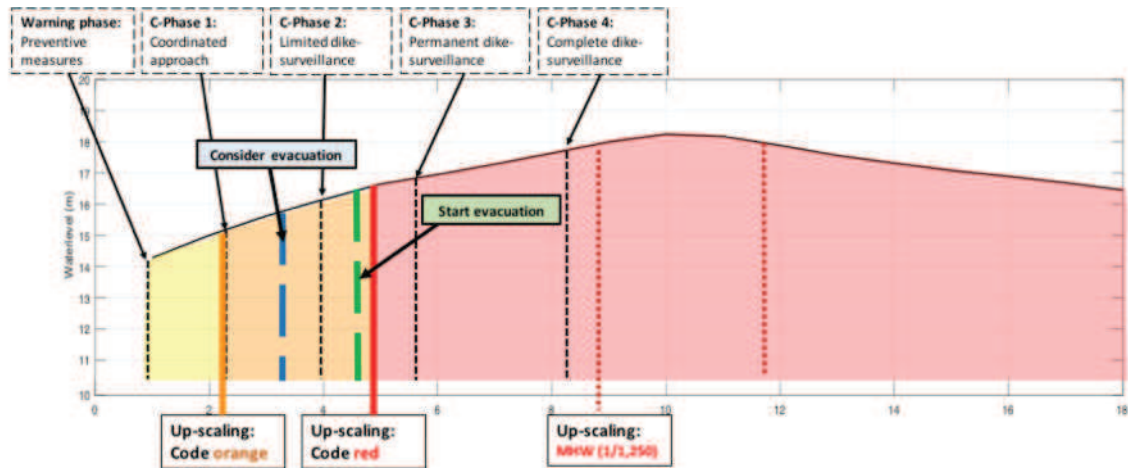


*Figure 18: Comparison of current emergency-procedures with the calculated alarm-waterlevel to call for evacuation (MHW is defined as the water level with a return period of 1250 years.*

The analysis of dikering-area 43 makes clear that the cost-benefit ratio of evacuation is already favorable in scale orange. This scale currently corresponds with the consideration of flood-prevention measures instead of evacuation. Accordingly, it is wise to make a clear distinction between the first moment of considering evacuation and the start of the evacuation-process itself, since time is needed for decision-making and preparation.

**Conclusions and discussion**

The study focused on the development of a decision-method to find an alarm-waterlevel to call for evacuation in the case of a flood-threat, for dikering-areas in the Netherlands. A sensitivity-study resulted in two main conclusions. First, an alarm-waterlevel to call for evacuation relies on the performance of the evacuation-process. If more people can be saved within the same amount of time, the possible benefits of an evacuation increase. This puts more favour to the decision evacuation over no evacuation for the same loading- and strength-conditions. Concluding, if the performance of evacuation improves, a lower alarm-waterlevel is economically satisfied. Second, strength of a dike influences an evacuation-decision positively. If strength of the dikering is in-creased by reducing the contribution of a failure-mechanism as piping, conditional failure-probabilities become less significant for the same waterlevels. Therefore, if the same waterlevel-forecasts are expected for a stronger dike, failure will be less likely to occur. As a result, a worthwhile decision for evacuation can be found for an increased alarm-waterlevel. The decision-method is finally applied to dikering 43 in the Netherlands. The analysis used dike-strength information of [Rijkswaterstaat VNK Project, 2015] and evacuation-estimates of [Kolen et al., 2013] to quan- tify the possible benefits of evacuation in this area. The analysis made clear that an evacuation-consideration

can be made sooner than currently stated in the emergency-protocols. Accordingly, it is advised to revise current emergency-protocols and explicitly include uncertainties as strength and evacuation-performance to the evacuation-consideration. Finally, the same method can be applied to a broader variety of emergency- measures, which can provide insights for optimal decision-making in the case of a flood-threat.

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