Rijkswaterstaat
Ministerie van Infrastructuur en Milieu

RWS ONGECLASSIFICEERD

Implementing risk based flood defence standards

Design practice since 2014,
Assessment of Flood Defences in the Netherlands 2017-2023,
Maintenance and interpreting flood forecasts
Research from 2016 onwards

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April 24th 2016

Colofon

Published by	Rijkswaterstaat
Information	Robert Slomp
email	Robert.slomp@rws.nl
Date	April 24th 2016
Version	7

Inhoud

Samenvatting

Dit rapport[1] heeft tot doel de context rondom de invoering van nieuwe normering te schetsen. De invoering van de nieuwe systematiek is sinds de jaren 80 in gang gezet. De eerste grote stap wordt op 1/1/2017 formeel genomen. Dit rapport geeft historische context, de huidige stand van zaken en een blik op de kennisagenda. Het doel van de nieuwe normering is acceptabel veiligheidsniveau bereiken (zoals afgesproken in de water wet). Een belangrijk achterliggend doel hierbij is een efficiëntere inzet van de middelen om de veiligheid van Nederland te bereiken. Met de oude normering, toetsregels en ontwerphandreikingen zou het te duur worden (inefficiënte bestedingen) en te lang duren om aan de norm te voldoen.

Probabilistiek

- Bij eenvoudige gebieden zoals de kust en bovenrivieren zijn er in de jaren tachtig vrij snel (semi) probabilistische modellen ontwikkeld voor duinen en dijken. Deze voldeden tot 2017 goed. Nu onzekerheden meegenomen worden bij hydraulische Belastingen voldoen ze echter niet meer.
- Voor complexe gebieden waar stormvloedkeringen werden gebouwd zijn probabilistische modellen voor hydraulische Belastingen ontwikkeld (Oosterschelde, Maeslantkering en Ramspol. Deze waren essentieel om efficiënt te kunnen ontwerpen. Deze complexe modellen waren toen al geschikt om in heel Nederland gebruikt te worden. Latere versies van deze modellen hebben ook de basis gelegd voor de nieuwe normering via Waterveiligheid 21^{e} eeuw (WV21) het latere Deltaprogramma Veiligheid (DP V).
- Naast deze probabilistische modellen voor hydraulische belastingen is PC ring ontwikkeld door TNO. Dit model integreerde versimpelde hydraulische Belastingen met versimpelde sterkte mechanismen. In de loop der jaren is dit doorontwikkeld en in VNK-2 gebruikt. Kennis uit VNK-2 is gebruikt als aanscherping op het advies van de nieuwe veiligheidsnormen in het DP V.

Sterktemodellen

- Veel sterkte modellen zijn empirische modellen.
- Om echt onzekerheden op een correcte manier mee te nemen, dan is het essentieel dat een overstap gemaakt wordt naar proces gebaseerde modellen. Deze proces gebaseerde modellen moeten dan wel het gehele faalproces beschrijven. Bij een aantal faalmechanisme beschrijvingen zoals bij "piping", terugschrijdende tunnelerosie onder een waterkering, zoals beschreven door Sellmeijr is dat nog niet geval.

WTI2017 en OI

- In WTI2017, het Wettelijke Toetsinstrumentarium 2017, nu WBI Wettelijke Beoordelings Instrumentarium, is het mogelijk om de kennis uit deze bovengenoemde kennisvelden te combineren in nieuwe belasting modellen (die consistenter zijn) en in een toetsinstrumetnarium waar belastingen en sterkte meer geïntegreerd zijn.
- Deze kennis uit WTI2017 is in 2014 vrijgeven in het OI, ontwerpinstrumentarium en zal in 2018 verder ontwikkeld worden op basis van het WTI2017.

[1] Noot: de Nederlandse en Engelse samenvatting zijn bewust anders. De doelgroepen zijn anders. Dit is nog een concept, kwaliteitsborging is nog niet afgerond.

Door de nieuwe invoering van de nieuwe normering veranderd er heel veel. De toetsing krijgt een andere vorm en er ontstaat een nieuwe referentie situatie, het ontwerp, de zorgplicht (beheer en onderhoud van waterkeringen) en het beheer van de watersystemen (met name rivierbeheer) moeten aansluiten op deze nieuwe referentie en de eigen processen aanpassen. Ook bij crisisbeheersing is er een nieuwe referentie situatie, daar worden echter ook anders omgegaan met kansen. Dit zijn de kansverwachtingen bij een voorspelling. Het zal een aantal jaren duren voordat iedereen deze nieuwe referentie situatie in de vingers heeft en voordat de kennis uit de werelden van crisisbeheersing en toetsing geïntegreerd zijn.

Het Ministerie van Infrastructuur en Milieu (IenM) heeft daarom een implementatie programma nieuwe normering opgezet. Dit implementatie programma bevat formele elementen (zoals de voorschriften) en informele elementen (zoals cursussen, coaching en workshops).

Een belangrijke leerervaring bij het onderzoek tot nu toe is dat Rijkswaterstaat onvoldoende haar regie rol heeft genomen. Rijkswaterstaat heeft zowel een rol bij het uitstippelen van ambitie (na overleg met alle betrokkenen, kennis instituten, de markt partijen, beheerders en universiteiten) als bij het bewaken van de consistentie. Dit laatste is altijd de uitdaging en is de hoofdrol van het Rijk. Het toets- en ontwerpinstrumentarium haar doelen kan alleen verwezenlijken bij consistentie tussen de werkvelden.

Consistentie is niet star vasthouden aan bestaande modellen, maar een focus op onderzoeksvragen die met name leiden tot producten die toepasbaar zijn voor toetsing, ontwerp, beleidsadvies maar die onderzoek niet op slot zetten. Dit kan door een regie te houden op de ontwikkellijnen (door life cycle management) voor probabilistische modellen, hydraulische belasting modellen en voor de sterkte modellen. Het belangrijkste handvat hierbij is "good modelling practice" en een centraal beheer van acceptatie criteria voor modellen en toetsregels.

"Good modelling practice" is in essentie:

- stap voor stap werken – eerst een referentie situatie narekenen, dan pas de variaties doorreken, zodat wijzigingen in producten herleidbaar en traceerbaar blijven.
- geen overstap op nieuwe modellen, zonder aan te tonen dat die echt beter en nodig zijn (geen arbitraire veranderingen)

Hydraulische Belastingen,
Inhoudelijk is het essentieel dat klimaatmodellen voor alle processen worden gebruikt, voorspellen, klimaatstudies, toetsing en ontwerp. Het gebruik van ensembles is de gemene deler voor een consistentie in kansverwachtingen bij voorspellingen, kansberekingen in klimaatstudies, ontwerp en bij de toetsing. Als deze consistentie is bereikt, dan kan naar 2^{e} en derde orde effecten gekeken worden. Dit vraagt een grotere rol voor het KNMI.

Sterktemodellen,
Er moet een grotere focus komen op proces gebaseerde modellen die het gehele faalproces beschrijven. Deze moeten wel in samenhang met probabilistische modellen ontwikkeld worden. Door gecombineerd onderzoek te doen met probabilistische modellen kan bepaald worden welk fenomeen werkelijk een kansbijdrage heeft en verder uitgezocht moet worden.

Summary[2]

On January 1st 2017 the Netherlands formally will adopt a more risk-based flood risk management policy. This will be carried out through a change in legislation, the new risk base standards will be laid down in an update of the Water Act. The design water level methodology of 1958 and safety standards of 1996, will then be formally abandoned as the major policy tool in risk assessment and funding. The flood defence assessment is important for managers of flood defences since national and regional funding for reinforcement is based on this assessment. The research and development of Flood Defence Assessment tools project (WTI2017) is responsible for the development of flood defence assessment tools for the 3600 km of Dutch primary flood defences, dikes/levees, dunes and hydraulic structures.

This new policy is based on maximum allowable probabilities of flooding per area. A uniform maximum level of acceptable individual risk has been determined, this is the probability of life loss of 1/100 000 per year for every protected area in the Netherlands. Safety standards for the flood defences have been adjusted using information from cost benefit analysis, societal risk and large scale societal disruption due to the failure of critical infrastructure. The resulting risk-based flood defence safety standards expressed in probability of failure vary from 1/300 per year to 1/100 000 per year. Two policy studies WV21 (Safety from floods in the 21st century and VNK2 (the National Flood Risk in 2010) prepared the way for these improved risk based safety standards for flood defences. The ground work for this policy change was laid down between 1980 and 1990. It has taken a number of large projects as practice runs like VNK-2 to prove it is feasible. The WTI2017 project will provide the assessment tools for flood defences based on these new risk based standards for flood defences and thus is essential for the intended policy change.

A major issue to be tackled was the development of user-friendly tools to be used by managers of flood defences, rather than just by a number of experts in probabilistic assessment. Data management and the experience with the new software are main issues to cover in courses and training in 2016 and 2017. All in all, this is the largest change in the assessment of flood defences since 1996, when probabilistic techniques were first introduced for determining hydraulic boundary conditions for design water levels and waves (wave height, wave period and direction for different return periods). To simplify this policy change, the assessment still consists of a three-step approach, moving from simple decision rules, to the current methods for semi-probabilistic assessment, and finally to a fully probabilistic analysis to compare the strength of flood defences with the hydraulic loads. The formal assessment result is mainly based on the fully probabilistic analysis and the ultimate limit state of the strength of a flood defence. For extremely complex flood defences additional models and software have been developed. The current Hydra software suite (for policy analysis, formal flood defence assessment and design) will be replaced by the model Ringtoets. New standalone software has been developed for

[2] Please note: the Dutch and English summary differ. This is because readers have different backgrounds.

revetments, geotechnical analysis and slope stability of the foreshore. Design software and policy analysis software including the Delta model will be updated in 2018. Life cycle management plans for software cover the proposed changes.

A fully probabilistic method results in more precise assessments and more transparency in the process of assessment and reconstruction of flood defences. This is of increasing importance, as large-scale infrastructural projects in a highly urbanized environment are increasingly subject to political and societal pressure to add additional features. For this reason, it is of increasing importance to be able to determine which new feature really adds to flood protection, to quantify how much its adds to the level of flood protection and to evaluate if it is really worthwhile.

Research funding is subject to similar societal pressure. A lot of scientific proposals come from the scientific community and do not always address the problems in the field of design and assessment of flood defences. Research on flood defence assessment tools should always involve using probabilistic tools in determining the importance of the subject. The use of probabilistic analysis provides information on how important knowledge gaps are in strength and hydraulic load models, since they combine both fields.

New developments of research should always show what should be improved, by comparing the method to existing methods. This is to show changes are not arbitrary.

Acknowledgements

Implementing new risk based flood risk standards has taken almost 35 years if we start counting in 1990 when it was considered feasible and 70 years since the Delta commission considered the possibility in 1956. By selecting English language articles as much as possible I know I will acknowledge only part of everyone involved.

I want to thank my colleagues for reviewing this document and providing me with ideas and feedback.

- Han Knoeff (from Deltares), our discussions and our joint powerpoints on the WTI2017 program helped me define what I wanted to communicate through this document.
- Pieter van Berkum and Wout de Vries, from Rijkswaterstaat for the review of chapter 7 and ideas for the chapter, on the changes in maintenance of flood defences
- Wouter Rozier, from Rijkswaterstaat) and Nadine Slootjes, from Deltares) with new figures for this document.
- Jan Stijnen (from HKV lijn in Water), Hans de Waal (from Deltares) and Quirijn Lodder (Rijkswaterstaat) on objectives for the software and how to realise these objectives through life cycle management. Hans is very important since he knows how to say no when I want something impossible, as a new feature branch. I appreciate Quirijn for his systematic approach. Jan has made the development possible of Hydra-models for assessment, policy analysis and design.
- Chris Geerse and Matthijs Duits (from HKV lijn in Water), for making some of my wildest ideas for software to work. We have worked on the main software tools since 1998, with new features and functions every year.
- Bas Kolen (from HKV lijn in Water) for his ideas on improving crisis management and evacuation strategies in the Netherlands and combining the fields of policy studies and crisis management. Some of these ideas we have developed together in 2006 and 2007. I have used his ideas for combining the different fields of flood risk management, assessment, design, flood forecasting and crisis management.

Finding the right documents 20 to 35 years after they were written was often a challenge. Rijkswaterstaat is a part of a governmental organisation, formal policy documents are publicly available. The supporting documents, sometimes personal opinions are less accessible. Finding articles from 1980, before the digital age was also a challenge. I want to thank a number of the authors, especially from Delft Technical University for taking their time and providing me with their original documents.

Finding the right recent article is also a challenge. I received many of the articles written by members of the WTI2017 team. I have tried to cover all the fields which are now implemented in the WTI2017 assessment tools for flood defences.

Implementing a policy change involves many people.

The following people at the Directorate General Water and the Environment, the Ministry of Infrastructure and the Environment are currently responsible the whole implementation policy of risk based flood defence standards.

Anouk te Nijenhuis[3] and Annemiek Roeling for assessment and design tools
Mario Cerutti, John Maaskant and Peter for the implementation strategy of the new risk based flood defence standards
Mark de Rooy for policy studies and the Deltamodel
Wim de Vries for measures to replace flood defence construction by river enlargement (Room for the River measures)

The joint program management of the Research and Development of Flood Defence Assessment Tools (WTI2017) program are:
Harry Stefess[4], Robert Slomp[5], Hoite Detmar[6] (Rijkswaterstaat)
Han Knoeff[7] and Goaitske de Vries[8] (in 2016) (Deltares)

Formal Assessment Documents were elaborated by:
Alessandra Bizzarri, Marieke Hazelhoff (Rijkswaterstaat)
Han Knoeff (Deltares)
for the general flood defence regulations[9]

Huub de Bruin, Robert 't Hart, Goaitske de Vries, Han Knoeff, (Deltares)
Marcel Bottema, Robert Slomp (Rijkswaterstaat)
for the formal assessment regulations

Robert Slomp, Marcel Bottema, Deon Slagter, Marieke Hazelhoff (Rijkswaterstaat)
Leo van den Nieuwenhuijsen and Ronny Vergouwe (HaskoningDHV),
Peter van der Tol (Witteveen en Bos), Paul Landa (Witteveen en Bos)
for formal regulations to derive Hydraulic Loads

The probabilistic models and semi-probabilistic assessment rules team consists of
Marcel Bottema (Rijkswaterstaat)
Ferdinand Diermanse, Houcine Chbab, Ana Teixeira (Deltares)
Ruben Jongejan (private consultant),
….

The Software teams consisted of :
Hillie Wams[10] (quality management, Rijkswaterstaat),
Louis Verhagen, Hans van Putten, quality management (BMTargoss and Deltares)

Pieter van Geer[11] , Hans Venema (Deltares), Elmar Kleijn (consultant), Dzmitry Hryb (consultant), Marten Janssen (consultant), Joël van den Berg

[3] Preceded by Frank Hallie and Anne-Geer de Groot as client
[4] Preceded by Remco Schrijver as project manager
[5] Technical Management Rijkswaterstaat
[6] Preceded by Don de Bake as head of the communciation strategy
[7] Technical Management Deltares
[8] Preceded by Frans Hamer and Frank den Heijer were as part of program management at Deltares
[9] This is a separate program.
[10] Preceded as client by Maikel Leugering (KPN), Deon Slagter (Rijkswaterstaat), Robert Slomp

(consultant), Bas des Bouvrie (consultant), David Rodriguez (consultant) for Ringtoets Reviews of Ringtoets and documentaion Goaitske de Vries, Rob Brinkman and Hans de Waal.

