Conditional flood risk management

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ABSTRACT: The modern water manager not only looks at the protection against flooding but also at possible consequences when protection fails and how the risks and consequences can be reduced. In a risk approach (as adopted in 2017 in The Netherlands) the acceptable probability of failure per year of levees is determined based on the acceptable risk (risk = probability x consequence). During operational flood risk control the failure probability per year is not key information, but measurements and forecasts describe the conditional risk. The method 'continuous insight' focuses on daily risk based floodcontrol. The knowledge and information for low frequent assessing and designing of levees, is made continuous available given forecasts of the next days, we speak of the conditional floodrisk. Choices in day-to-day work processes such as inspection, maintenance, operational management can be optimized based on the conditional risk. The same applies for flood fighting, warning and evacuation. All processes are fed from a single point of truth of information (which is dynamic). The water manager is in control and reduces the risk effective. In this article we outline the experiences with this method for a case in the Netherlands, the role of fragility curves and human assessment.

RÉSUMÉ: Le gestionnaire d'eau moderne ne se préoccupe pas seulement de la protection contre les inondations, mais également des conséquences éventuelles en cas d'échec de la protection et de la manière dont les risques et les conséquences peuvent être réduits. Dans une approche fondée sur les risques (telle qu'adoptée en 2017 aux Pays-Bas), la probabilité de défaillance acceptable par année de levées est déterminée en fonction du risque acceptable (risque = probabilité x conséquence). Lors du contrôle quotidien des inondations, la probabilité de défaillance par an n'est pas centrale, mais les mesures et prévisions réelles décrivent le risque conditionnel. La méthode «vision continue» se concentre sur le contrôle des inondations basé sur les risques quotidiens. Les connaissances et les informations permettant d'évaluer et de concevoir des levées à faible fréquence sont rendues disponibles en permanence, compte tenu des prévisions pour les prochains jours, nous parlons du risque conditionnel. Les choix dans les processus de travail quotidiens tels que l'inspection, la maintenance, la gestion opérationnelle peuvent être optimisés en fonction du risque conditionnel. Il en va de même pour la lutte contre les inondations, l'avertissement et l'évacuation. Tous les processus sont alimentés à partir d'un seul point de vérité de l'information (qui s'améliore continuellement). Le gestionnaire de l'eau est en contrôle et réduit efficacement les risques. Dans cet article, nous décrivons les expériences avec cette méthode pour quelques cas aux Pays-Bas, le rôle des courbes de fragilité et les facteurs humains.

1 INTRODUCTION

1.1 *Conditional Flood risk management*

Different approaches for flood risk management have been adopted in various parts of the world. Flood risk management strategies can contain different measures to reach and maintain an acceptable level of risk. Possible measures are the reduction of the probability of failure of levees or dams, but also measures to reduce the consequences of a flood as building codes, warning systems and evacuation protocols (Kolen & Kok 2011). Risk can be defined as the probability of the event multiplied by the consequences of the event. This definition is commonly accepted in the flood risk literature (Vrijling 2009; ten Brinke et al. 2008). The consequences are often expressed in economic damages or loss of life in the flooded area. Alternative definitions describe the risk in terms of hazard, vulnerability and exposure (Kron 2002; Gendreau et al. 1998). Both approaches for defining risk lead to similar outcomes, as they both consider the occurrence of a hazard (the probability) and the consequences (vulnerability, exposure) of a given occurrence.

To compare different strategies and evaluate decisions, risk analysis can be used in a rational approach (Benjamin and Cornell 1970). Costs and benefits of measures can be defined and the optimal decision can be selected resulting in the lowest total (social) costs. Flood risk is mainly applied for the design of the system. Examples are the design of levees and dams, development of early warning systems, or definition of zones for building regulation (as the 1/100 flood zone) and for insurance.

In case of a threat for flooding, emergency measures can be taken to reduce the probability of occurrence and the consequences. Forecasts of water levels and the strength of levees or dams are made during the threat event and might become more certain when the lead time reduces. More frequent inspections can be implemented to monitor levees and dams. When weak spots are detected, flood fighting measures can be implemented. In case a potential failure of levees or dams warning and evacuation can be considered. These measures can be costly with respect to time, money, and credibility (Bourque et al. 2006). Decision makers have to deal with uncertainties and great consequences of their decisions (including a delay of decisions) (Kolen & van Gelder 2018):

- The probability of flooding.
- The positive consequences of measures (as reduction of failure probability of levees, reduction of damage or loss of life in case of a flood).
- The negative consequences of measures as the costs of them, potential loss of life because of evacuation and the economic damage because normal economic processes are disrupted.
- When a decisions is postponed this is also a decision because the effectiveness of measures might decline.

When the time needed to execute the measures, is limited, or when the available resources are not available, priorities have to be set as well.

In this paper we introduce the method ‘Continuous Insight’. The method 'continuous insight' focuses on daily (operational) risk based flood control. Therefore we speak of the conditional risk. The conditional risk is the risk for the upcoming event given measured or forecasted water levels, the strength of levees and possible consequences. In this article we outline the experiences with this method for a few cases in the Netherlands, the use of fragility curves to describe the conditional probability of failure and conditional risk. This paper also discusses the role and importance of a human assessments to validate results and correct data and information for biases.

2 METHODOLOGY CONTINUOUS INSIGHT

2.1 *Purpose of the method*

‘Continuous Insight’ used a single point of truth of information for all the daily operational working processes of water authorities e.g. inspection, maintenance, operational management, flood fighting, emergency management (including warning and evacuation). The data, knowledge and information of levees, dams developed for risk assessments of levees is used during daily activities: the working processes. In the Netherlands the risk based approach is developed to define the safety standards for levees and for an assessment of levees each 6 years (ENW2017, Kok et al 2017, Slomp and Oostinga 2018). This knowledge is also used for reinforcement of levees if needed. This reinforcements have a planning horizon of 50 year in many cases. For daily work processes the use of risk information is less explicit, a checklist is used to see if procedures are followed.

Although fragility curves are widely used in flood risk management literature in the Netherlands (Schultz 2010, Bachman et al 2008, Rogers 2012, Wojciechowska et al 2015) there is a strong focus on the levee assessment to check if levees meet the standards set by law. Therefore the focus is mainly on the return period related to the safety standards of levees (as 1/10.000 per year). For daily working processes the information of the levee assessment is less useful and accessible. The use of fragility curves, based on the same data and knowledge, can make this information applicable for daily working processes. This creates the opportunity for conditional flood risk management.

During an actual event, the failure probability per year or the risk per year, is no critical information because this is not related to the actual event. In the risk per year all possible scenarios and the probability of them are taken into account, for example hydraulic loads caused by storms and the tide (which are relative short periods in The Netherlands) and hydraulic loads caused by extreme river discharges (which takes weeks) or the combination storms and river discharges. In case of an event, the conditional failure probability and conditional risk is vital information to make risk based decision.

The risk information used to express risk in the consequences per year given the probability per year is used in an operational context. Therefore we do not speak of the risk per year but the conditional risk during the current event. We distinguish 3 steps to define conditional risk and the conditional probability of failure (see Fig. 1):

1. Data; the data describes characteristics of levees, geotechnical parameters, flood scenario's, etc.
2. Knowledge; the knowledge transfers data into information. This can be done by models based on algorithms but also by expert judgment (the human assessment) to correct for biases and unforeseen consequences. With knowledge, data can be combined and information is generated. The procedures for human assessment are described in chapter 3.
3. Information; this is the result and input for daily flood control. Because of the different stakeholders involved in operational flood risk control, the presentation of the information differs per end user. A decision maker for evacuation for example, is interested in the actual probability of failure of levees, while a flood fighter is more interested in the conditional probability of failure for the next days and the relevant mechanisms of failure (e.g. seepage or overtopping).

All data and information is stored in a (semi) dynamic database. When new (or refreshed) data becomes available, the conditional flood probability and risk will be automatically updated as well. Two update frequencies are foreseen:

1. A low frequent update. This update is called semi dynamic, for example each year the levee characteristics, fragility curves or flood scenario's will be updated, based on annual inspection data (for example after inspection of grass revetment) or developments or processes of nature (as subsidence). New knowledge about for example failure mechanisms, can be implemented as well. Also more detailed information can be added when maintenance or reinforcement projects are finished or after measurement campaigns. This low frequent update results in the basic data and knowledge which is used during operational flood risk management.
2. A continuous update: During an event forecasts of water levels become available. Also new data about levees can become available as a result of inspection, and measures can be taken as well. This results are added to the basic data which was available at the start of the event. Also the estimations of conditional failure probabilities and flood

risk can be evaluated and overruled (human factor) because of biases in models or data.

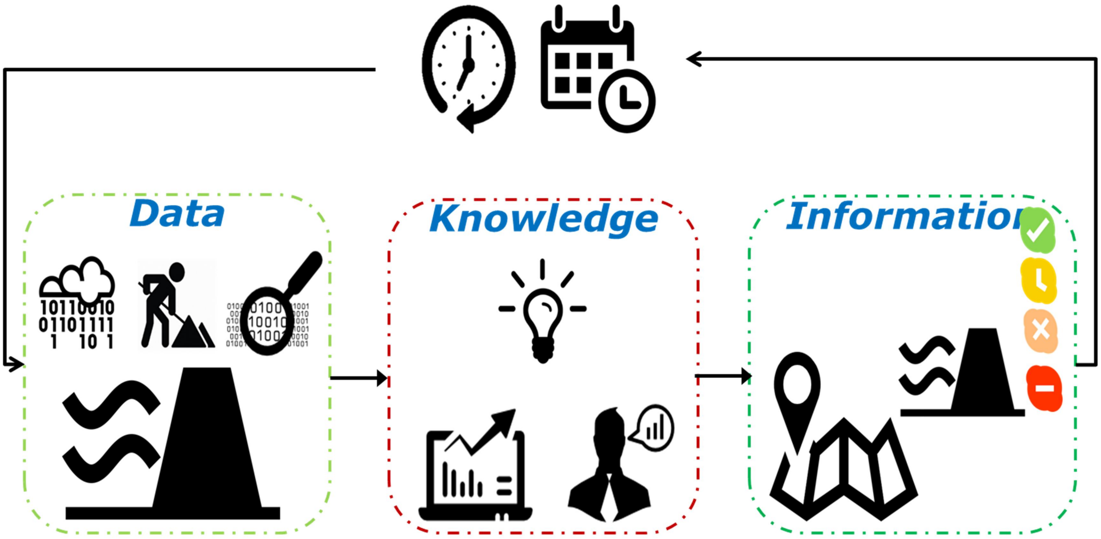

Figure 1. Method Continuous Insight.