Wim van Balen (Deltares), Henri Steenbergen (TNO), Karolina Wojciechowska (HKV lijn in Water) for Hydra-Ring, the probabilistic kernel
Pieter van Geer (Deltares) for Morphan (Dune erosion)
Frank Engering (Deltares) for Dflowslide

Robert Slomp (Rijkswaterstaat) and Tom The (Deltares) for the development of kernels for strength models and the standalone models
Raimond van der Meij, Alexander van Duinen, Rob Brinkman, Lourens Dijk, Rob Brinkman, Tom The and Viriginie Trompille (all Deltares) for the slope stability kernel
Samy Ouahsine, Peter Blommaart, Marcel Visschedijk, Timo Schweckendiek, Ulrich Förster, John Bokma, Rob Brinkman, Paul Lindhout, Pim Witlox and Viriginie Trompille for the piping kernel
Robert 't Hart, Bernadette Wichman, John Bokma, Wim Kanning, Jurjen van Deen, Pim Witlox, Rob Brinkman, Joost Icke, Viriginie Trompille, Hans van Putten (Deltares) for the Asphalt Kernel and Ringtoets requirements
Hans de Waal, Andre van Hoven, John Bokma, Viriginie Trompille, Bart Adriaanse (all Deltares) and Jentsje van der Meer (private consultant) for the Grass Revetments outer slope kernel
Jan Kramer, Mark Klein Breteler, Dorothea Kaste (all Deltares) for the Block Revetments kernel
Bastiaan Kuijper, Matthijs Duits, Robert Kamp (HKV lijn in Water), Hans de Waal and Paul van Steeg (Deltares) for the Run-up and Overtopping kernel
Rob Delhez (Green Rivers), Joost Breedeveld, Tom The, Edwin Spee, Wim van Balen and Henk van den Boogaard (all Deltares) for the kernel for Non-Closure of Hydraulic structures
Bob van Bree (private consultant), Hans de Waal, Tom The, Edwin Spee, Wim van Balen, Henk van den Boogaard (all Deltares) for the kernel for overtopping of Hydraulic structures
Ruben Jongejan (private consultant), Joost Breedeveld, Rob Delhez, Hans de Waal, Tom The, Edwin Spee, Wim van Balen, Henk van den Boogaard (all Deltares) for the kernel Structural failure of Hydraulic structures
Joost Beckers, Rob Brinkman, John Bokma, Virginie Trompille (all Deltares) for new Goda Tables, wave pressure on hydraulic structures (part of the Structural failure of Hydraulic structures kernel)

Bianca Hardeman and Joost van der Hammen (Rijkswaterstaat) for the Stochastic Subsoil database and Dsoilmodel
John Bokma, Kin Sun Lam and Irene van Zwan for the development of Dsoil model
User tetts Goaitske de Vries and Irene van Zwan (Deltares) and Dennis Hordijk (RPS)

[11] Preceded by Erik Vastenburg, Robert Kamp, Kin Sun Lam, Joost Icke, Hans Veldman, Ferdinand Diermanse, Marcel Visschedijk

The data management team consists of:
Joost van der Hammen, Marieke de Visser, Iris van der Kerk[12] (Rijkswaterstaat)
Kin Sun Lam, Lieven Spits, Irene van Zwan, Frank Keppel, Jan Blinde, Mark Hijma, Michel Ponziani (Deltares)

The Hydraulic loads team consists of:
Deon Slagter[13] (Rijkswaterstaat)
Jacco Groeneweg, Alfons Smale, Sofia Caires, Hans de Waal, Houcine Chbab, Joost den Bieman, Mark Hegnauer, Jamie Morris, Dana Stuparu, Joana van Nieuwkoop, Caroline Gautier (Deltares)
Ron Agtersloot (private consultant), A.J.Paarlberg (HKV lijn in Water)

The Slope Stability team consists of:
Bianca Hardeman (Rijkswaterstaat)
Alexander van Duinen, Cor Zwanenburg, Wim Kanning, Timo Schweckendiek, Ed Calle (Deltares)

The piping team consists of:
Jan Jaap Heerema[14] (Rijkswaterstaat)
Ulrich Förster, Vera van Beek, Wim Kanning, Timo Schweckendiek, Ed Calle, Huub de Bruijn, Gerard Kruse, Marc Hijma, Laura Vonhögen-Peeters (Deltares)

The dune erosion team consists of:
Wout de Vries[15] (Rijkswaterstaat)
Marien Boers, Ab van Dongeren, Joosten den Bieman, Pieter van Geer, Bas Hoonhout (Deltares)

The revetment team consists of:
Astrid Labrujere[16] (Rijkswaterstaat)
Mark Klein Breteler for stone revetments (Deltares)
Bernadette Wichman and Jurjen van Deen (Deltares), Arjan de Looff (Coac) for Asphalt revetments
Andre van Hoven, Wouter Jan Klerk, Gijs Hoffmans (Deltares) and Jentsje van der Meer for grass revetments

The Hydraulic structures team consists of:
Arnaud Casteleijn[17] (Rijkswaterstaat)
Dirk Peereboom, Joost Breedeveld, Ad Verweij, Henk van den Boogaard, Edwin Spee (Deltares)
Rob Delhez (Green Rivers)
Bob van Bree (private consultant)

The fore shore slope instability team consisted of:
Hoite Detmar (Rijkswaterstaat) and Geeralt van den Helm (Deltares)

---

[12] Preceded by Manon Harmsen
[13] Preceded by Mark Franssen, Astrid Labrujere and Marcel Bottema
[14] Preceded by Peter Blommaart and before him Maarten Borgdorff
[15] Preceded by Albert Prakken
[16] Preceded by Bianca Hardeman
[17] Preceded by Hoite Detmar

Communication strategy
Hoite Detmar (Rijkswaterstaat)
Marjanneke Grobben, Roeli Suiker, (Deltares) and Anna van Gils (private consultant)

Support
Carla Bennink (Rijkswaterstaat)
Patricia Tetteroo (Deltares)

Reviews for the WTI2017 program were carried out by

For program consistency and expected impacts :
Robert Slomp, Marcel Bottema, Joost van der Hammen (Rijkswaterstaat)
Han Knoeff, Ferdinand Diermanse, Kin Sun Lam (Deltares)
Wouter ter Horst and Bob Maaskant (HKV lijn in Water)

For Software
Carlijn Bus and Peter van der Tol (Witteveen en Bos) for Ringtoets, Dsoilmodel, Dflowslide
Ilse Hergarden (DHV –Haskoning) and Gert-Ruben van Goor (Fugro) for piping in Ringtoets
Diederik van Hogendorp and Peter van den Bosch (Arcadis) for the evaluation of the inner gras revetment and dike height in ringtoets.

Werner Kramer, Erwin Mulder, Alja Vrieling (Vortech) for Hydra-Ring
Leo van der Nieuwenhuysen (HaskoningDHV) for Grastoets (update 2006 version)[18]
Roy Mom (Infram) for revetment software, Grastoets (outer grass revetments), Steentoets (outer rock revetments) and Golfklap (outer Asphalt revetments)

For Hydraulic Load modelling
Deon Slagter, Marcel Bottema, Robert Slomp, Robert Vos (Rijkswaterstaat), Henk van den Brink (KNMI), Gerbrant van Vledder (consultant).
Jan Stijnen, Chris Geerse, Bastiaan Kuijper, Matthijs Duits, Ton Botterhuis (HKV lijn in Water)
Douwe Meijer and Anneke de Joode (private consultants)

For Slope Stability
Henk van Hemert (Rijkswaterstaat/private consultant), Martin van der Meer (Fugro)

For piping
Ilse Hergarden (DHV –Haskoning)
Gert-Ruben van Goor (Fugro)

For Dune models
Quirijn Lodder and Wout de Vries (Rijkswaterstaat)

For Revetments
Roy Mom (Infram)

For Hydraulic Structures

[18] a excel program built in 2006.

Arnaud Casteleijn (Rijkswaterstaat), Ton Vrouwenvelder (TNO), Ed Calle (Deltares), Martin van der Meer (Fugro), Hessel Voortman (Arcadis).

Other large programs

The design tools program[19] (Ontwerp Instrumentarium, OI) is currently managed by Bart Vonk and Henk van Hemert (Rijkswaterstaat)

The training program is currently managed by Arjan Kooij (STOWA[20]) en Nicoline van den Heuvel (Rijkswaterstaat)
This is supported by Frans Hamer and Theo Stoutjesdijk (Deltares)

The experience sharing program for flood defence assessment tools of STOWA is managed by Petra Goessen and Margo Akkermans.

The KPR a team of coaches, organised by Rijkswaterstaat and the Regional Water Authorities for advice to designers in the field.
This program is managed by
Niels Roode, Deon Slagter (Rijkswatestaat)
Arjan Kooij (private consultant)

The Delta program team for new risk based flood defence standards consisted of:
Ilka Tanczos, Durk Riedstra (Rijkswaterstaat)

The implementation program of risk based flood defence standards is managed by Hoite Detmar (Rijkswaterstaat) and Ruud Hoogendoorn (Deltares).

[19] The program was initiated by the WTI2017 program management in 2013. Harry Stefess, Robert Slomp and Han Knoeff. This resulted in the OI2014 design directives.
[20] The applied research institute for regional water authorities in the Netherlands.
http://www.stowa.nl/foundation_for_applied_water_research_stowa/

1 Dutch Flood Risk Management Policy

In 1958 the flood risk standards for coastal areas were formally laid down in law [Deltawet,1958] after a cost benefit analysis [van Dantzig, 1956] for the largest population centre of the Netherlands protected by a single continuous line of flood defences. This is the largest part of the urban circular agglomeration called the Randstad. Amsterdam, Leiden, Delft, The Hague, Rotterdam and a the new western part of the city of Utrecht (Leidsche Rijn) are included in this flood prone area, another name for the area is dike ring 14 (see figure 1). A dike ring has a continuous line of flood defences consisting of dunes, structures and dikes (see figure 2). The flood defence system currently protects 3,6 million people. The exceedance of design water levels was used as a proxy for the probability of flooding. In 1956 models to evaluate more failure modes in a risk analysis were not available. The first operational models were developed between 1980 and 1990 [Bakker and Vrijling 1980], [Graaff van de, 1986] and described for use in other countries in [CUR, 1990]. All 3600 km of primary Dutch Flood defences (figure 1) received formal flood risk standards in 1996, in the Flood Defences Act [Wet op de Waterkering, 1996] based on a mixture of policy decisions and regional cost benefit analysis [MNP, 2004].

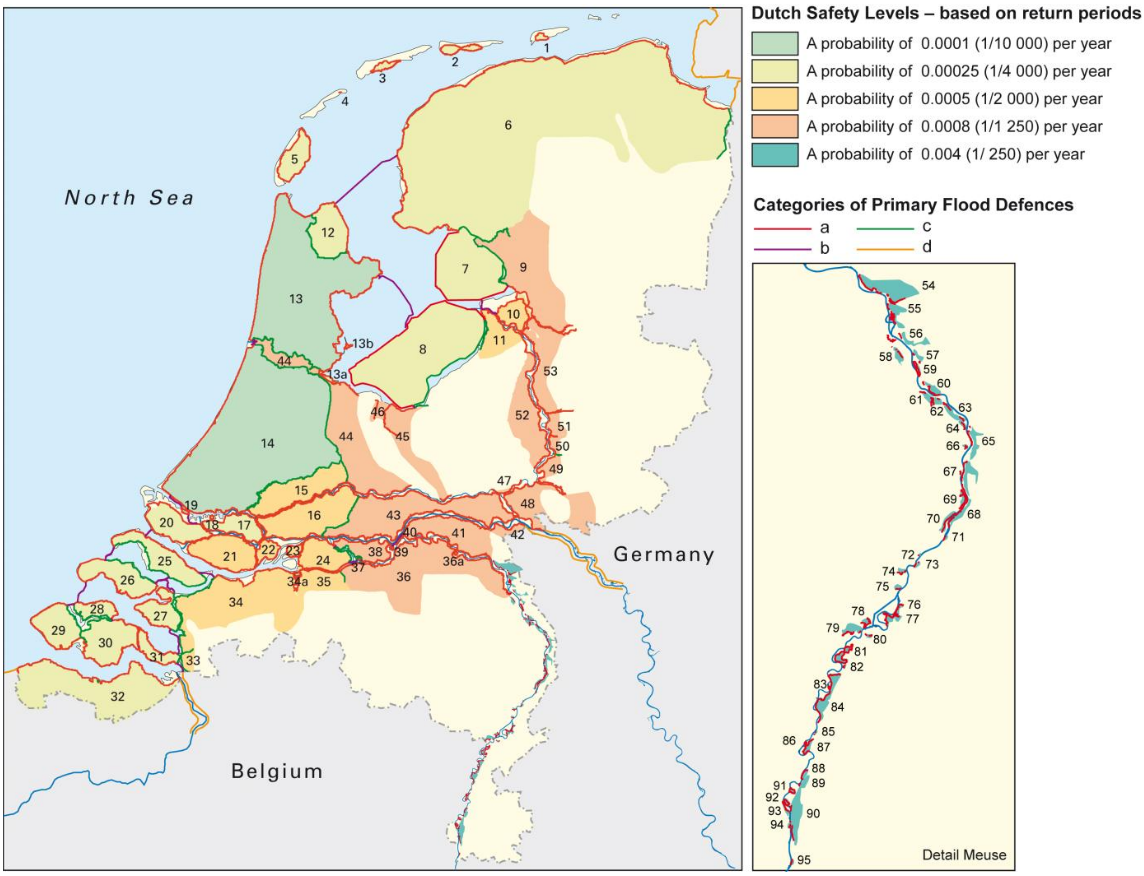

figure 1. current flood risk standards for flood defences in the Netherlands.

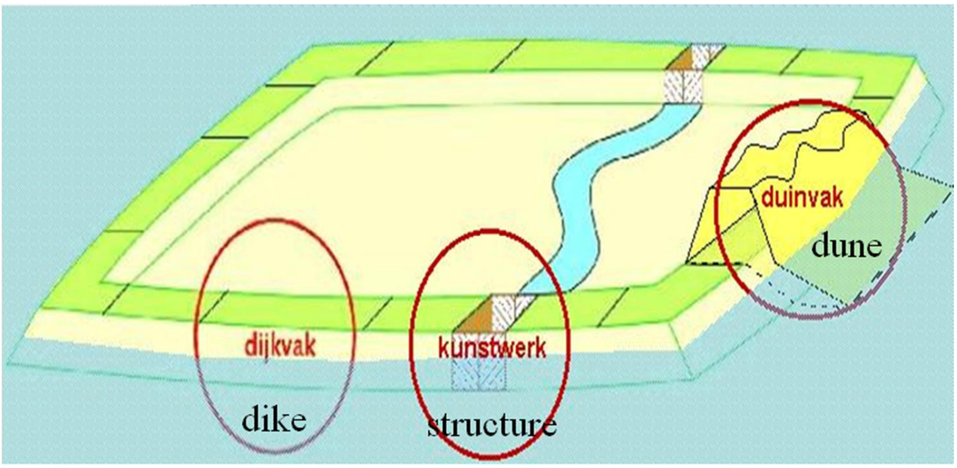

Figure 2. The concept of a dike ring, a continuous line of flood defences

The dike ring approach was chosen, given the principle that a chain is as strong as its weakest link. A single flood manager is needed per dike ring. Based on this approach over the last 70 years the 2400 water boards have merged into 23 regional water authorities. Currently each dike ring is managed by a single water authority. There are a number of exceptions, two dike rings still have more two flood risk managers and large navigation structures in dike rings are maintained by Rijkswaterstaat, the National Water Authority.

The 15 000 km of secondary or regional flood defences received formal flood risk standards from each provincial government in the period 2009 -2012. An example are the Flood Risk standards set by the province of South-Holland [VenW, 2009]. Flood Defence assessment tools for regional Flood Defences as DAM, the "Dike Assessment module" for geotechnical assessments [van Zwan, Vastenburg, 2013], [Peters, and van den Berg, 2016] and Promotor to determine Hydraulic Loads [Bakker et al, 2010] have been developed through funding by STOWA, the research institute for regional water authorities. The major difference between assessment tools for regional flood defences and primary flood defences is the funding structure and the required detail of the assessment. On the technical level there are few differences. No casualties are expected when regional flood defences fail, therefore the standards are less stringent. This article will only cover tools for the primary flood defences. Often, research and development of software tools are carried out together by the same teams. All laws and changes to laws are available on the internet, the references in this article to current, past and future legislation are internet links.

The WV21 "Water Veiligheid 21e eeuw", a policy study (flood risk safety analysis for the 21st century) using the probabilistic Hydra-models [Geerse, 2011] of the WTI2011 (formal assessment tools of 2011) carried out a national flood risk assessment for the Netherlands [Kind, 2010] using the Optimalisering model [Brekelmans et al, 2014] for the Cost Benefit Analysis. Climate change and economic growth were important variables in this study. The probability of flooding was determined using the failure modes overflow and overtopping. Simultaneously the VNK2 "Veiligheid Nederland in Kaart" was carried out, a national safety analysis [Jongejan et al, 2011]. The VNK2 study determined the actual flood risk for the situation in the year 2010. Flood probability was determined using a fully probabilistic model PC-ring [Vrouwenvelder, 2001] for the main failure modes for flood defences. The failure modes for dikes in the Netherlands are geotechnical failure (piping and inner slope failure), outer revetment failure (grass, asphalt and

stone) and subsequent failure of the underlying layers, overtopping and overflow and subsequent erosion of the inner slope. The failure mode for dunes is erosion due to wave action. The failure modes for hydraulic structures are overtopping, structural failure, non-closure, stability and piping. Implementing knowledge uncertainties the probability of flooding for flood defences along rivers was experimented on in a study on the usefulness of emergency storage areas [Stijnen et al, 2008].
Flood damages in the WV21 and VNK-2 study were determined using overland flow models as FLS [Duinmeijer, 2002] and flood damage curves [Kok et al, 2004]. For the WV21 study the cost of reinforcements or new flood defences were determined in the mode KOSWAT [Grave P., 2014] using information from the past 20 years of reconstruction and reinforcement of flood defences. Based on the WV21 study and the VNK2 study new risk based standards for flood defences were recently set. The VNK2 project proved we can determine the probability of flooding based on the main failure modes, as described above. Hence, this new policy is based on maximum allowable probabilities of flooding. These new standards will become law on January 1st 2017 in an update of the "Water Act" [IenM a, 2016]. Since January 2014 the WTI2017 method has been introduced in all new projects. The Netherlands has now formally abandoned design water levels as the major policy tool to be used in the assessment of flood defences and in funding decisions. Differences in expected design. water levels were used a proxy for flood risk assessment. These new risk-based standards for flood defences vary greatly. The maximum probability of failure varies from 1/300 per year to 1/100 000 per year (figure 3)[21].

Developing tools which have to be used by managers of flood defences, rather than just experts in probabilistic design or assessment, was a major issue which had to be tackled in the WTI2017 project. This is the largest change in the assessment of flood defences since 1996, when probabilistic techniques were first introduced for determining hydraulic boundary conditions for assessment and design water levels and waves (wave height, wave period and direction for different return periods).