2.2 *Data and information*

In Continuous Insight risk information is presented for the actual situation (using measurements) and upcoming day's using forecasts. Information is clustered into:

- Water levels: Measured and forecasted water levels at different locations, and the translation of these water levels to the hydraulic load (including wind and waves) to a levee or dam at a certain location.
- Levees: A levee can be divided in different sections based on common characteristics. For each levee section the characteristics are described that determine the strength of the levee. Given these characteristics the relation between the hydraulic load and the probability of failure is described by a fragility curve for each levee section. The fragility curve is the result of the contribution of the relevant mechanism of failure. For each mechanism a specified fragility curve is available. Combining the measured or forecasted water levels with the fragility curve results in the conditional probability of failure of the levee or dam.
- Zones: the conditional risk in an area is quantified using flood scenarios and the probability of failure. An area can be divided in different zones for example based on zip code. The conditional risk is quantified in a conditional risk of economic damage, conditional risk of people at risk and conditional fatalities and local probability of exposure to a flood.
- Measures: For each levee or dam also a library of different fragility curves which describe the effectiveness of measures can be prepared in advance. For example the height of the levee can be corrected, as the states of the grass revetment etc. When a measure is selected the fragility curve used to define the conditional failure probability and conditional risk will be updated. For each section of a levee or dam or zone also the contribution of the risk per levee section can be ranked from high too low to support decision makers to prioritize measures. Also for zones measures can be taken to reduce the consequences.
- Human assessment. The probability of failure, as the consequences can be corrected for biases by human assessments.

For purposes of learning, validation, asset management also synthetic 'what if' events (water levels) can be defined. This synthetic events can describe potential or historic flood events.

2.3 *Viewer for visualization of information*

During operational flood risk management different types of stakeholders are involved. The flood risk expert has a background in the assessment of levees and the flood scenarios. Other emergency managers, for example responsible for warning or evacuation, deals with 'summarized' information. In that case only the probability of a flood is needed, and not the contribution of different mechanism to the failure probability. A flood fighter however needs more information about the relevant failure mechanism (as seepage or overtopping) because the flood fighting measure is related to the failure mechanism. Continuous insight therefore offers information about water levels, conditional probability of failure and conditional risk in zones which is presented in different levels of detail. Information can be viewed and extracted by an interactive viewer (see fig. 5, 6 and 7). In this viewer the status of measured and forecasted water levels, the conditional probability of failure of levees and the conditional risk in zones is presented in categories and maps. For each parameter these categories can be defined. For example 4 categories are distinguished (related to the level of alarm) for the conditional probability of failure of a levee:

- 'Code red' (critical) when the conditional probability of failure is > 10%.
- 'Code orange' (danger) when the conditional probability is between 1% and 10%.
- 'Code yellow' (warning) when the conditional probability is between 0,1% and 1%.
- 'Code green' when the conditional probability of failure is < 0,1%.

After selecting an object (location, levee or area) on the map more detailed information is presented using descriptions, graphs and numerical time series.

For levees and zones, measures can be selected to reduce the probability of flooding or the consequences. This will result in an update of the calculated conditional failure probability and conditional flood risk. The information can be used for several work processes. Examples are to support inspectors in the field for expected failure mechanism, the validation of data and information by a comparison of measurements and results of inspections, for emergency managers to set priorities in case of limited means. Priorities can be set to minimize the conditional probability of failure but also to minimize the conditional risk (which will not result by definition in the same measure or levee). The information can also be used to improve warnings to the public and increase effectives of emergency measures.

Changes in the alarm phases of locations, levees or areas are logged. Also the moment and effectiveness of measures is logged. This information can be exported to a report to be used to make reconstructions and evaluations.

2.4 *IT Architecture of data model*

All data and information for continuous insight is stored in a central data warehouse, this is called the 'single point of truth'. The work processed are described by different modules. The result of work process A (information) can be input (data) for work process B. The connection of modules (data protocol) is based in a IT standard called 'Digital Delta' which are widely accepted in the Netherlands. The use of such a standard , makes it possible for others to easily connect other modules or database.

Data and information generated used in continuous insight can be extracted using a viewer. The viewer can be used to export the data as text or pictures. Data and information can also be extracted directly out of the database (by an API or WMS connection) so numiceral values and ASCII / GIS data can be used for GIS analyses. Also external databases and models can use the database of continuous insight as a (real time) source to support netcentric working. In Fig.2 the architecture model is described.

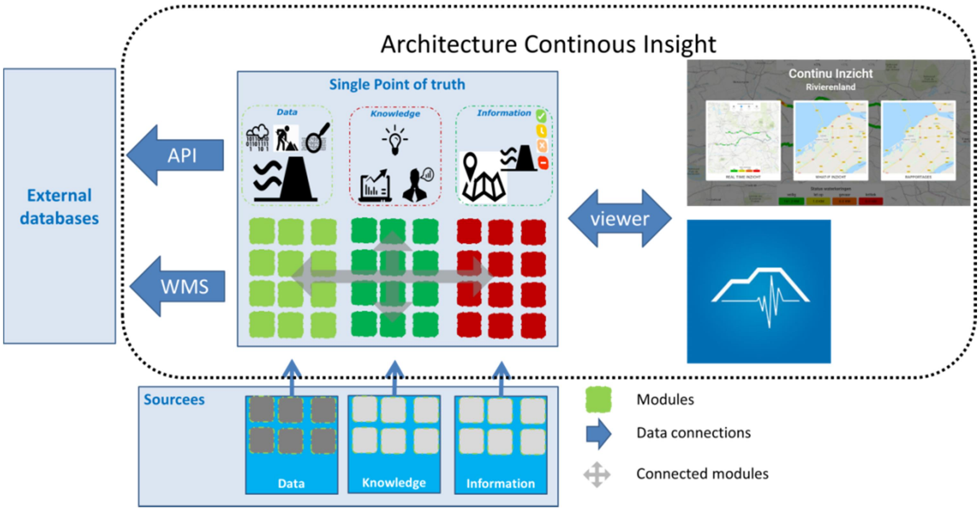

Figure 2. IT Architecture of continuous insight

2.5 *Mathematical description continuous insight (knowledge)*

The mathematical description is summarized in fig. 3. This figure also shows the (semi) dynamic updates which are described in section 2.2.