The current flood risk standards for flood defences are used per cross section in a dike ring. A dike ring is a continuous line of flood defences, comprised of dikes, dunes, hydraulic structures and natural high ground (see figure 2). New safety standards have to consider dike sections rather than full dike rings. The former dike rings (figure 1) have been broken up into dike sections which cause the same flood damage in case of a flood [van der Most et al, 2014]. For different water systems the extent of flooding and speed of flooding is different. The new safety standards have been based on societal risk, individual risk and cost benefit analysis [Slomp, 2012] and [Most et al, 2014]. The reasoning in detail for breaking up dike rings into sections is shown by [Nillesen and Kok, 2015] for a dike ring on two Rhine river branches and the tidal area of the Rhine river. From January 1st 2017 these flood risk based standards will vary from probability of 0,0033 to 0.00001 per year (figure 3). These new risk-based safety standards for flood defences differ greatly in form and use from the current standards. One can also note that safety standards along the Rhine branches and some deep polders have become rather stringent, mainly due to the large consequences of flooding in these areas.

In general it is not cost-effective to build extra dikes to partition large dike rings into smaller dike rings [Moll and Meulepas, 2008]. Secondary dikes have proven to

[21] There is one exception. The dike at the nuclear plant at Borsele in Zeeland has a maximum probability of failure 1 in one million per year.

increase resilience when primary flood defences do not meet the standards or when primary flood defences are badly maintained. Secondary dikes can however increase casualties when the flood prone areas are very small (due to high rising rates of the water e.g. meters within an hour). This was the case in 1953 storm surge disaster in Zeeland. The only secondary dike which retained its formal status is shown in black in figure 3. Since 1277 due to military and economic reasons a secondary defence line was built and maintained, the "Diefdijk" . Floods from upper river areas could be contained in a designated area and diverted back to the river after the passage of the flood wave on the main river. Floods through a polder take more time than through the main river, the time lag can be a week [Ham van der, 2004]. The area could also be artificially flooded through gates in case of a military threat. Long term spatial planning was provided by the military since the 18h century and after the forts lost their purpose in 1950, by national and provincial governments. They maintained the flood storage area by allowing only sparse urban development.

figure 3: Risk-based safety standards for flood defences valid from 1/1/2017

2 Flood Defence Assessment, our experiences

2.1 The role of probabilistic models for design and assessment of flood defences

Since 1980 probabilistic design studies have been carried out in the Netherlands [Vrijling and Bruinsma, 1980]. Swiftly after this simple probabilistic models for hydraulic loads were quickly developed for assessment of flood defences in coastal areas and upper river areas. In river areas water levels and waves are fully independent. Along a straight coast they are almost fully dependant. A semi-probabilistic model was developed in 1985 for rivers [Dillingh and Cappendijk, 1985]. In coastal areas like the dunes and dikes along the shore of Holland (the western provinces) there is almost a full correlation between water levels and waves (as mentioned above). For Dunes a semi-probabilistic model was developed by [Graaff van der, 1986]. For dikes a model was developed in 1990. This model was replaced by the Hydra-K model in 2001 [den Heijer et al, 2008]. Because these systems are not very complex, the models have been considered adequate for a long time. These simple models are being phased out due to the fact they cannot account for uncertainties.

For complex systems like lakes with wave action and water levels which are not fully correlated a probabilistic Hydraulic Load model was also developed in 1994 "Peilof". This was replaced by the model Hydra-M in 1998 [Westphal, and Hartman, 1999]. River discharges in this model were simplified in the "statistics for lake water levels".
For complex systems with storm surge barriers tailor made models were developed by the teams involved. Each storm surge barrier generated a group of more or less independent model developers.

- Eastern Scheldt Barrier in operation in 1985 [Vrijling and Bruinsma 1980]
- Rotterdam Storm Surge Barrier in operation in 1997 [de Deugd, 1995]
- Ramspol Storm Surge Barrier 2002 [Kors et al, 1994]

The institute for building codes "CUR", the technical Advisory Committee on flood Defences (TAW) and the national government provided a document in English on development of probabilistic models in 1990 [CUR, 1990].

In 1994 for the design of the Rotterdam Storm surge barrier a probabilistic model was used to provide design water levels "Freq-FK" [de Deugd, 1995]. Then a probabilistic strength model "Dijkring" [Den Heijer et al, 1995] was used to determine the Hydraulic loads on flood defences using a "wave run up failure mechanism" [van der Meer, 2002]. Both the National (Rijkswaterstaat) and Regional government (the province of Zuid Holland) developed their own models. For maintenance of Storm surge Barriers the National Government (Rijkswaterstaat) developed the "PROBO" model [Bogaard and Akkeren, 2011]. This considers the whole fault tree of a storm surge barrier.

Around 1994 for the evaluation of the strength of Flood Defences the Technical National Research institute (TNO) developed the model PC-ring [Vrouwenvelder et al, 2001]. This model combined both the hydraulic load models and the strength models. Since the model covers a lot of different fields it is more complicated than hydraulic load models and uses a lot of general descriptions for stochastic processes and for failure modes. The model works and has been used in the VNK-I/ national flood risk study 2001-2006 and in the VNK-2 study 2007-2014 [Jongejan et al, 2011].

In 1996 Rijkswaterstaat decided to harmonize probabilistic Hydraulic Load models in the Hydra-model suite (figure 4). The first of these models to be developed was Hydra-M [Westphal and Hartman, 1999] This harmonization will be completed in 2023 when coastal dike and dune models will be consistent with the Hydraulic Load models as described by [Geerse, 2011].

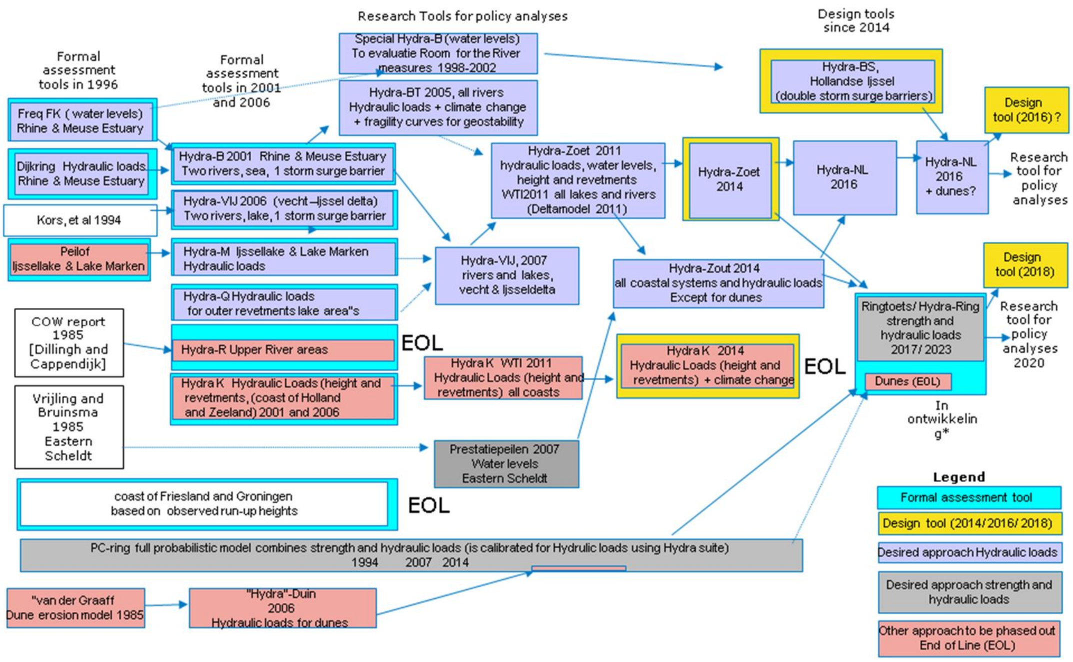

figure 4 harmonization of probabilistic models 1985-2023[22]

It has almost taken 30 years to harmonize the Hydraulic Load models. Coastal areas, both Dikes and Dunes do not use hydrodynamic models (e.g. WAQUA) for calculating water levels. They still rely on statistical models and triangular interpolation techniques. This means changes in bathymetry e.g. dredging a channel for a sea port are not accounted for.

The integration of strength and hydraulic load models also started around 1990. This integration will probably also be completed in 2023. Both types of models will probably be needed for policy research and scientific research. Hydraulic Load models as Hydra-Zoet [Geerse, 2011] provide additional diagnostic tools and detailed probability information per stochastic variable when conditional probabilities are calculated. This makes the models ideal for the use by flood defence managers who are not hydraulic load experts or probabilistic experts. In essence this is what is needed, multi-functional models to be used by trained engineers for flood defence assessment and design, but who are not researchers. Having a model which can be understood is essential, many of our past models lacked up to date documentation, making the models black boxes. The same model (and source code) is available for researchers[23] who will provide the next step in model development. It is extremely

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[22] Note: not all available (semi) Probabilistic models are shown. This figure is just to show how much time it takes to harmonize a field with multiple institutions and individuals.
[23] The models are both available for researchers and for students.

expensive to have so many parallel model suites. Each model has a number of user modes for the same source code : assessment, design, policy research, research and testing (figure 5). This is essential for keeping models consistent and to reduce running and maintenance costs for the software.

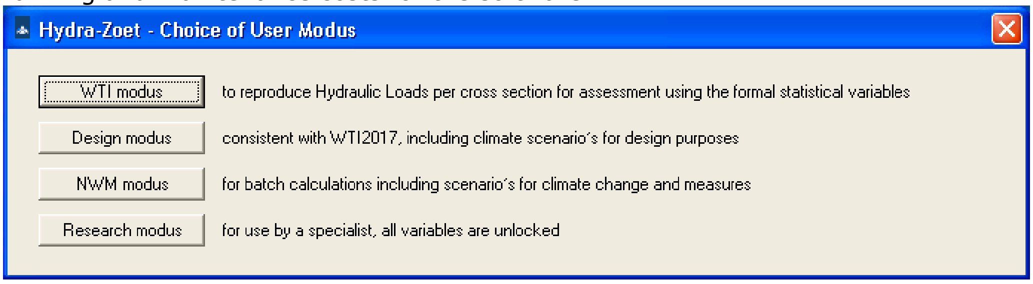


figure 5 Hydra-zoet 2016 (mockup of in English) with different user modes for the same source code

At the moment only two probabilistic model lines are being developed
- Hydra-NL [Duits, 2015]
- Ringtoets (the g*raphical user interface* and Hydra-Ring the probabilistic hart of the model [Roescoe et al, 2016]

2.2 Our recent experience

Formal Flood risk assessment started in 1996. A first assessment report to parliament was submitted in 2001. Funding to improve water defences up to the required standard was allocated based on this report. To simplify decision making the results were binary: a flood defence fails the assessment or a flood defence complies with the standards. However for about 38% of the flood defences no formal result could be given [VenW, 2001]. Since 1996 three formal assessments have been carried out 1996-2001, 2001-2006 and 2006-2011. The percentage of no formal result remained high. This is one of the reasons the 2011-2017 assessment was suspended. The other reason is that the workload from the third assessment was higher than could be carried out in 6 years. During, the whole period between 2001 and 2014, efforts were made to reduce the number of dike sections with no formal result. There are three main reasons why the percentage of no formal result remained high:

- Not all formal rules and software were available at the start of each assessment period. This also meant that training material was not available on time.
- Difficulties in getting the required data (especially getting data on the subsoil, the exact materials contained in the dike and the properties and strength of historical sluices)
- Lack of incentive to make full assessment as flood defence managers had to pay the assessment themselves.

Because of the binary approach not all available information on the state of flood defences is being used efficiently for decision making. In the National Water Plan of 2009 [VenW, 2009] a new policy measure was announced. A binary approach was not considered to be efficient as the number of dikes to be reinforced became higher than the available budget for the allocated time to carry out reinforcements. Therefore the assessment of 2017 -2023 should provide additional information to make prioritization of funds for reinforcement possible. To deliver this information the tools to carry out the assessment should be more precise. Probabilistic tools provide this information. The former semi-probabilistic tools based on safety factors also provide information to what extent on how much a flood defence does not meet (i.e., exceeds) the safety standards, however the information was not used. A binary approach was easier for funding purposes. Also, with just semi-probabilistic tools, it was difficult to combine information from different failure modes. This is however feasible if the probability of flooding is used in a full probabilistic approach.

2.3 What is the assessment of flood defences

Assessment of flood defences essentially means you compare the strength of a flood defence structure with the expected Hydraulic loads. The ultimate limit state of the strength of a flood defence is determined for certain assessment/design loads. In the past, essentially a serviceability state was used for assessments, as managers wanted flood defences to be accessible for emergency measures during a storm. The serviceability state is a more conservative approach. Other conservative approaches have also been hidden in the current assessment rules (see the next section on semi-probabilistic versus probabilistic approach).

Determining the ultimate limit state means describing the uncertainties for both the hydraulic loads and the strength of flood defences in a consistent way. For the WTI2017 project this is described by [Diermanse, 2015]. In the past model uncertainties and statistical uncertainties were not considered for hydraulic loads. This was a national policy choice. Statistical variability of hydraulic loads was considered through the "Hydra-models", see chapter 3. In general adding statistical uncertainties in a wind driven system like Lake Ijssel adds 1meter to the required dike height [Meermans, 1999]. The Hydraulic loads required for the assessment depend on the formal risk-based standards for flood defences (figure 1). The Hydraulic loads are often expressed in design or assessment water levels or the combined hydraulic load of water levels and wave action for a given return period or probability, often expressed as a required dike height (for a given critical overtopping limit e.g. 1 of 0.1 l/s/m.)

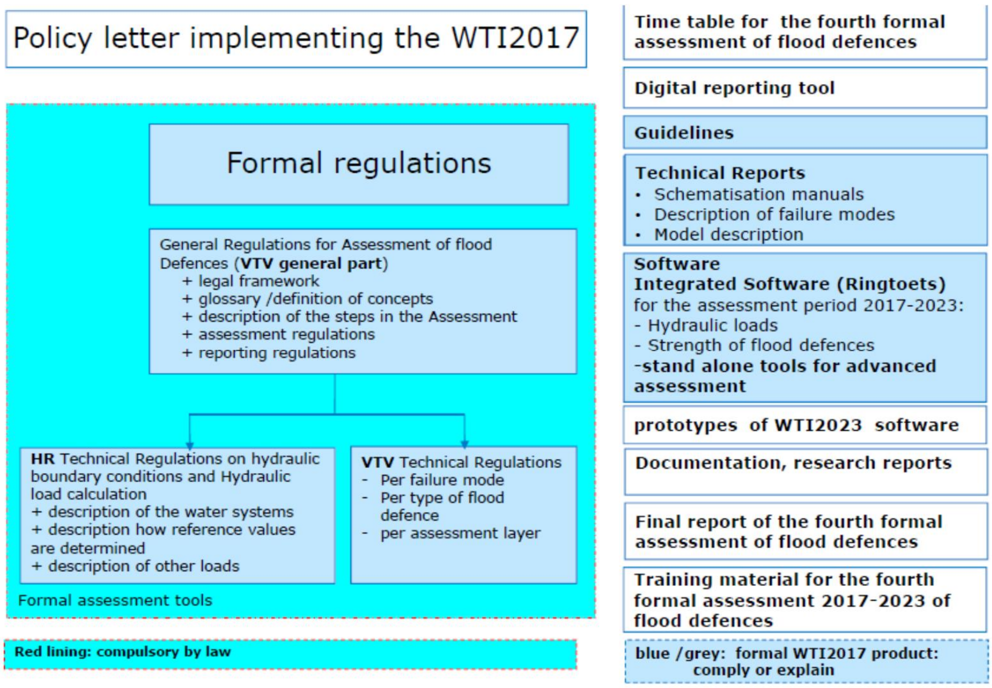


Figure 6: Formal and informal flood defences assessment tools

A mathematical description of the full failure process often does not exist. To determine the ultimate limit state of flood defences one would like to determine the exact moment of failure. This is often not possible. Sometimes only empirical models as the wave run-up model [van der Meer, 2002] are available. Process based models are preferred because uncertainties can be modelled accordingly. However process based models often only describe part of the failure process e.g. the Sellmeijer model [Sellmeijer, 1988] with piping, which describes the transport capacity of an erosion pipe beneath a flood defence. It does not describe how many sand particles get detached to be transported [van Beek, 2015]. The transport capacity is larger than the number of particles which will detach themselves. Information from [van Beek, 2015] is needed to determine a more precise definition of failure for piping. It will take a number of years to develop a working model. Using the Sellmeijer formula means we have a rather conservative approach to piping. Given the difficulties mentioned above, a mix of empirical and processed based models has been used pragmatically in the project. In every assessment period, models are improved so that modelling the exact moment of failure of flood defences gets closer and closer.

The flood defence assessment tools are a combination of formal and informal instruments (figure 4). Some rules and regulations are set by law (left side of figure 6) [IenM b, 2016], other formal rules (in blue/ grey) and instruments have to be used except if they are not applicable. The principle of comply or explain has to be applied for these rules (e.g. schematisation manuals) and software.