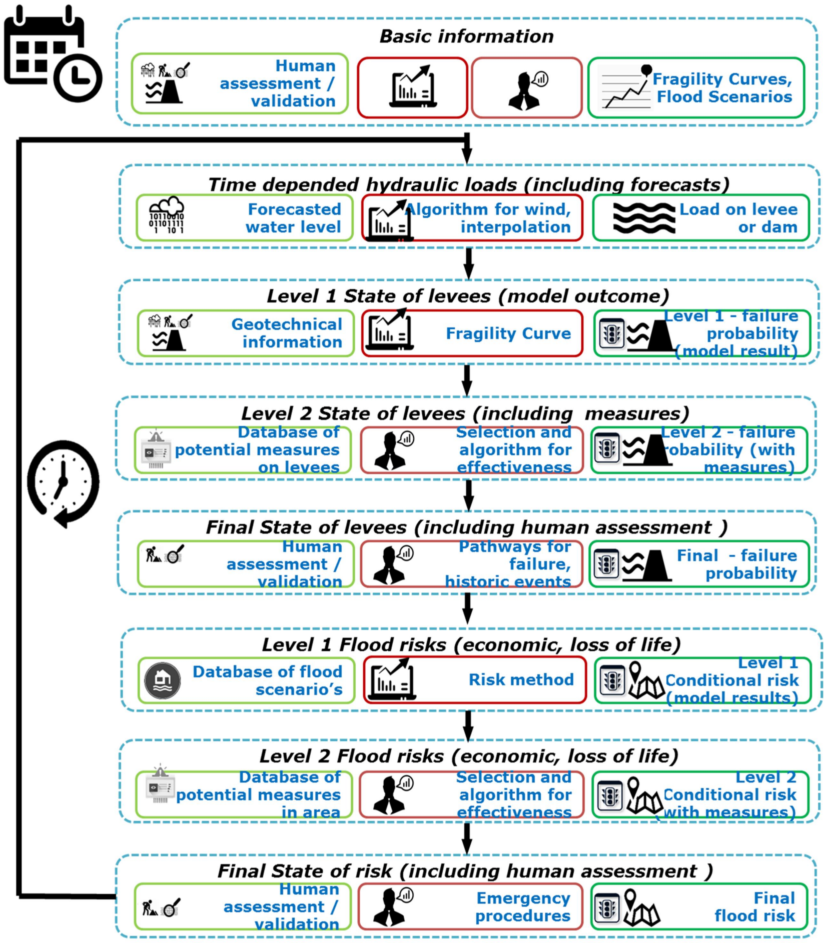

Figure 3. Summary of mathematical description of Continuous Insight and the low frequent updates (the agenda) and the continuous update process (the clock).

The water level $H$is the measured or forecasted water level at a certain location. These water levels are often measured or forecasted in the center of the river and have to be translated to the hydraulic load near the levee or dam. For example wind can setup up the water level and cause additional waves. The water level near the levee is H'. The probability of failure $P$of a dike section depends on the water level H'. P is defined in three steps:

1. $P_1$is the probability of failure based on theoretical models or a fragility curve, this is called the state level 1.
2. $P_2$is the probability of failure taken measures into account given P_1, this is called the state level 2. These measures result in a new fragility curve. When no measures are taken P_2 is equal to P_1
3. P is the final state of the probability of a levee after a human assessment and possible adjustment for biases in the definition of P_1 or P_2. When no human assessment is done P is equal to P_2.

Given the actual or forecasted water level, the most likely flood scenarios (which describe the consequences of a flood) can be selected from a prepared database. Because the number of possible flood scenarios are endless and uncertain, we use categories of flood scenarios. By default, we use a factor 10 in the probability, so categories are used between an 1/30 to 1/300 frequency, a 1/300 to 1/3.000 frequency etc. In case of a forecasted 1/200 per year water level the 1/100 per year flood consequences are used to define the conditional risk. In many cases this classification is acceptable to define the risk for The Netherlands because the difference in total damage between a 1/100 and 1/1.000 per year event is less than a factor 2 (Leenders et al 2015).

Given the forecasted water level the most likely flood scenario is selected to define the conditional risk. Combining all possible flood events (given the conditional probability for failure and forecasts of water levels) results in a conditional 'area at risk'.

The conditional risk R can be defined combining the consequences C and the probability of failure P per event. Therefor the flood depth per zone (F) of each relevant flood scenario is used. Given F the consequences can be described in different dimensions: the economic damage in Euro (C_e), the loss of life in persons (C_l) and the exposed population in persons (C_p). The consequences can also be adjusted by measures of human evaluation. The same approach as for the probability of failure is followed:

1. $C_{x,1}$ are the consequences defined with the model (with x is the value for $e, l\ or\ p$), this is called the level 1 consequences.
2. $C_{x,2}$ are the consequences including measures, this is called the level 2 consequences.
3. C_x are the final state of the consequences including a human assessment and adjustment for biases.

Combining the final consequences C_e, C_l and C_p with P results in the final conditional flood risk R_e, R_l and R_p.

The probability of failure of a levee or dam P is not equal to the probability of local exposure to a flood. The probability of local exposure to a flood P_L(so a location somewhere in a flood zone) can be defined using P and each location with a flood depth F higher than 0.