2.4 Semi-probabilistic versus probabilistic approach

In a semi-probabilistic or deterministic civil-engineering approach, an expected design maximum load (S) for a the design period is compared with the expected design strength of the structure (R) (see figure 7) [Vrouwenvelder, 2008]. The strength of the structure has to be higher than the expected load (R>S) to pass the assessment. To be sure the situation is safe, a safety factor is often added to the expected strength. The safety factor can be larger due to formal rules or due to policy choices in each country for building codes or design codes. Using large safety factors however is not very cost-efficient. A full probabilistic approach is more cost-efficient in both design and assessment. The first application of probabilistic methods was during the design of the Delta Works, when it was realised that superposition of worst-case assumptions of different hydraulic load components was clearly conservative [Vrijling and Bruinsma, 1980]. Vrouwenvelder has used probabilistic models to determine safety factors for building codes (euro-codes) [Vrouwenvelder, 2008]. Vrouwenvelder also developed the probabilistic PC ring model for flood defences [Vrouwenvelder, 1999, 2001] which was used in the VNK-2 project. This PC ring model was used in the WTI2017 project to determine the first safety factors for flood defences in 2010 using the national data sets for flood defences of the VNK-2 project. In 2017 all safety factors will be calculated using the new software. This consistency between probabilistic tools and semi-probabilistic tools is essential in the WTI2017 approach.

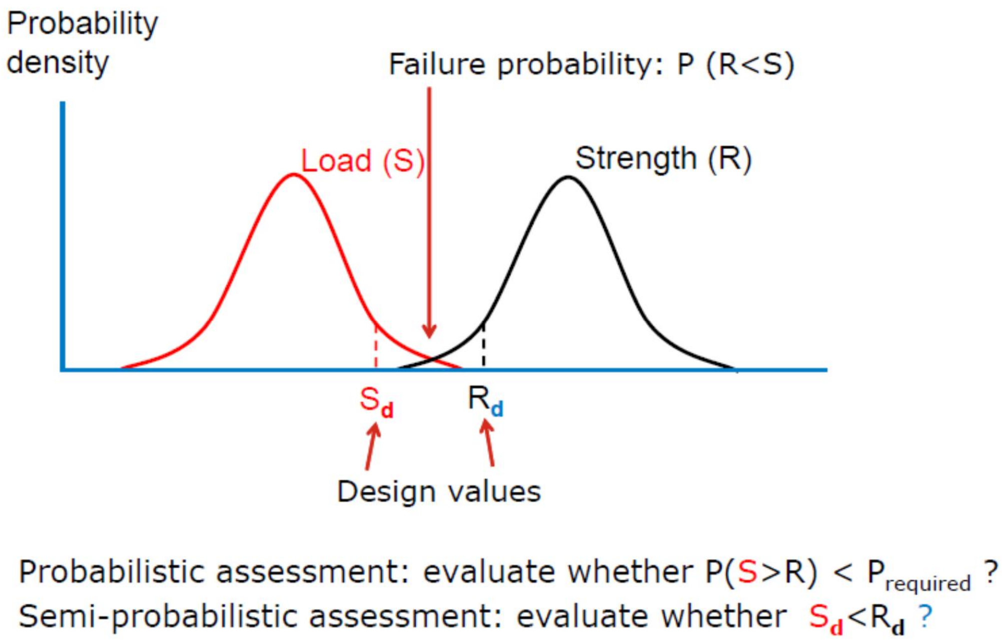


Figure 7. How a structure is assessed both using probabilistic and semi-probabilistic assessment, the figure also shows the relationship between both techniques

Determining which factors to include in a full probabilistic model and in a semi-probabilistic model and how to provide all the data to run the model is the main issue. In a semi-probabilistic approach one often adds to safety factors if a variable cannot be modelled correctly. In a probabilistic model adding all theoretical stochastic variables provides a scientifically correct model which however will never run. Both dilemmas have to be tackled pragmatically. Throwing out stochastic variables or replacing them with an good mean value can significantly reduce the number of variables in probabilistic model and will not provide a lesser result. This a process that takes time, it is based on past experience, trial and error. The model is improved step by step over time. Other models are often needed for calibration purposes. One of the main issues for system reliability is modelling the spatial correlation of interdependent variables. This is an issue for both hydraulic load modelling and strength modelling. for the latter this has also covered by [Vanmarke, 2011]. For Hydraulic load modelling this has been successfully achieved and also theoretically correct [Geerse, 2011]. This has been possible through using Hydrodynamic models as WAQUA [Rijkswaterstaat, 2012], SWAN [Zijlema, 2007] and SOBEK [Deltares, 2016] to interpolate between the sites with sufficiently long time series where water levels and waves are measured and by using the Hydra-Model [Geerse, 2011]. For the strength models piping and slope stability a number of assumptions have been made based on information on geological deposits under flood defences and how we model the failure modes [Vrouwenvelder, 2006] and [Roescoe et al, 2016]. These assumptions work, however they are not ideal; the choices remain black boxes for many involved in flood defence assessment.
In the case of flood defences (dikes, dunes and Hydraulic structures), hydraulic loads are the determining loads for design or assessment purposes. The expected mean maximum load is considered for different return periods, expressed in the probability per year. In the Netherlands these values currently vary from a probability of 0.004 per year (river dikes along the Meuse to 0.0001 per year for coastal flooding, see figure 1).

2.5 Failure modes

In the 2006-2011 assessment about 40 failure modes. were considered. Now we focus on the most relevant failure modes (about 20, see figure 8).

Figure 8 represents a simplified fault tree for flood defences. In the 2017-2023 assessment all inspection techniques which have to do with maintenance were removed from the formal assessment. These inspections have to be carried out several times within the 6-12 year safety assessment period, so that repair can more adequately be linked to the inspections (either programmed or after storms and high-discharge events) than to the 6-12 yr assessment. Note that some damages like foreshore failure, slope-instability or severe revetment damage cannot be repaired in a short period. Other examples of assessments which have changed concern the risk of failure due to the existence of pipes, cables and other types of structures (e.g. trees, utilities and houses) in and on flood defences. These failure modes can be considered as scenarios in the formal assessment. Each scenario is given a certain probability.

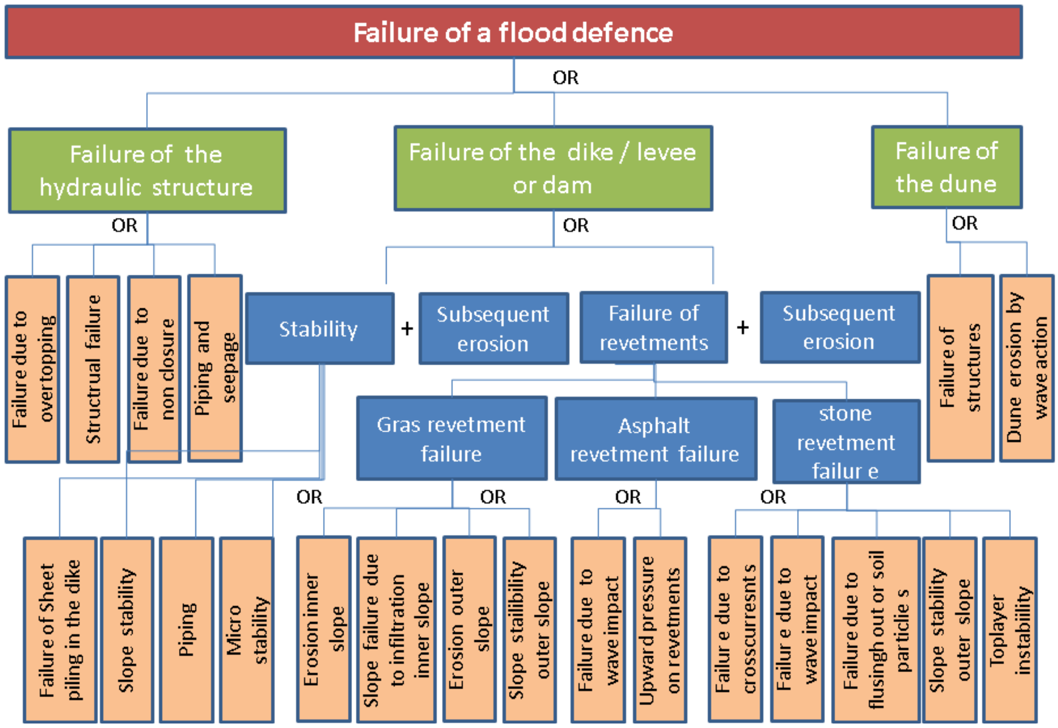


Figure 8. fault tree for the flood defences

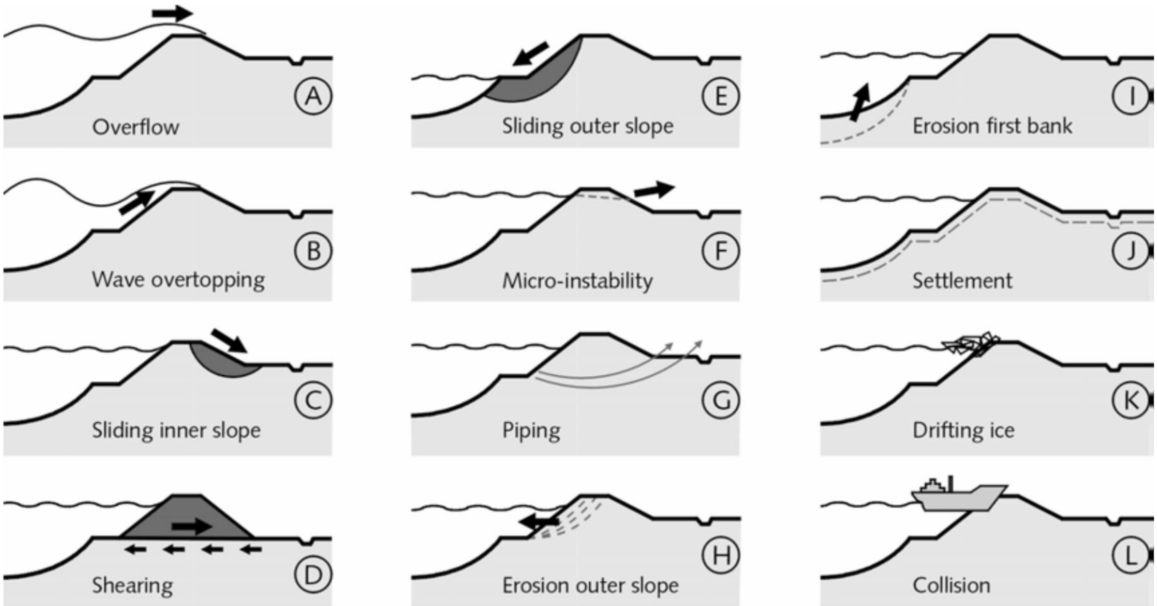


Figure 9a. A summary failure modes [TAW, 1998]

Three types of flood defences are considered: hydraulic structures, dikes and dunes. Transitions between these structures and hybrid structures also have to be assessed. These will be covered in paragraph 2.7. In figure 8 a simplified fault tree has been shown. Figure 9 shows each failure mode in an image.

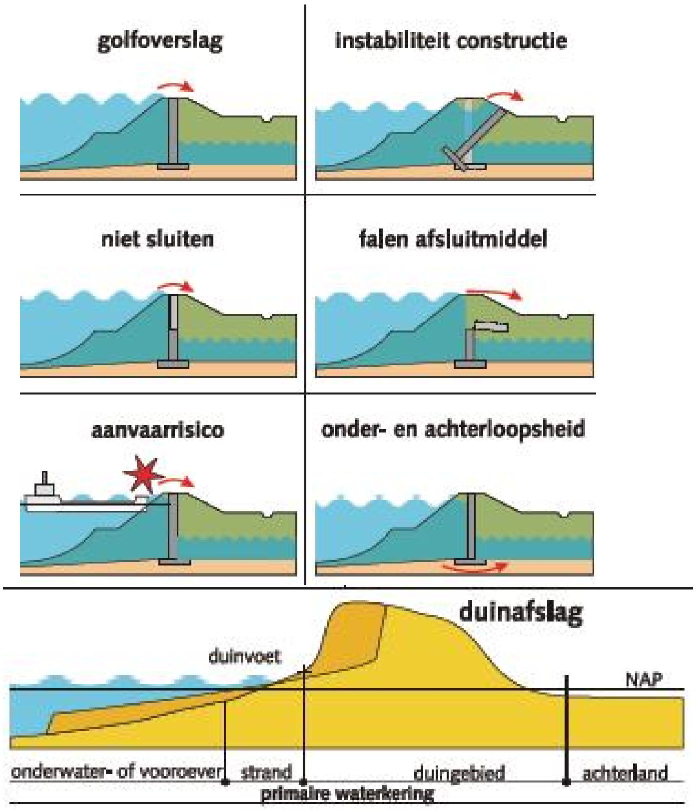


Figure 9b. A summary of the flood defences Assessment rules for structures and dunes, [TAW, 1998]

2.6 Hydraulic loads –using more and more climate data

Data to determine Hydraulic loads has to be updated every 6 years. From 2023 this will be every 12 years. Observed climate change and measures which influence hydraulic boundary conditions, like the Room for the River project [Slomp, 2012] have to be accounted for in each update. Statistical data from a large number of sites which measure wind speed, discharges and water levels have been used to determine extreme conditions. Time series for water level and discharge measurements vary from 100 to 200 years [Chbab et al, 2002] and [Chbab, 2016]. Often the last 100 years are reliable (with one or more than one measurement per hour). For river discharges we have used climate models to determine new statistical data based on 50000 years of discharges of the Rhine and Meuse rivers. The generated rainfall and discharge extremes (GRADE) project took 20 years to complete. In essence a time series of 50000 years of discharges is generated using about 30 years of climate data [Hegnauer et al, 2016]. A similar method was used with a generated time series of 3500 years to determine storm surges on the North Sea. This data was used to verify the statistical extrapolation and to determine the statistical uncertainties [van den Brink, 2015].

2.7 A layered approach

At the moment there is three step approach in flood defence assessment (see figure 10), simple assessment, detailed assessment and advanced assessment. A second detailed assessment layer was added, full probabilistic assessment. For the whole Dutch community of engineers involved in assessment, design and maintenance, it will take time to understand the step towards a full probabilistic approach. This three step approach (figure 10) proposed below is therefore important for educational purposes.

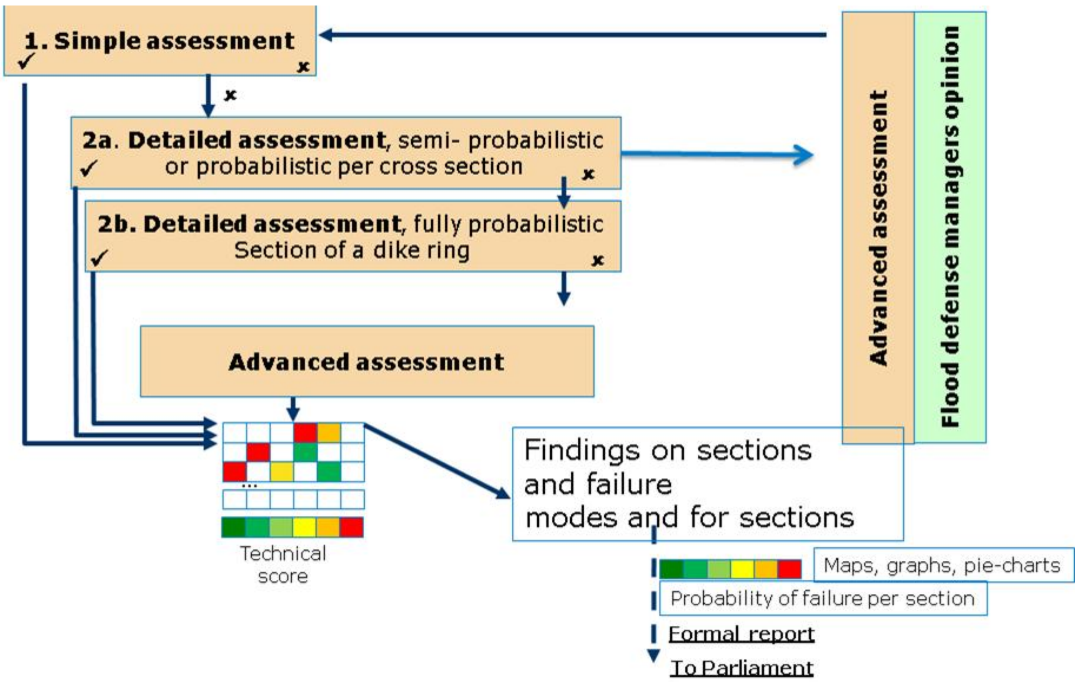


Figure 8. a layered approach for flood defence assessment

The three step approach is comprised of :

- a simple assessment to determine if the flood defence has to be assessed for a certain failure mode: Does the failure mode to be considered have a negligible contribution to the probability of failure? This is based on the relevance of the failure mode, on whether a hazard for the flood defence exists independent of the hydraulic load or whether the Hydraulics loads will never endanger the flood defence. The purpose of this assessment is to reduce the amount of data one has to collect. In the next few years we will reduce the cost of data collection and analysis by using more and GIS based tools. This step will be less and less relevant.
- a detailed assessment, now a two-tier approach
  - first (step 2a) a semi-probabilistic analysis for dikes for geotechnical issues and outer revetments for narrow homogeneous sub-sections (50 to 100 meters wide)
  - or (step 2A) a probabilistic approach for overtopping an inner slope erosion, overtopping for narrow homogeneous sections sub-sections (50 to 100 meters wide) or hydraulic structures
  - then a full probabilistic analysis (step 2 b) for all failure modes per full 5-20 km section of a dike ring (figure 3); for each failure mechanism, these full sections may be composed of several independent sub-sections.
- advanced assessment. New research can be used here. The WTI2017 project gives advice on what is available on the National website http://www.helpdeskwater.nl/ The person using the new research first has to prove it is relevant for the purpose of the assessment of flood defences. Transitional structures and hybrid structures (e.g. dike in a dune) will be assessed this way. A dike in a dune can also be assessed using the formal tools but it can then be assessed as only a dike. The residual strength provided by the dune can be assessed separately. The experimental model Xbeach can also be used [Roelvink et al, 2009] in Morphan [Lodder en Geer, 2012] to evaluate hybrid structures dikes in dunes and the influence of structures on dune erosion (e.g. bunkers from the Atlantic Wall).

2.8 The calibration process, determining safety factors for semi-probabilistic assessment

For the detailed semi-probabilistic assessment new semi-probabilistic assessment rules have been determined using the full probabilistic models. This process is called the calibration procedure and is covered in [Jongejan and Calle, 2013], figure 11 gives a summary of the procedure.

	Type of section of flood defences	
Type of flood defence	Dunes	Dike/levee
Dikes		
Overflow and wave Overtopping	0,0[24]	0,24
piping, heave and rupture of the cover layer	0,0	0,24
Slope stability (inner slope)	0,0	0,04
outer revetment failure	0,0	0,10
Hydraulic Structure		

[24] Overtopping of Dunes is an advanced assessment

failure due to non- closure of hydraulic structure	0,0	0,04
piping at a hydraulic structure	0,0	0,02
structural failure of a hydraulic structure	0,0	0,02
Dune		
Dune erosion due to wave action	0,70	0 / 0,10[25]
Other		
other failure modes (no probabilistic model available)	0,30	0,30 / 0,20
Total	**1**	**1**

Table 1: Maximum allowable contribution to the probability of flooding

(1) The first step is to establish a reliability requirement: This is carried out per failure mechanism. Each mechanism has a maximum allowable contribution to the probability of flooding (table 1). This is a choice based on experience, which is based on past design practices and existing dikes and dunes. This requirement is defined as a maximum allowable probability of failure for the failure mechanism under consideration. In practice, length effects are also accounted for as the semi-probabilistic assessment takes place on relatively narrow sub-sections of a dike.
(2) The second step is to carry out probabilistic and semi-probabilistic analyses for a set of cases for a selection of flood defences. This step is comprised of the following, closely related activities:

- Decide on the stochastic variables and safety factors that are to be included in the semi-probabilistic assessment rule.
- Select a characteristic set of cases (test set). These may concern existing or generalized so fictitious cross-sections of levees, dunes or hydraulic structures, depending on the type of failure mechanism considered. In the WTI2017 project the VNK-2 national data sets were used.
- Modify the members of the test set so that they comply with the semi-probabilistic assessment rule, that is, by changing their height or width, for different values of the safety factors.
- Calculate failure probabilities for each case, that is, for every modified member of the test set.

(3) The third step is to apply a calibration criterion to select the safety factor(s). This is based on the outcomes of the probabilistic analyses, the values of the safety factor(s) are chosen such that a predefined calibration criterion is met. The calibration criterion provides a reference for deciding which values of the safety factors are sufficiently safe.

[25] Some inland water sections (closed off estuaries contain dunes.

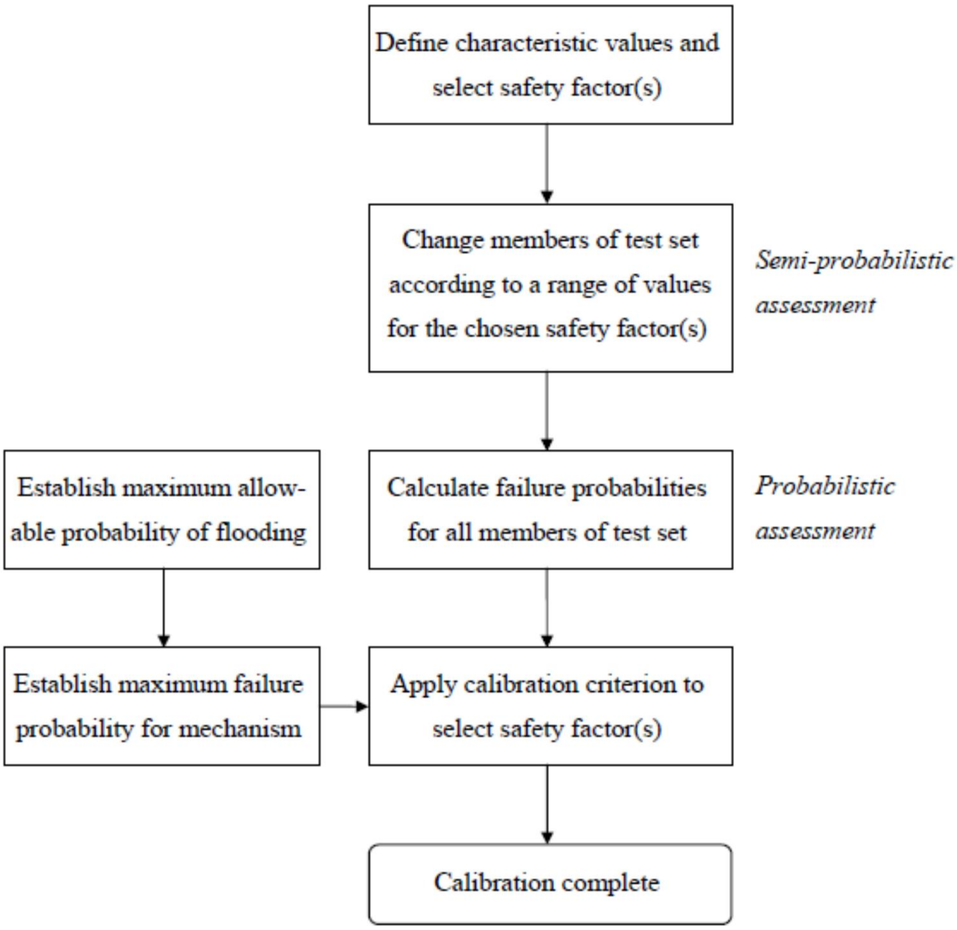


Figure 11. Schematic overview of the calibration procedure [Jongejan and Calle, 2013]

The use of these safety factors in the semi-probabilistic assessment is more conservative than a full probabilistic analysis. The purpose of the using semi-probabilistic assessment (layer 2a in figure 10) is to quickly determine if a flood defence fulfils the standards for flood defences. If it fails one carries out a full probabilistic analysis in layer 2b. The maximum allowable contribution to the probability of flooding per failure mode is a project choice and has been documented in [De Waal, 2014 and 2016].

3 Software:

Software only works if the necessary data is made available.

In 2006 there were probabilistic tools for determining Hydraulic loads and deterministic (semi-probabilistic) tools for the strength assessment of flood defences (see figure 12)

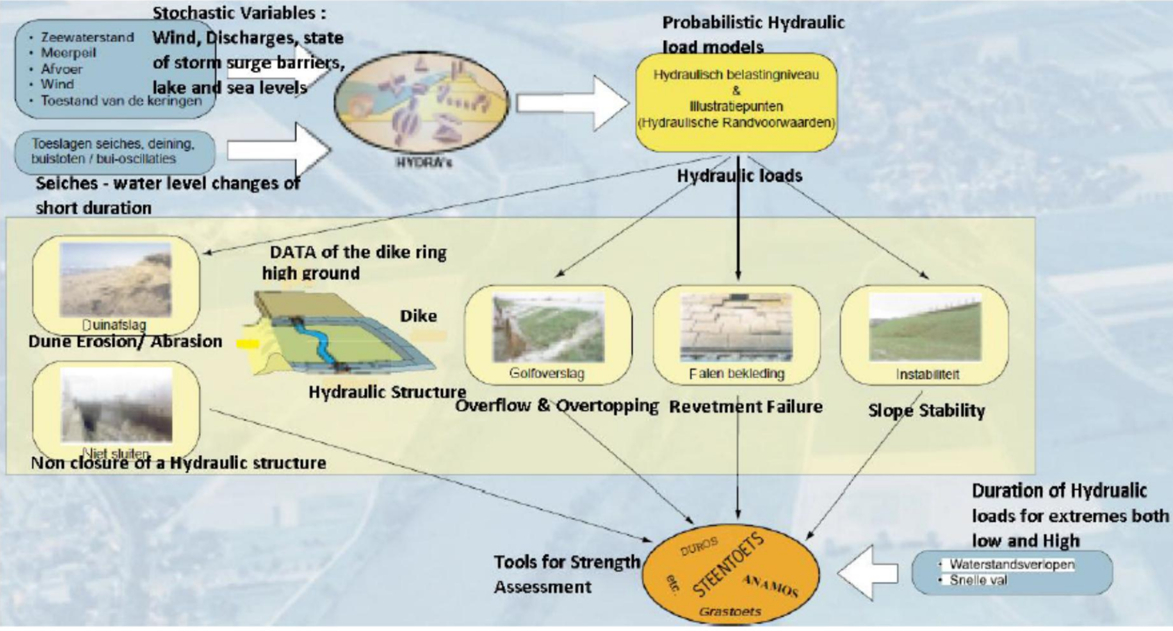


figure 12: workflow of for the assessment of flood defences in 2006[26]

In figures 13, 14, 16 and 17 examples of the workflow and the necessary software tools of WTI2017 are given. Data management issues themselves will be covered in the next chapter.

3.1 Current software tools

Life cycle management for current and future software tools has been taken up systematically since 2007. This has been formally documented for current tools by [de Waal, 2013] and for future assessment tools [de Waal, 2014] and for design tools by [Den Heijer, 2010].

3.1.1 Hydraulic Load Models

The current formal software (assessment, and design tools) are focussed on dike overflow and overtopping, Hydra-Zoet [Geerse, 2011] and Hydra-K [den Heijer et al, 2008]. These models need information about the flood defences (form, angle of the flood defence and roughness of the revetments (grass, stone, asphalt)) to determine hydraulic loads for overtopping and revetments.

[26] Note for piping we used Bligh in 2006 [Bligh, 1910].

These models will be replaced by the model Ringtoets with a full probabilistic kernel "Hydra-Ring" [Roscoe et al, 2012].

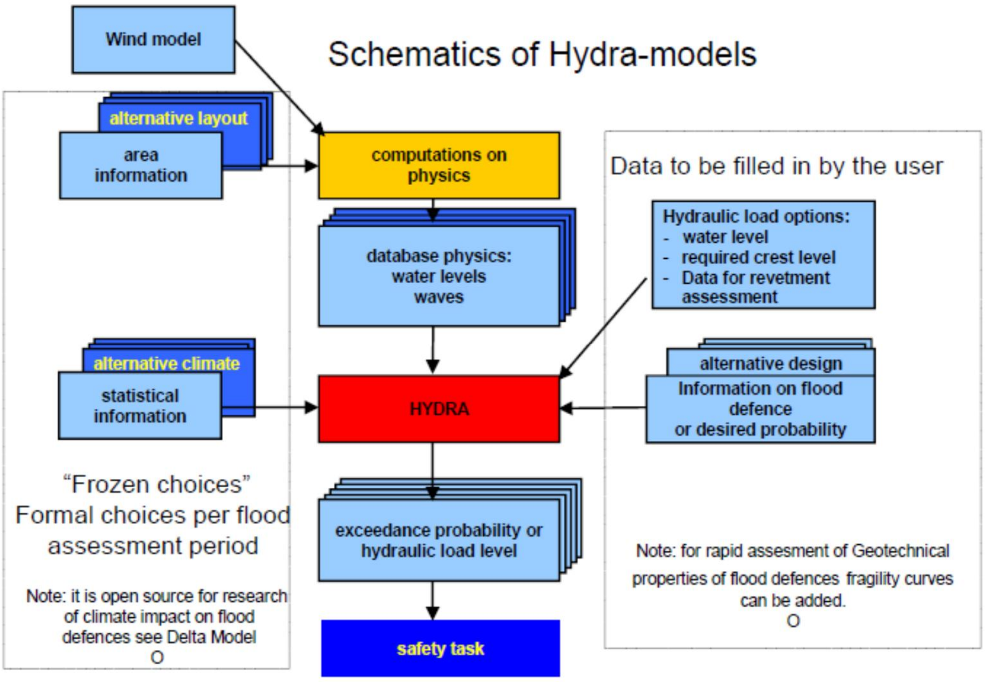


Figure 13. Hydra-Schematics for determining Hydraulic loads

The main concept of Hydraulic load models, Hydra-models [Geerse, 2011] is that a large database is made with all states of the water system for situations varying from a 1 in 10 year event to a 1 in 100 000 year event (figure 13). For each stochastic variable water level statistics for coastal stations, discharge statistics and wind statistics are determined for the whole range mentioned above. The models can be used for assessment, design and policy studies [Slomp, et al, 2014]. The Hydra-models primarily use the overflow/overtopping failure mode description to determine all possible wave run up or overtopping possibilities and then weigh each situation to determine the probability of failure or the desired assessment height. This depends on the input. If you desire the probability of failure you fill in / schematise the flood defence including its height. If you wish to calculate the desired dike height you only schematise the flood defence slope and roughness properties. The different states of the water system are calculated using hydrodynamic models such as WAQUA (water levels, currents) and SWAN [Zijlema, 2007] (waves). For each state the maximum combinations of water levels and waves are filtered out [Santbergen, 2005] for deep water locations (coast), locations on the river axis ("thalweg "), just in front of the foreshore and near the flood defence (figure 14).

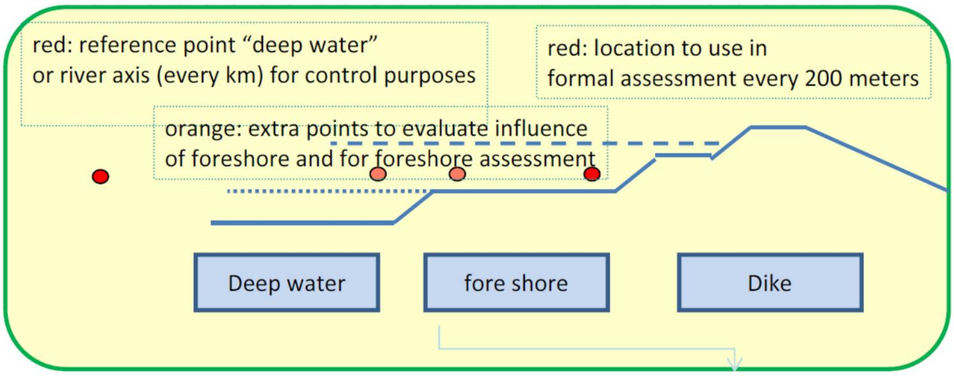


Figure 14a. Location for hydraulic load data for dikes

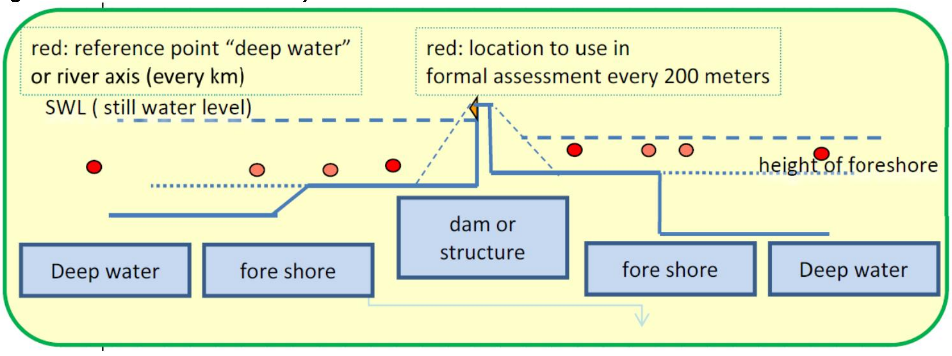
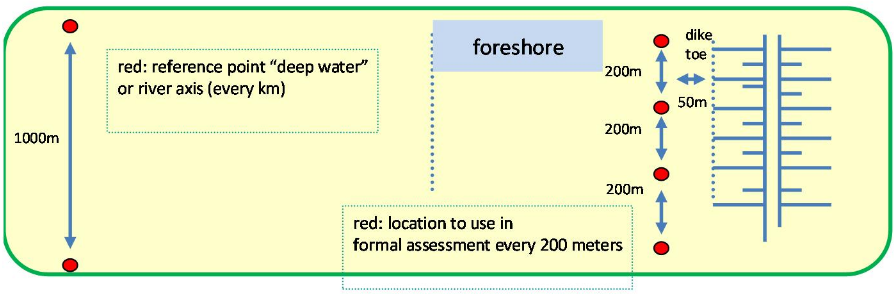
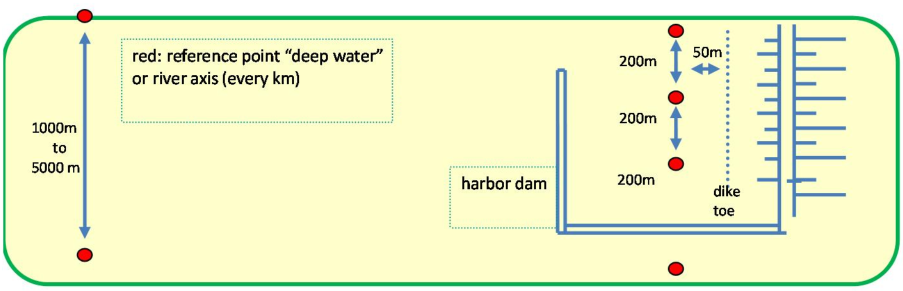


Figure 14b. Location for hydraulic load data for dams and structures (cross section)



locations for hydraulic load data



locations for hydraulic load data at a dike protected by a harbor dam

figure 14c. Topview locations for Hydraulic load data

For complex estuaries with storm surge barriers about 20 000 calculations with WAQUA and SWAN are needed. If all separate gate failure modes all included (e.g.