3 HUMAN ASSESSMENT

Because of the low frequency of events, the lack of experience and uncertainties in data, models are used to describe the probabilities and consequences. These models consist of algorithms which describe physical processes. Also uncertainties can be taken into account using probabilistic approaches. However during an event mechanisms can occur which are not foreseen, or mechanisms happen which are not foreseen. During an event levees will be inspected more frequent by dike control teams, by remote sensing and other sensors. This information is used to evaluate the need for flood fighting measures. To select measures however weak spots have to be detected first, than choices have to made on how to act, and finally the measures can be executed (Lendering et al 2015). Continuous Insight offers information where (and which) failure of the levee is most likely to occur and can be used to increase the effectiveness of inspection during high water levels. The increase of effectiveness of inspection is the result of a better understanding of the levee so inspectors can set priorities.

Both the algorithms used in Continuous Insight as the detection by humans and remote sensing (and other sensors) are based on models. A validation of the outcome of these models is part of Continuous Insight. This is called the human assessment. The outcomes of the model can be fine-tuned because outcomes can be corrected for biases and new information can be added. After an event this knowledge can be used to improve basic information or models. The human assessment is a measure to reduce so called blindness (Boin et al 2005).

For a transparent and reproducible human assessment, a procedure has been developed using case studies. The role of this procedure is also to create acceptance of the final risk assessment and actual alarm categories by all the stakeholders.

3.1 *Procedure for Human Assessment*

This procedure is based on the standard Delphi method and can be used for continuous updates and semi dynamic updates as well. This method structures group processes so that the process is effective in allowing a group of individuals as a whole, to address complex problems (Linstone and Turoff 1975). This method is further described and analysed by Rowe and Wright (1999). For continuous insight the following steps are defined:

0. Selection of experts. The selection of experts depends on the alarm phase and is done prior to an event. Therefore this is called step zero.
1. First (individual) assessment of each expert using:
    a. Level 1 state of information of continuous information
    b. Results of inspection (from dike control teams, remote sensing, etc.)
    c. Technical background information (see chapter 3.2)
2. Discussion of estimation among the experts and exchange of arguments.
3. Final estimation by the experts which result in a probability distribution of estimations and an expected value.

The selection of experts is based on the alarm phase because of the impact of an alarm phase to the society. Therefore we used the lessons learned with weather warnings and alarms in the Netherlands and the response of the public, media and politicians to these warnings and alarms. A warning is issued given a relative low probability for an event in an area. The warning is issued after consultation of weather experts. An alarm is issued given a relative high probability of extreme weather but also the potential impact of the extreme is taken into account (KNMI 2015). For example in case of extreme rainfall or fog during rush hour might result in an alarm, while on a weekend evening only a warning is issued.

In phase yellow of continuous insight the focus is on the prevention of a flood and related flood fighting measures. Therefore only flood risk experts participate. In phase orange also emergency managers (including a representative of emergency services) participate because of the increase of flood risk, potential warnings and impact to the society. In case red also decision makers participate because of issues of evacuation and business interruption.

3.2 *Technical background information*

Technical background information of levees and dams can be prepared to support decision makers. The fragility curves describe the probability of failure given a definition of failure. For the Netherlands failure for the mechanism seepage is defined as the start of the failure process. This means that it might be possible that although the failure process started, there is no breach yet. Figure 4 shows the failure definition used for seepage in the Netherlands. The definition of failure is related to a critical length of a pipe which is not by definition breaching. This definition is used in the standardized procedures for the 6 yearly assessment of levees (`t Hart et al 2016).

After reaching the critical length of a pipe the levee has to decrease in height before it breaches. This means that the probability of breaching is less than the probability of failure, this is called additional strength. In case of a levee assessment in the Netherlands this additional strength can be taken into account when additional research is done. For operational flood risk management this additional strength can also be taken into account, but also a better understanding of a more detailed description of the process of failure for each mechanism can be used to validate model outcomes or correct for biases.

A pathway of failure for a mechanisms describes the different phases to breaching of a levee. The pathway describes the possible conditions which are required using fault trees. Using probabilities the most significant pathways can be selected and the probability of failure can be updated, also the effectiveness of measures can be defined using pathways.

Preparation of the pathways as part of the knowledge in continuous insight can support human assessment during operational flood risk management.

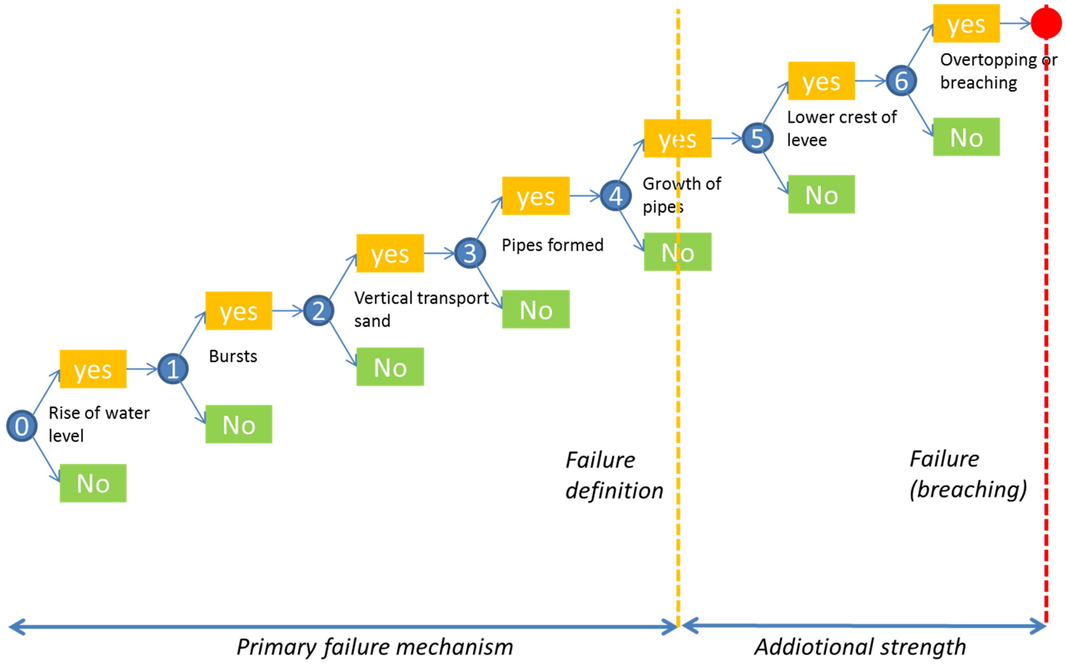

Figure 4. Pathway of failure for piping and failure definition for piping used in Dutch levee assessment approach.

4 CASE STUDY

Water authorities in the Netherlands have the task to maintain the levees. Therefore the conditional probability of flooding is used to minimize the probability of a dike breach (and set priorities for dike patrol and flood fighting measures). In case of a severe flood risk, for example a probability of breaching of more than 1%, water authorities also inform the emergency services and safety regions (which are chaired by mayors of a region) about the conditional risk. The primary concern of the emergency services is to reduce the risk for loss of life and as second concern the avoid damage to the critical infrastructure. The conditional risk can also be used to support decision making where tradeoffs between costs of measures and positive and negative impacts are made.

In this chapter we present a case study for the water authority Rivierenland in the Netherlands of Continuous Insight. The water authority of Rivierenland is 201.000 ha and 950.000 people live in this area. The water authority has to maintain 560 km of primary flood defenses along the river Rhine and Meuse and 510 km regional flood defenses along canals. In this case study we focus on dike ring area 43 which has 162,4 km primary levees. The water authority has the ambition to be in control 24 hours a day, 7 days a week. Because of the total length of the levees which have to be controlled an overview is needed, therefore the method continuous is tested.

The water authority defined the following users (or roles):

- Flood risk expert, this expert advises the operational teams of emergency organization. Priorities can be set to reduce the probability of a flood or to reduce the risk in the administrative area (f.i. of water authority of Rivierenland).
- Levee experts, several experts specialized in failure mechanisms.
- Team leader flood fighting teams (action center), this expert prioritizes flood fighting measures for a section of levees to reduce the probability of failure, this team leader also is a reviewer of inspection results for this section.
- Liaison in the safety region, this expert advises emergency services about the risk and conditional probability of flooding.

The flood risk expert is also responsible for the low frequent updates of information.

The water authority of Rivierenland defined the fragility curves for levee sections in dike ring area 43 using the algorithms based on the standardized approach of the Dutch levee assessment method (once in the 6 years each levee has to be evaluated if the current probability of failure meets the required standard as for example a probability of failure of 1/10.000 per year). Used data to describe the levees strength was based on the VNK2 project (VNK2, 2012, Jongejan et al 2011).

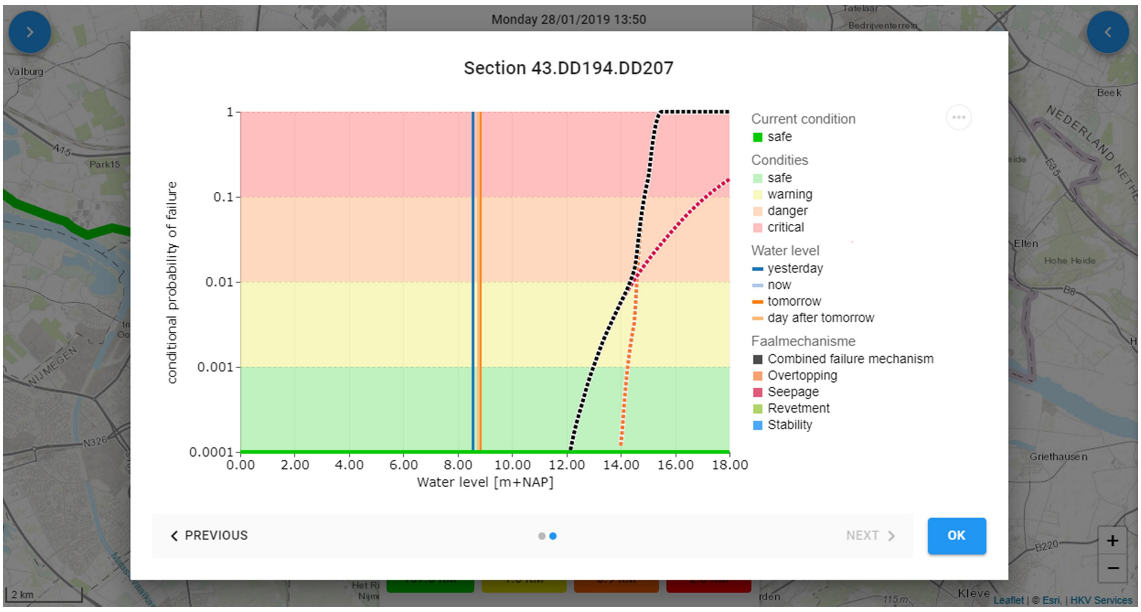

Figure 5. Fragility curve for a levee section (black dotted line) and the contribution failure mechanisms (overtopping by the red dotted line and seepage by the dark red dotted line) combined with the actual water level (dark blue vertical line), and two forecasts (light blue and red line). The graph also shows the alarm categories red, orange, yellow and green and the relation with the conditional failure probability.