Eastern Scheldt Storm Surge Barrier) about 7 million calculations are needed and a 1-dimensional hydrodynamic model is used (e.g IMPLIC [Rijkswaterstaat, 1984] or SOBEK. Modelling the variability and statistics for wind speed and wind direction is extremely important [de Waal, 2003], [Caires et al, 2009] and [Caires 2009]; wind duration must be considered as well. Modelling the spatial variability of wind during one storm event is done rather pragmatically and not in a full probabilistic form. Research within the WTI2017 project shows this is not yet feasible with the chosen approach [Jongejan, 2013]. In 2017 and 2018 research using climate models will continue the work of van den Brink [van den Brink, 2008 and 2011]. A major issue is tackling 50 000 years of SWAN wave data. This will be used instead of statistical extrapolation techniques, which were investigated up till now in the WTI2017 project [Groeneweg et al, 2012].

3.1.2 Strength models for Dikes and Dunes

No formal tools exist for piping and slope stability.

For piping Bligh was used in the third assessment period 2006-2013. For slope stability Deltares (previously GeoDelft) has developed the model Dgeostability [Deltares, 2011], formally Mstab for Rijkswaterstaat in the past decades.
The model Morphan [Lodder en Van Geer, 2002] has been developed for coastal zone management, to program the beach nourishment program.

The model Golfklap [de Looff, et al, 2006] has been developed for the assessment of Asphalt revetments.

The model Steentoets (formally Anamos) [Breteler, 2014] has been developed for the assessment of stone defences on the outer slope.

The model Grastoets [van Nieuwenhuizen, 2005] has been developed for the assessment of gras defences on the outer slope.

3.1.3 Hydraulic Structures

No formal software tools exist for strength assessment of hydraulic structures.

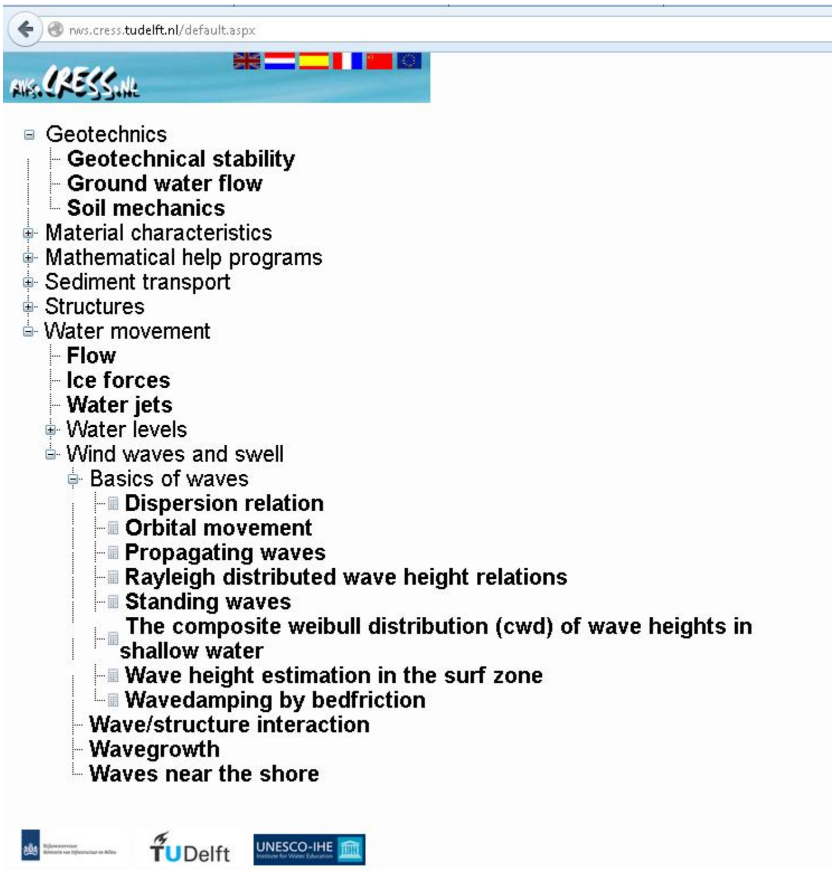


figure 15 website of the cress models and documentation

Rijkswaterstaat has provided models in the CRESS project[27] (figure 15) for hydraulic structures. These include both hydraulic load models and strength models. Hydraulic loads have to be determined through the Hydra-models. So the CRESS model can only be used if the Hydra-model does not provide the hydraulic load.

For evaluating hydraulic structures the VNK project developed assessment tools, these were used in the VNK policy study.

3.1.4 *Advanced assessment tools*

The Netherlands has participated in a number of manuals and handbooks.

- the Rock manual [CIRIA, CUR, CETMEF 2012]
- Eurotop manual [EA, ENW, KFKI, 2007]
- International levee handbook [CIRIA, 2013]

These manuals and handbooks can be used in advanced assessment. The person using the tools has to prove they are applicable in the formal assessment.

3.2 WTI2017 software tools

The source code of software has been written from scratch and set up in a modular way to allow for updating and multiple applications (assessment, design, policy and maintenance studies). The main tools (see figure 16) are the user interface,

[27] http://rws.cress.tudelft.nl/default.aspx

"Ringtoets" and the probabilistic kernel "Hydra-Ring" (not shown in figure 16), the pre-processing tools Dsoilmodel and Morphan, and the kernels for each failure mode (not shown in figure 16). This was done to be sure there are no "hidden" safety factors in the code, software errors or choices by programmers which have not been documented. Algorithms from past software e.g. from the PC-Ring code have often been re-used.

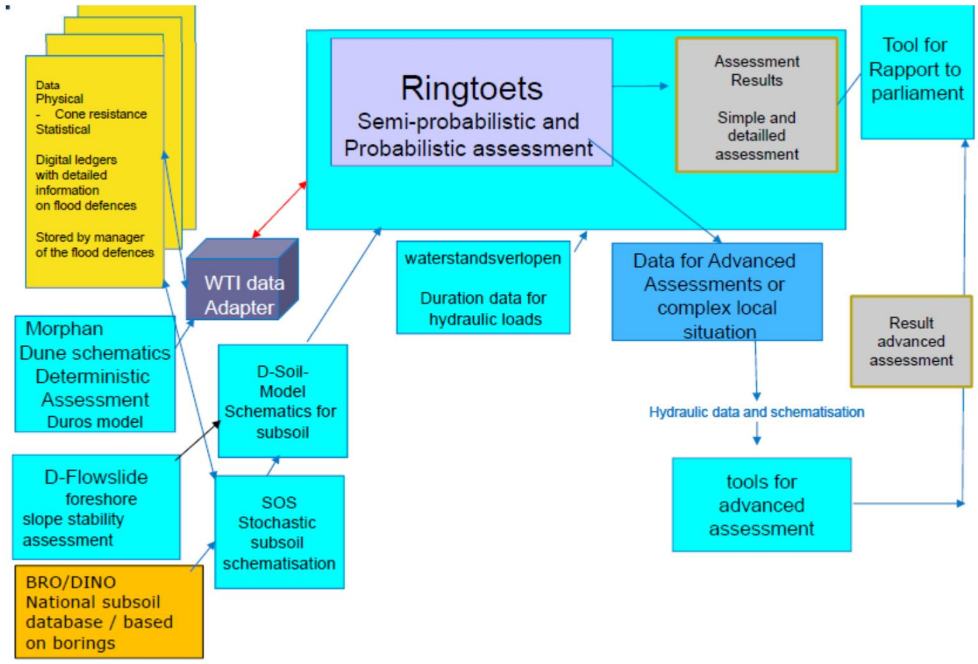


Figure 16. An overview of the WTI2017 assessment tools (software) and workflow for primary flood defences

For extremely complex flood defences additional models and software have been developed (figure 17). New standalone software has been developed or is under construction and will be ready on January 1st 2017. For slope stability of the fore shore we have developed Dflowslide. For revetments a number of models are being redeveloped. "Steentoets" [Kramer, 2015], Waveimpact in Dutch "Golfklap Asfalt" [Bokma, 2015a] and "Grastoets" [Bokma, 2015b] as well as for geotechnical analysis (e.g. Dgflow for piping) [van Esch, 2013]. The models will first appear with a Dutch language user interface, due to the formal character of the assessment tools. For educational and research purposes at the Delft Technical University English user interfaces will be developed by Rijkswaterstaat in 2017 and 2018. The Hydra-models for assessment and research Hydra-B and Hydra-BT for the Rhine-Meuse Estuary are already available in English for [Duits, 2004 and 2006].

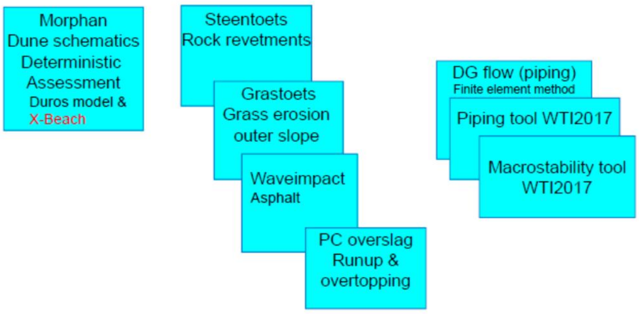


Figure 17. Advanced assessment tools (software) WTI2017 for primary flood defences

4 Data Management

Introducing new software means introducing new data formats. Data management is costly and has to be done efficiently. Regional Water Authority and most services of the National Water Authority, Rijkswaterstaat, each have their own database systems with data on flood defences. Institutional barriers make common data storage choices difficult. This data on flood defences has to be schematised before it can be used in the WTI2017. The source data and schematised data have to be accessible for other processes e.g. maintenance and for the re-design of flood defences. Having meta data is essential in this process as they provide the link between the results of the assessment, the schematised data and the source data. This will be a major improvement compared to past assessments and compared to policy studies as VNK-2 and WV21.

The WTI2017 project has chosen GIS shapes files as "data carrier". The GIS coordinates of the outer boundary of the crest of the flood defense has been modelled in the National Repository of flood defence data, "Nationaal Basisbestand Waterkeringen". Per failure mode cross sections of schematised data on flood defences are added to this file by the manager of the flood defences.

Data exchange formats between software tools are being elaborated with the regional water authorities and the National Water Authority. This AQUO standard http://www.aquo.nl/aquo-standaard/ is set by the Informatie Huis Water (IHW) in close cooperation with the WTI2017 program. Post processing tools, a national website to present all assessment results and the progress of reinforcement projects will also be developed by IHW.

A number of pre-processing tools have been developed to facilitate this process.

- Dsoilmodel for subsoils
- The Profile generator for height assessment (overflow /overtopping) and determining hydraulic loads for revetments (grass, asphalt, stone).

4.1 Dsoilmodel, schematisation tool for subsoils

The Dsoilmodel [van Zwan, 2016] uses the National registry with subsoil information[28] based on boreholes and cone resistance data to construct a general subsoil schematisation which is geologically correct (figure 18). The user builds a local schematisation using additional information from local and dedicated measurements. The information is run in the Ringtoets model (see figure 16). If the results are not satisfactory more field research will be necessary. A new local schematisation has to be made and the Ringtoets program has to be rerun.

[28] http://www.broinfo.nl/

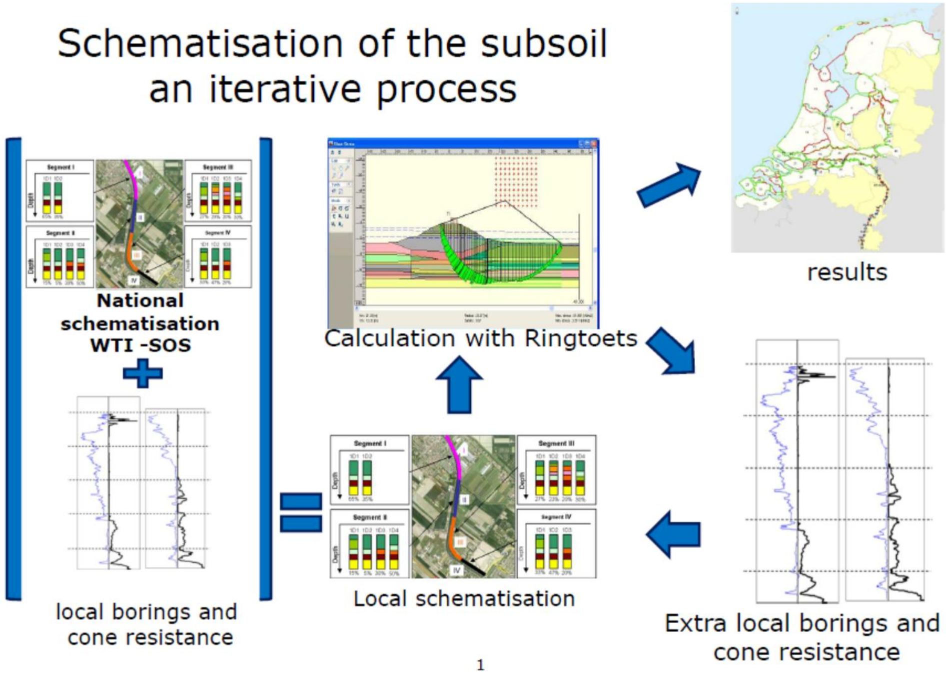
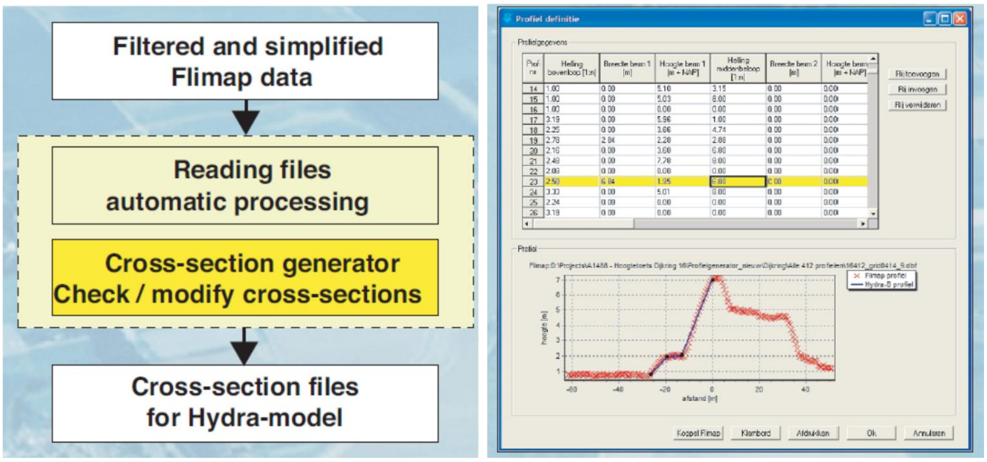


Figure 18: Schematisation for the subsoil.

4.2 Profile Generator

Currently pre-processing tools are being (re)built to comply with the WTI2017 software standards for erosion en wave impacts on outer revetments, for wave run-up and overtopping. This will be carried out in close cooperation with staff from the regional Water Authorities. They have often built similar tools in the past.

One important tool is the "profile generator" (figure 19). This uses measured dike profiles or cross sections derived from the national digital terrain model AHN2[29] or other digital terrain models (e.g. Fli-Map data[30]) to generate dike profiles for overflow/overtopping and for determining Hydraulic loads



[29] http://www.ahn.nl/pagina/viewer.html

[30] http://www.fugrogeospatial.com/capabilities/aerial-mapping/fli-map/

figure 19: workflow for making cross section data and example of the cross section generator

5 Implementation

To facilitate the implementation of the new flood risk management policy of lot of extra programs were set up and activities within WTI2017 were carried out.

- The national advisory committee on flood risk management "ENW", previously the TAW[31] has been continuously involved in quality control. In September 2016 they will formally advise the minister of Infrastructure and the Environment on technical applicability of the new tools.
- The stakeholders have been involved closely. This concerns:
    - engineers who manage flood defences – staff from the regional water authorities and Rijkswaterstaat, the national water authority. They have been involved in user trials in 2014 and 2015. They have been asked to give feedback on the practical applicability of the new tools and regulations. This group of staff from regional water authorities and Rijkswaterstaat will continue giving feedback in 2016.
    - consultants who carry out a large part of the work during the assessment period. They have carried out both technical reviews and reviews on the combined use of the new regulations and software.
- The new concepts from the WTI2017 project [Rijkswaterstaat, 2015] are being used in current design projects. These projects still use former semi-probabilistic design practices but with new design rules set by the WTI2017 project. Feedback from recent design projects has led to some changes in the rules and schematisation manuals
- A parallel project (OI2018) will provide a full set of new design tools in 2018 based on the WTI2017 tools. Every year this project chooses which of available WTI2017 and WTI2023 rules and tools will be made available to designers of flood defences and how to adapt assessment tools to design tools.
- Policy tools will be updated from 2019 onwards. Monitoring of the policy change will start soon. Consistency between flood risk assessment tools, design tools and policy analysis tools remains essential for this policy change to succeed.
- A team of coaches, organised by Rijkswaterstaat and the Regional Water Authorities, "KPR" gives advice to current individual design projects. Participants, often consultants, who gained experience during the VNK-2 project play a large role as coaches.
- An ultimate trial in September 2016, this is a practice run with the new tools, documents en software with staff from all the managers of the flood defences and a large selection of the consultancies.
- A large training program for soil laboratories, consultants and flood defence managers has been started to introduce new rules concerning slope stability. New rules for field test and soil laboratory tests have been elaborated.
- Since 2009 every year progress in the program was discussed with stake holders in symposia, workshops and published on a national website "Helpdesk Water"
- A general training program has been started for policy advisors (in 2015), for engineers involved in the assessment of flood defences and design (from 2016).
- A special training program was set up by Rijkswaterstaat in 2015 to train the staff from the Human Environment and Transport Inspectorate.
- A new more professional approach to data management is needed. Two organisations are tasked to provide assistance IHW and Waterschapshuis. IHW is a collaboration between the regional water authorities and the national Water

[31] Technical Advisory Committee on water Defences, http://www.enwinfo.nl/

Authority Rijkswaterstaat and provides standard definitions for all input and output variables. They will provide a postprocessing tool on the internet. Waterschapshuis, a collaboration between the regional water authorities provides a new database structure to store data on flood defences. They will provide part of the pre-processing tools. The WTI2017 project will provide money to generalize data management pre-processing tools developed by regional water authorities for the others. These will be open source programmes. GIS formats, shape files, will be used to carry source data and schematized data. We use proven technology which people are familiar with.

6 Design according to new standards since 2014

After the 3rd formal assessment period 2006-2011 the first estimate for reinforcements according to the current design standards was more than 7 billion euros and impossible to carry out within 6 years. This was one of the reasons to accelerate the proposed change [TAW, 2000] in Dutch flood risk management policy. A more risk-based method was needed to use the available budget more efficiently.

In 2012 Rijkswaterstaat proposed to make design tools available on short notice based on the WTI2017 philosophy but using the available tools. Design standards are never formal. The national advisory committee on flood risk management "ENW"[32] provides guidelines. The manager of the flood defences (regional water authority or a regional service of Rijkswaterstaat) has to prove the design is done according to the latest information, dikes had a design life of 50 years, (foundations of) hydraulic structures a design life of 100 years. The designer has to prove the design will pass the next assessment and that a design is expandable after 50 or 100 years (without major costs).
In each design period 1990-2001, 2001-2006, 2006-2011 had different financial arrangements. These financial arrangements often were combined with other regulations, and therefore often functioned as formal design rules.

Design for flood defences in the Netherlands has to take into account observed climate change [IenM, 1996]. Design for storm surge barriers also took into account projected climate change [van Urk, 1989]. Observed changes to design discharges were accounted for through a number of Room for the River projects from 2001 until 2017. For room for the river measures projected climate change could be taken into account if a cost benefit analysis proved it was an efficient measure, relocating a dike twice in 50 years is often not cost efficient. Taking into account projected climate change for dike design was formally implemented in the National Water Plan of 2009[33].

In January 2014 a document[34] [Rijkwaterstaat, 2013] was provided to make designs based on the probability of flooding possible. The main reason was not to design dikes with the former flood defence standards and assessment rules and to have these flood defences fail the next assessment directly after construction. Since WT2017 assessment rules were not fine-tuned in 2013 a certain conservative approach is accepted. It is less expensive to over dimension current designs than to have to come back and redesign a flood defence.

6.1 Hydraulic loads

Two models for Hydraulic loads including Hydra-Zoet [Duits, 2014] and Hydra-K [Thonus, et al, 2012] were provided for this purpose, both models can take climate change (changes in river discharges and sea levels into account. Data sets with Hydraulic Boundary conditions (water levels and waves) for different climate

[32] http://www.enwinfo.nl/
[33] https://www.rijksoverheid.nl/documenten/rapporten/2009/12/01/nationaal-waterplan-2009-2015
[34] http://www.hoogwaterbeschermingsprogramma.nl/Documenten+openbaar/Kennis+en+Innovatie/default.aspx#folder=274378

scenarios were provided using the Delta model [Slomp et al, 2014] for river systems.

The National Water Plan of 2009 has chosen for an IPCC scenario with an 10% increase in river discharges (due to higher rainfall) and 1 meter of sea level rise. At this moment climate scenario's do not have a probability. This is currently being investigated there are no formal documents available [Smale, 2016].

The most important change was a reduction of the criteria for overtopping. The accepted critical overtopping rate was increased from 0.1 l/s/m and 1 l/s/m to 5 or 10 l/s/m. This significantly reduces the necessary dike heights.

A deterministic approach from 2009 for design was used to determine surcharges in meters. This concept was introduced in 2009 because many people find probabilistic design difficult to comprehend. This was a policy decision [Rijkswaterstaat 2008] and [VenW and ENW, 2009 a and 2009 b]. Explaining complex policy decisions in a simplified way to the general public, not to endanger the projects themselves was considered more important than cost efficient design rules. That it is possible to find a trade-off between both dilemmas was proven by the Room for the River project [Slomp, 2012] . Simplifying complex decisions e.g. the risk based approach to be understood by the general public without losing the essence of the risk based approach is the main issue to tackle in the near future.

The two supplements for dike heights were

- 10 to 30 cm for to dike height due to the uncertainty in water levels
- a supplement of 10% for wave heights for uncertainty along the coast and along the shores of large lakes.

In 2014 this concept was not changed because overall supplements for all water systems for uncertainty were considered generally correct with the PC ring model [Nicolai et al, 2010].

6.2 Geotechnical failure modes

For piping and slope stability conservative design rules were derived. These will be fine-tuned in September 2016.

Design for slope stability also has to address the construction phase. Slope stability during the construction phase is a temporary but essential issue to cover.

6.3 Design of outer revetments

For revetments the current models for stone revetment (Steentoets), asphalt (Golfklap/Waveimpact) and grass (grastoets) have been updated in the WTI2017 program. They will be made available in September 2016.

6.4 Innovative design

Flood defences most often have multiple functions. In cities where space is scarce budgets are higher to accommodate for different functions. The HWBP program only finances the flood defence aspect of flood defences, other parties have to finance the other functions. To assist in this process a manual was written to describe the process for innovative design [Knoeff et al, 2013].

7 A changed maintenance of Flood Defences

The 23 Regional water authorities (formally the 2400 water boards) and the regions of Rijkswaterstaat are responsible for the daily maintenance and crisis management of the 3600 km of primary flood defences ,15000 km of secondary flood defences and 55 000 km of secondary waterways in the Netherlands.

In 2009, in the Water Act, the inspection on how flood defence managers and water managers carry out their tasks was centralized, the inspection (ILT) is now responsible. The provincial governments are no longer responsible for inspection. They remain responsible for oversight of the organisational and financial aspects of regional water authorities and for spatial planning.

With the introduction new risk based flood defence standards and new assessment rules the reference levels for maintenance have changed. This means the whole process of how maintenance is carried out has to be reviewed.

An important funding and responsibility issue was tackled in the past; ownership of flood defences and maintenance of flood defences were separated. Management of flood defences trumps ownership, this is laid down in law[35]. This choice made water boards effective institutions since the year 1200. The water boards, now regional water authorities provide a public service (safety against flooding and controlled water levels in polders (for irrigation and drainage). This service is covered by a seperate tax, the tax rate is democratically controlled by an elected body of the water board/ regional water authority [Slomp, 2012].

7.1 The main goal of maintenance

Maintenance of flood defences is in fact one main task, "holding on to what you have.

7.1.1 Planning and monitoring

In essence maintenance is program management

- determine measurable goals
  - The top requirement is that a Flood defences always has to comply with the ledgers[36].
- make a plan
- carry out the plan
- monitor progress and the effects
- report on what has been carried out
- evaluate and adjust the plan

7.1.2 instruments

instruments for maintenance are

- The national set of terms of reference for maintenance[37]

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[35] Legislation in the Netherlands for flood defences is covered in [Slomp, 2012]. In the constitution an exception was made for government servants to enter a house without a warrant, this was for houses on flood defences. During a flood inspections had to be possible. This exception was removed in 2009.

[36] Ledgers have to be re-written due to new flood defence standards. This will take place from 2017 onwards.

[37] http://www.helpdeskwater.nl/onderwerpen/waterveiligheid/primaire/zorgplicht/ and examples are available on www.inspectiewaterkeringen.nl/zorgplicht

- the ledger of the flood defences and
- By-laws for flood defences, water ways / drainage systems and structures. These are called “De Keur” in Dutch.
- an independent permanent and pro-active inspection process by the national environmental and transport inspection (ILT)[38]

7.1.3 *daily assessment*

Maintenance is carried out through the daily assessment of the flood defences. This task has been subdivided in a number of tasks:

- Regular inspection of flood defences by the regional water authority, from daily to annual or biannual activities (covered by the plan mentioned above).
- Regulatory tasks covered in by-laws. These by-laws cover the use of flood defences for other activities. A formal permit has to be obtained from the regional water authority[39] for each of these activities.
    - roads
    - grazing
    - passages for pipes and cables (e.g. public utilities)
    - housing
    - public utility buildings
    - when certain large maintenance and (re-)construction are allowed (between April 1st and September 30th)

Structures on, in or near dikes (e.g. houses, pipes, cables, structures or buildings for public utilities e.g. gas, electricity, phones and sewage) can influence the strength of a flood defence. Failure of flood defences can occur even in non-extreme conditions, e.g. to non-closure of sewage systems which cross dike systems.

Assessment of flood defences, every 12 years (covered in chapter 2) and re-design of flood defences (see chapter 6) can also be considered maintenance tasks. These are often organized differently and carried out by different staff. Therefore they are not covered in this chapter.

Repair of flood defences follows the regular inspection. Water boards are adequately financed for this task, since they can cover these activities using their own tax[40].
If public organisations, private citizens or private companies do not comply with the regulations set by the regional water authorities they

7.2 Changes in assessment rules and the inspection

In the former three formal assessments, a number of failure modes were adressed which have more to do with daily or annual maintenance than with the probability of flooding. These are called indirect failure mechanisms[41]. The assessment period was extended from 5 years to 6 years after 2006, and will be extended from 6 years to twelve years in 2017. One of the reasons for this change is that it takes about 12 years for planning, design and execution of improvement to flood defences. An important reason to implement this change know are recent developments in data management and software. It is now possible to carry out the assessment at any

[38] https://www.ilent.nl/
[39] All permits from all levels of goverment can be obtained through the municipality. The environment act, to be introduced in 2018, which merges all spatial planning acts and the Water Act will implement this measure [Slomp, 2012]
[40] In general maintenance costs are about 40 euro’s per household per year [UvW, 2010].
[41] In some cases these failure mechanisms influence the direct failure mechanisms. This is solved by using scenario’s and is described in the chapter on flood defence assessment.

given time in the year, if the data is readily available (in databases). This is why a yearly report of the state of flood defences has to be given (to (re)allocate funding), and a report to parliament every 12 years (for political oversight and for long term budgeting).

The actual state of the flood defence has to be assessed, some suppositions and checks are needed as to how maintenance is carried out. This is because many failure modes depend indirectly on the state of the maintenance e.g. grass revetments, wooden flood gates, asphalt and stone revetment or maintenance of structures or objects in front of flood defence (a harbour dam or the foreshore).

The main water system also has to be maintained. This is not part of the maintenance of flood defences. River discharges should not be obstructed by vegetation or by building in the flood plain. Since the Dutch coast is an eroding coastline, coastal nourishment is carried out to maintain the coastline and building in and on dunes is restricted. These regulatory issues have been covered in [Slomp, 2012]. In rivers coasts and lakes, regulatory issues from regional water authorities and the National Water Authority overlap geographically, both regulations have to be adhered to.

7.3 Hydraulic Structures

The most important discussion are:

- functional requirements for hydraulic structures both for flood defences and the reason of the hydraulic structure (often drainage, irrigation and/or shipping)
- on the aging of elements of hydraulic structures, steel, wood, concrete, composites age differently[42].

7.4 Dunes

The research project Kust Genese (mentioned above) addresses daily processes on the coast. The project goal is to determine a new long term strategy for coastal nourishment. Coastal nourishment has multiple goals.

Hybrid structure/ innovation
Each new construction has to determine maintenance, monitoring and inspection for structures e.g. boulevards on the dune coasts. Innovation has to be possible in the design phase. Evaluating this information and determining new formal maintenance and monitoring rules for hybrid structures is an issue to tackle in the future.

7.5 Revetments

In the former assessment rules if one could calculate that one stone could be removed from the revetment it failed the assessment. This is not efficient.

This is the reason a number of assessment rules were removed from the formal assessment, but remain part of the daily/yearly maintenance and inspection of flood defences.

Similar issues play a role for grass revetments and asphalt

[42] Aging is partly taken into account in the formal assessment eg for asphalt..

- the daily maintenance of grass influences the quality of grass in case of an extreme event.
- cracks in asphalt should be immediately sealed off, infiltration of water degrades the subsoil under the asphalt.

Only if it is expected repairs to a flood defences cannot be carried out before the next flood event (storm surge or river flood) then expected damages can be used in the formal assessment as scenarios.

7.6 The hydraulic role of vegetation in the flood plain

The flood plain of rivers in the Netherlands have been cultivated by farmers as pasture or cropland (in places where floods occur rarely (e.g. every 20 years) and mainly in the winter). The main goals of the Room for the River and Meuse works projects were both flood protection (by reducing design water levels) and spatial quality. Spatial quality is increased when natural river banks are allowed to develop naturally. Due to regular floods (on average every two years) flood plains do not have the same rate of return as protected farm land. This land was bought up by the projects and also by wildlife conservation organisations and subsequently allowed to develop by itself, with some grazing by domesticated or wild cattle or horses. However Vegetation can increase flood levels and can accelerate sedimentation, which subsequently increases flood levels even more. In the Netherlands the project "Stroomlijn", streamlining was launched to reduce the vegetation back to the 1997 levels.

Trees and large shrubs can also reduce wave action, especially on rivers and trees can reduce also ice damage to flood defences. In Hungary along the Danube and its tributaries (figure 20) and along the Elbe large trees in front of the dike in the flood plain have this purpose. The ice flows are broken up against trees. Ice dams can cause flooding upstream and Ice flows can damage the dikes and increase maintenance costs (figure 21) .

figure 20 Row of trees in front on the dike to reduce damage from ice (Bognar Zoltan, OVF, Hungary).

*figure 21 Ice on the Houtribdike, Lake Marken 1987and observed damage afterwards (*Hans Johanson, *Rijkswaterstaat DWW)*

7.7 High ground

High ground has lost its formal role, since the legal concept of a dike ring was abandoned (see chapter 2). High ground is not defined in a consistent way [Herten, 2015]. Some high ground should still be maintained as such (and permitted), both provinces and regional water authorities have a role in maintaining the high ground. Due to higher flood defence standards many flood defences will be bypassed between the high ground [Meijer and de Joode, 2016]. In the formal assessment the flood defence manager has to assess each of the transitional zones.

7.8 Crisis management

Plans for crisis management will have to be updated based on new knowledge on evacuation strategies and based on new flooding scenarios based on the new flood

8 Disseminating and interpreting flood forecasts

Flood forecasting is necessary to save lives and reduce damages. Reducing damages is important to save livelihoods and to reduce the recovery time. Flood alerts should contain expected time of the event, location and extent of the event. A flood alert is not only one message but part of a rehearsed flow of information using multiple canals. First people have to accept the fact that there might be a threat and what the threat is about. The population has to be made aware of flood hazards before the crisis occurs. This is now not the case in the Netherlands [OECD, 2014]. People need a reference to understand the situation and be aware of possible measures they can take assure their own safety and reduce damages. This reference is different for the public and for professionals. Information to the general public has to be consistent with the information used by managers of flood defences and emergency services. This information has to be very clear about consequences and context of possible measures (as shelter in place or preventive evacuation). Emergency services should monitor how the public is responding to adapt their communication en operation during a crisis. This is even more important now everyone is permanently connected through the internet.

Flood warnings, management of flood defences and emergency services are often coordinated by different government organisations. This is an extra handicap for having consistent information out on time for people to use. Every organization wants to take time to assess and check incoming information before sending it out. This can cause unnecessary delays.

For the managers of flood defences the reference levels have been changed (see the chapters on flood defence assessment). This means all information for all actors involved, flood forecasters, flood defence managers, emergency services and the public has to be updated.