Used measurements of water levels and forecasts of expected water levels are from www.waterinfo.nl which is open data supplied by Rijkswaterstaat. Forecasts are available for 48 hours from now. In the case study the conditional probability of failure and conditional flood risk is presented for 4 moments: 24 hours ago and the actual situations (using measurements of water levels) and 24 and 48 hours ahead using forecasts of water levels. More information about forecasts, with ensembles and a time horizon of 15 days, are also made available by Rijkswaterstaat, but not as open data. The ensembles can be used to define a probability distribution of the forecasted water level which could be used for a complete probabilistic forecasting of the conditional risk.

Combing the forecasted water level and the fragility curve (assuming no measures and human assessment) the conditional probability of failure can be defined. Fig 6 shows a map in which the alarm categories are presented for all levee sections.

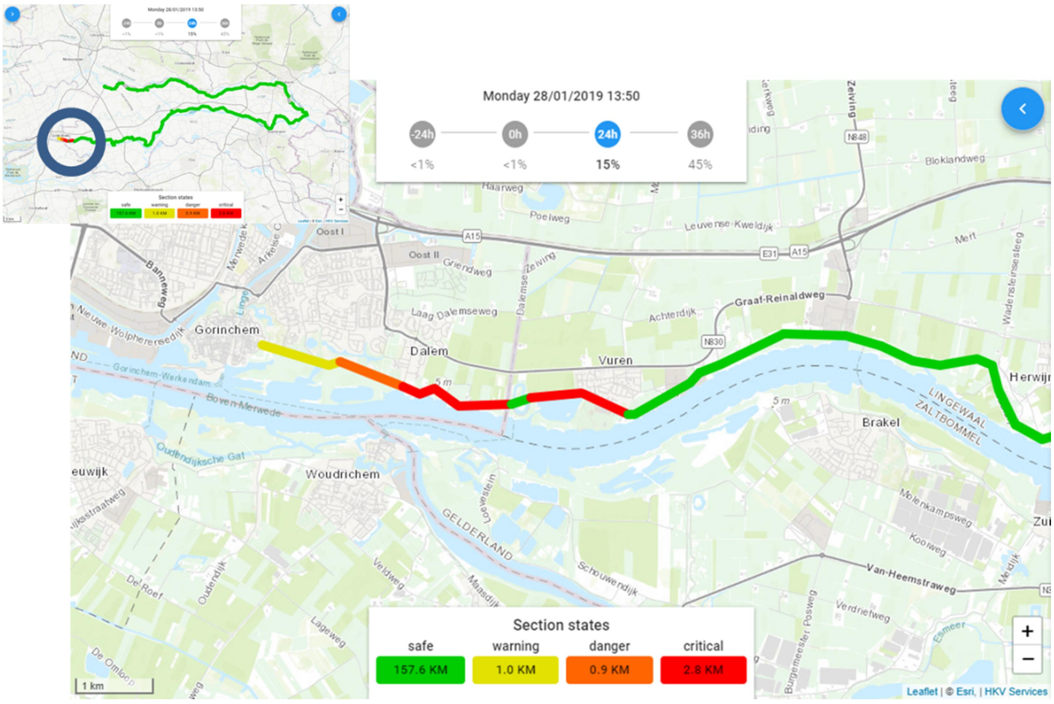

Figure 6. Interactive map of dike ring area 43 showing the actual conditional probability of failure in an area (<1%) and increases to 15% inn 24hours and 45% in 48 hours. Below in the figure the total length of levees in an alarm class over 24 hours are given (157.6 km in class safe (green), 1.0 km in class yellow (warning), 0.9 km in class orange (danger) and 2.8 in class red (critical)).

The consequences of a flood are described by flood scenarios. In theory unlimited numbers of flood scenarios can be defined. However because of uncertainty in the hydraulic loads, the characteristics of the breach and the flooding pattern categories are used. A scenario is assumed to be representative for a whole class. The number of categories depends on the characteristics of an area. In de case study we used flood scenarios of the database www.basisinformattie-overstromingen.nl. Sceanrios are available per levee section for return periods which vary a factor 10. We considered flood scenarios for exceedance frequencies of water levels of 1/100, 1/1.000, 1/10.000, 1/100.000 per year and a worst credibel flood events.

The conditional risk is per zone (see Fig 7 for an example) defined for 1) the people at risk 2) expected loss of life, 3) local probability of exposure to flood water and 4) expected economic risk. With the experts of Rivierenland also the need for prioritizing of measures was explored. For the team leader flood fighting the information about conditional failure probabilities and underlying mechanism could be used to plan flood fighting measures for critical sections of a levee. The levee experts use the information to prioritize the human assessment. The combination of continuous insight, with the conditional probability of failure, and inspection in the field are used to prioritize levee sections for human assessment.

For the flood risk experts prioritizes on two criteria: the reduction of the probability of failure and the reduction of risk. Levee sections can be ranked from high to low based on the contribution to the probability of a flood in the dike ring area or the contribution to the conditional risk. For the liaison in the safety region the conditional risk in an area is important to set priorities in evacuation and warning.

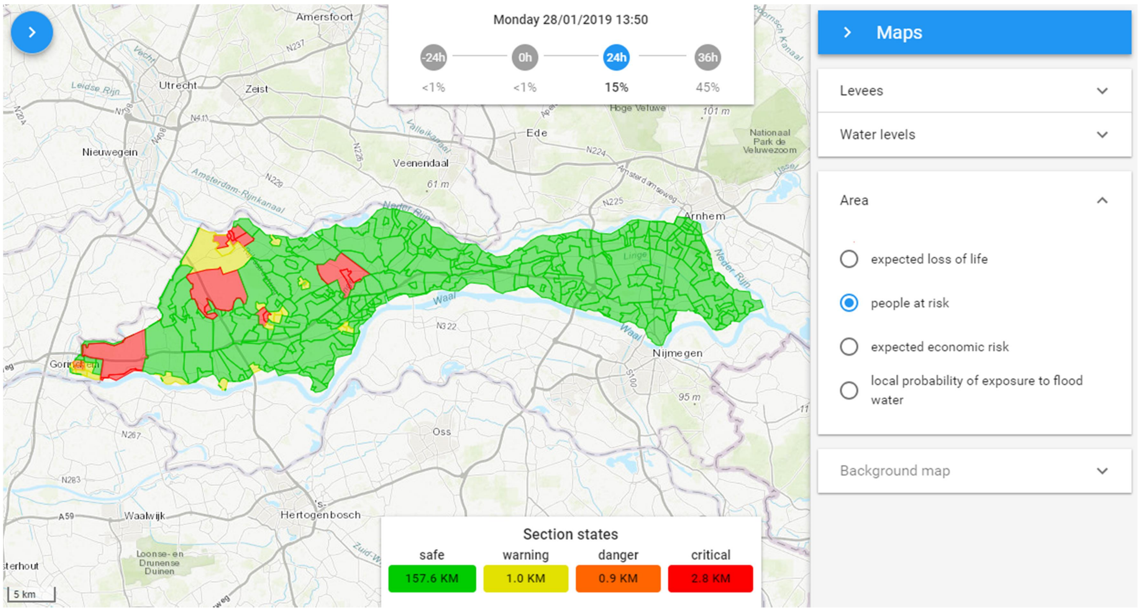

Figure 7. Interactive map of conditional risk in zones for dikering area 43. For each zone alarm categories are used to visualize the conditional risk.

The case study for Rivierenland showed the need for a human assessment of the data before operational use of the data. This is because all experts have to trust in the result of the risk assessment of continuous insight (and the underlying models). Although all data was already used in the working process levee assessments, now other stakeholders had to use the data as well in working processes as inspection, emergency management, etc.

To gain trust and understanding of the knowledge and the data a human assessment is necessary. Also the way of visualization and presentation of the data is essential for understanding and interpretation for the decision making process. When the information is too technical (like a %) it might be difficult to understand. The use however of alarm categories with color schemes were necessary. These categories also give te opportunity to reduce the sensitivity for uncertainties in the parameters which describe the different failure mechanisms for levees.

5 CONCLUDING REMARKS

The method continuous insight creates the opportunity to use and maintain flood risk information for daily working processes. Water authorities can be in control 24/7 based in the (forecasted) conditional flood risk level in their administrative area. Interventions can be prepared and evaluated based on the reduction of the risk level. Continuous insight creates the opportunity to design daily work processes, based on a (probabilistic)_risk approach and also inform other stakeholders about the risk in case of a threat for flooding.

While a levee assessment in the Netherlands is foreseen once in the 6 years (as set by law) continuous insight gives the opportunity for continuous assessment using forecasts of water levels and use the same flood risk information in daily working processes. However it is also shown that experts involved in these daily working processes only start to use the information when it is accepted by them. These experts have to understand the outcome and have an understanding of the data which is used. The fact that the data is used in the 6 year assessment by levee experts does not guarantee that other experts in the same organization use the data.

The case study showed that human assessment of the results of algorithms, as well as the yearly low frequent update of data and knowledge, is critical for the use of risk information in operational flood risk management. The confrontation of the outcomes of algorithms and human assessment will improve the data and knowledge. The low frequent update supports the technical readiness so the most actual data and knowledge is used and recent experience can be implemented. This will result in a single point of truth of data, knowledge and information. The low frequent updates are also needed for the social readiness that experts of the water authority start to use the information.

Also the visualization of the risk is important to support different work processes. For the low frequent assessment of the levees for example detailed information can be necessary, for others the alarm category might be sufficient information. The use of categories, which represent a bandwidth of the conditional probability or conditional risk, also makes the outcomes more robust for sensitivity in data or knowledge.

Because of the high safety standards for levees in the Netherlands the conditional probability of failure and the conditional flood risk is very small during >99% of the year. Also an extreme discharge on the rivers or storm surge of 1/10 per year is not expected to cause a significant probability of failure of levees. Because of the lack of extreme events in the Netherlands synthetic 'what if' scenarios describe the conditional risk. Given these water levels as a function of time, the conditional probability of failure and conditional risk can be used to get a better understanding (and trust) about the risk and show the added value of continuous insight.

Some literature has suggested that a probabilistic approach could create a focus on expected events and limit attention to other possible events (Clarke 2006). Such an approach could be biased in favor of what has already happened, encouraging us to neglect future possibilities. Clarke states that because of probabilistic thinking, less attention has been paid to the worst-case events. Therefore, he introduces the concept of possibilistic thinking. Using such an approach, more extreme events can be considered; however, the question remains whether these are realistic. By using ensembles of forecasts of water levels, uncertainty in water levels can be taken into account. In emergency protocols of the Dutch water authorities three scenarios to describe the consequences are used. The first scenario is the most likely scenario based on the expected value of the conditional risk. Uncertainties in de forecasted water could be used to define the conditional risk for a worst case scenario and a best case scenario. The worst case and best case could for example be related to the confidence interval of 10%.

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