A number of improvements have to be carried out anyway:

- In an information based society, where everyone has twitter, email and a camera, public organisations may have to trust the public more and send out the correct information as it comes in.
- the professionals should monitor information on the internet, to see how people react to the situation on the ground and to information disseminated by the authorities on the crisis .
- Increasing the resilience of the population by disseminating information from both updated policy studies (flood scenarios) and flood forecasts. This has been the project goal of the MEGO project "Module Evacuatie Grote Overstromingen", an information module for large scale evacuation due to floods. This information is available on a national website.
- Improving consistency between the information of the probability of occurrence by
    - using the same climate models for flood forecasting, policy research and flood defence assessment and design.
    - providing the same information on water levels and wave action (wave run-up and overtopping) in each workflow for rivers, lakes, estuaries and coastal area

In the Netherlands Rijkswaterstaat, the National Water Authority and the National Public Works Department is responsible for or involved in forecasting in case of floods, policy studies on flood risk, policy studies on maintenance, assessment and design of flood defences, elaborating rules and regulations for flood defences, advice on crisis management to the national government and maintaining the main infrastructure in the Netherlands (high ways and water ways). The Water Management Center in the Netherlands (WMCN) has developed a number of models to provide flood forecasts. The WMCN is run for and by all managers of flood defences and is hosted by Rijkswaterstaat. Other organisations use these forecasts to define the consequences of the forecast and to take measures (as the evacuation of camping places on rivers banks or lake shores or to estimate the conditional probability of failure of a flood defence).

8.1 Interpretation of forecasts

Interpreting data and disseminating consistent information from flood forecasts can be cumbersome. There are 3600 km of flood defences in the Netherlands. To simplify the production process and understanding flood alerts the focus has been on water levels at river gauging stations or at tidal gauging stations . The most basic information to get out to the public on time there is the possibility of a storm or river discharge which can cause major damages and/or casualties. In 1953 this information most often did not arrive. Large organizational changes were carried out to improve this process. This work is never finished, society changes, so flood forecasters and other involved in crisis communication have to adapt.

8.2 A reference for the public and professionals

Since 1800 information at gauging stations along rivers and the sea was often the only information available. The statistical information of gauging stations and past floods were used to determine if a hazard was a major risk. Combining information from a "rough" digital terrain model (based on levelling) and statistical information the main 53 flood prone areas were identified (see figure 22). In essence this is done by interpolating the statistical information (mathematically or through hydrodynamic models) and combining this digitally with a digital terrain model. This is a digital "putty knife method ". From 1996-2003 using laser altimetry a new open source digital terrain model has been built Algemeen Hoogte Bestand Nederland (AHN), with 1 point every 16 m2 or 1 point per m2. This was not precise enough for water management purposes [van der Zon, 2013]. After 2003 this was extended to 16 points per m2 in the AHN2 project. Currently the AHN-3 has been built. This has not been disseminated publicly yet.

For rivers the focus was on water levels at reference points, the river gauges on the border at main cities and in neighbouring countries (e.g Cologne for the Rhine river). In the 1990's statistical methods were used in forecasting using a relationship between upstream and downstream river gauges [Warmerdam, 1986] and [Torfs, 1990]. At river gauging stations on the border the relationship between water levels and the river discharges was determined. This relationship was used to calibrate models which are used to determine the water levels along the river. For flood forecasting we use SOBEK [Deltares, 2016]. In 1995 during the last high river discharges no information was available on water levels in polders after a breach. 250 000 people were evacuated. Some cities built on slightly higher ground which would not flood were never the less evacuated. Evacuation is costly, it disrupts society. The HIS "Hoog Water Informatie Systeem" [VenW, 1999] project was launched : Information System for High Water. This project had a number of goals:

1. disseminating information on flood forecasts water levels together with reference information on dike heights.
2. a database with flood scenario's for each province of the Netherlands calculated using the FLS model [Duinmeijer, 2002]

3.a method to calculate the number of casualties and the potential damages [Kok et al, 2005]

4.a set of models to calculate evacuation rates per area

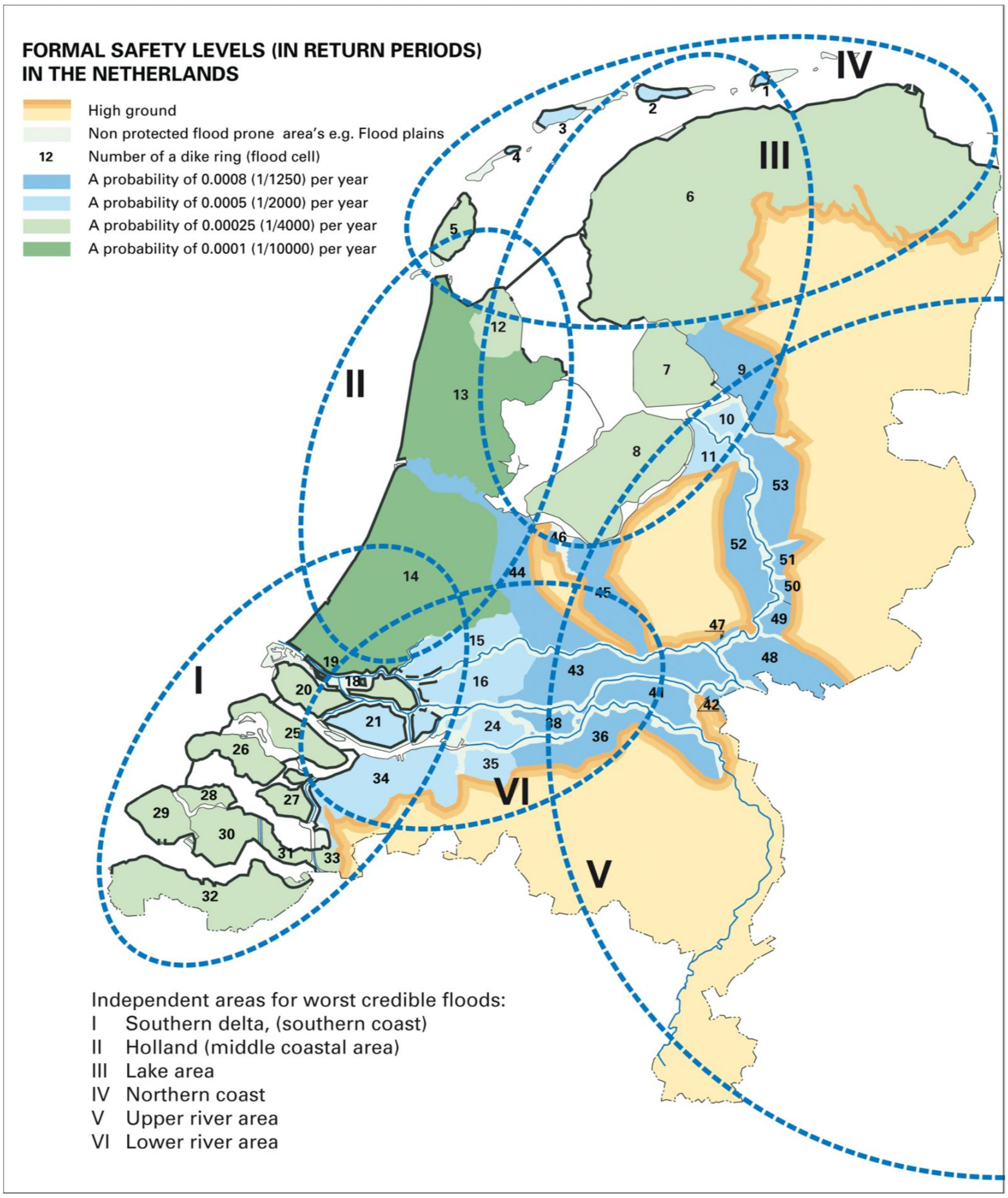

Figure 22. Formal risk based safety standards for flood defences 1996-2017 and the concept of "worst credible floods"[Kolen and Geerts, 2006]

Zone 1 Storm (>= Beaufort 12, >64 knots) in Zeeland en the South of Holland

Zone 2 Storm (>= Beaufort 12, >64 knots) the coast of Holland

Zone 3 Storm (> Beaufort 10 or 11) in het Ijssel lake area, estuaries of the Vecht and IJssel

Zone 4 Storm (> Beaufort 12, >64 knots) in the Wadden sea area

Zone 5 Discharge (discharge> 4000 m3/s Meuse and >16000 m3/s Rhine river) en storm (>Beaufort 6, 48-55 knots, to Beaufort 7, 28-33 knots) on the major rivers Rhine and Meuse

Since 1985 the forecasting in lake areas was carried out. This model provides run up heights for dike sections along the Lake Ijssel and Lake Marken and the 3 rivers deltas Ijssel, Vecht and

Eem. From 1985 until 2007 a database was used was built with a large number of storms using WAQUA and HISWA model (a precursor of the SWAN model).

In 2008 the worst credible flood concept was introduced. Which still plausible scenarios can still be expected. These scenarios per region have been given in figure 22. It is important to note that they are often mutually exclusive. A major 1/100 000 year event on the coast and rivers at the same time is not possible. A 1/10 000 year event for estuaries is often the combination of events we have already observed in the past. Also a major storm cannot be simultaneously threaten the south western and northern coast at the same time. A depression above Southern Norway threatens our Northern Coast. A depression above our Wadden Sea threatens out south western coast. This is important for contingency planning.

Figure 23 The names of the Dutch water systems and the sites of the storm surge barriers

8.3 Real time forecasting

The Netherlands has moved from forecasting based on statistical information (only possible for short lead times) to forecasting based on databases filled with scenarios of storms and or discharge, to real time forecasting models.

Currently a real time flood forecasting model is used for each water system.

- A SOBEK model is used for main rivers. Precipitation and discharge data from Germany, Belgium and France feeds the models.
- For the coast both tides and storm surges have to be considered together , a Hydro-Dynamic WAQUA model is used which starts at Portugal, Norway and Iceland.
- WAQUA and SWAN are used for the lake regions.

Since 2007 the Netherlands has merged flood forecasting centres at the national flood forecasting centre WMCN, managed by the National Water Authority Rijkswaterstaat. There are three main flood forecasting units for the sea coast rivers, rivers and lakes. The focus is still on water levels. Only the Lake region provides formal real time wave forecasts in combination with water levels. The water systems in the Netherlands are given in figure 23.

8.3.1 *Storm surge warning for the North Sea*

Storm surge warnings consist of predicted maximum water levels and a general description of the expected wind and tide and the moment of the expected maxima. The flow chart of information is given in figure 24.

Since 2012 wave action is also forecasted in an experimental setup. In the long term this is to facilitate the forecasting of dune erosion on account of water levels and waves and of wave run-up and wave overtopping for dikes.

There is a 10 day forecast from the National Meteorological office. However it remains difficult to determine the exact path of a depression with a 2 day lead time. Uncertainty information on the forecast is available from ensembles forecasts (each ensemble has a certain probability). This probability information is given along with the forecast.

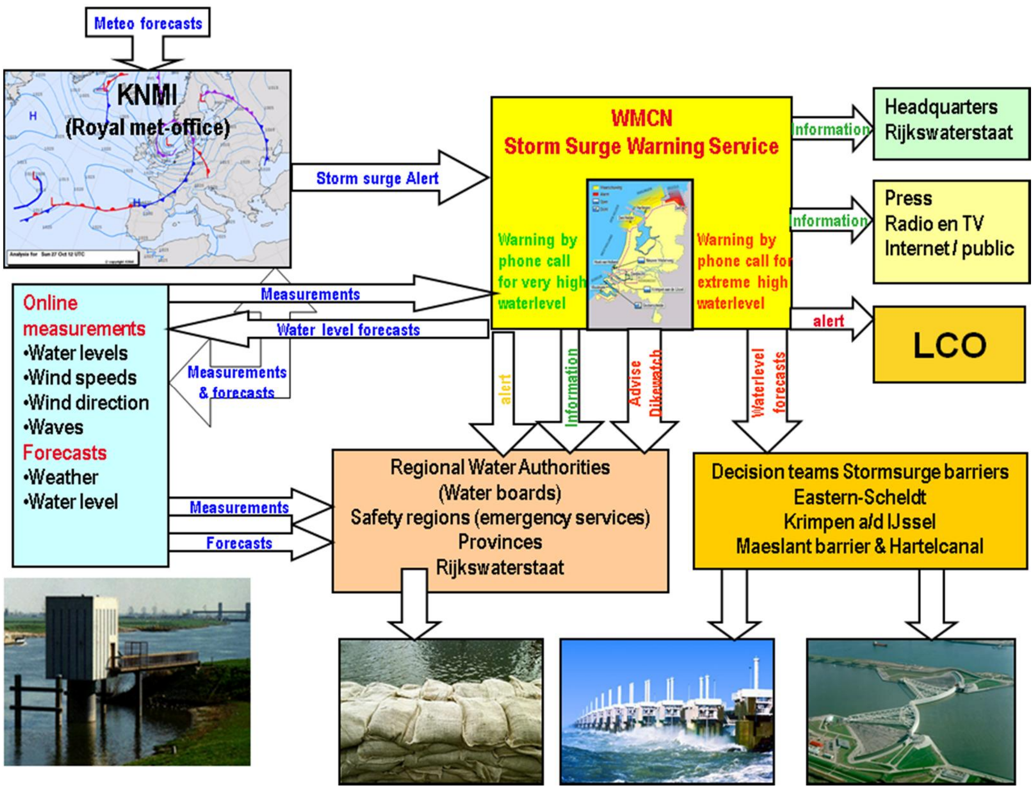

figure 24 flood forecasting for coastal areas, flow chart of information

8.3.2 *Flood forecasts for Rivers,*

The flood forecasts for the Rhine River (at Lobith) and for the Meuse river (at Borgharen and recently Sint Pieter) is given in water levels and discharges at the stream gauges. There is a 10 day forecast from the National Meteorological office for precipitation. Using precipitation and river gages upstream the current lead time is 1 to 2 days for the Meuse river and 3 days for the Rhine River (see figure 25) depending on where the rainfall event took place. Information from Ensembles is shown in figure 26.

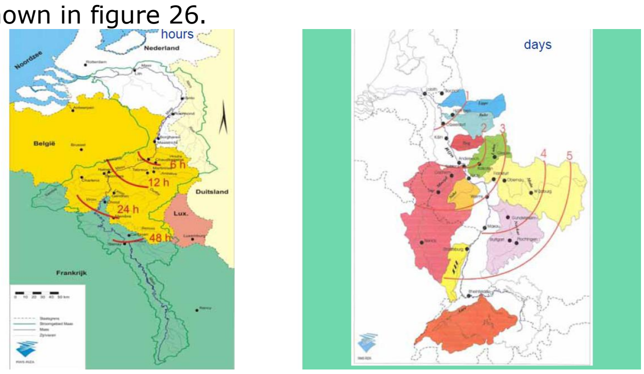

Figure 25 Lead time for the Meuse and Rhine Rivers at the stream gauges at Borgharen and Lobith [Sprokkereef, 2010]

Forecasts for rivers have become more and more reliable through the use of ensembles (figure 5).

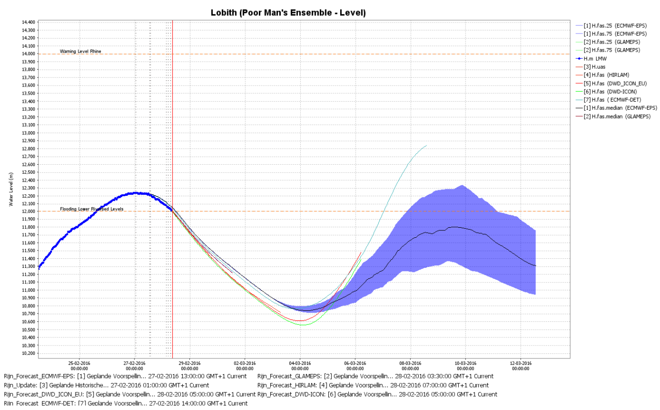

Figure 26: Example of the result of 50 ensembles for the Rhine River (FEWS model), February 28th 2016

The Regional Centres at Maastricht, Arnhem and Rotterdam inform different services about the forecast for the water levels along the rivers.

For the Meuse river and the Rhine River and the three Rhine branches ("Waal", "IJssel", "Nederrijn/Lek") the maximum water levels and the moment of the maximum water levels are given.

For the Rhine-Meuse Estuary flood warnings and storm surge warnings are combined. The maximum water levels and the moment of the maximum water levels are given. Hydraulic loads from wave action are large, but are not given.

8.3.3 *Forecasts for Large lakes*

The WMCN-lakes model is the most elaborate. It provides hydraulic loads for each flood defence in the Ijssel lake and Marken lake area, and the tributaries the Eem river, the IJssel river delta and the Vecht river delta figure 27. It is what the Netherlands should provide in the near future for all the water systems. Uniform flood forecasting information for all water systems makes all subsequent processes more efficient and reliable. KNMI, the national Meteorological service provides downscaled wind with the HIRLAM model[43], High Resolution Local Area Modelling for numerical weather prediction. [Unden et al, 2002]. Using the WAQUA model [Rijkswaterstaat, 2012], storm surges are calculated for the lakes and three river deltas. Subsequently using the SWAN model [Zijlema, 2007] wave height, wave periods and wave direction are calculated. And finally using dam and fore module [Kramer, 2016] (not shown) and the wave run-up model [van der Meer, 2002] the hydraulic loads and wave overtopping are calculated. The model chain which was introduced in 2007 has been described by [Genseberger et al, 2013] and [Slomp, 2012].

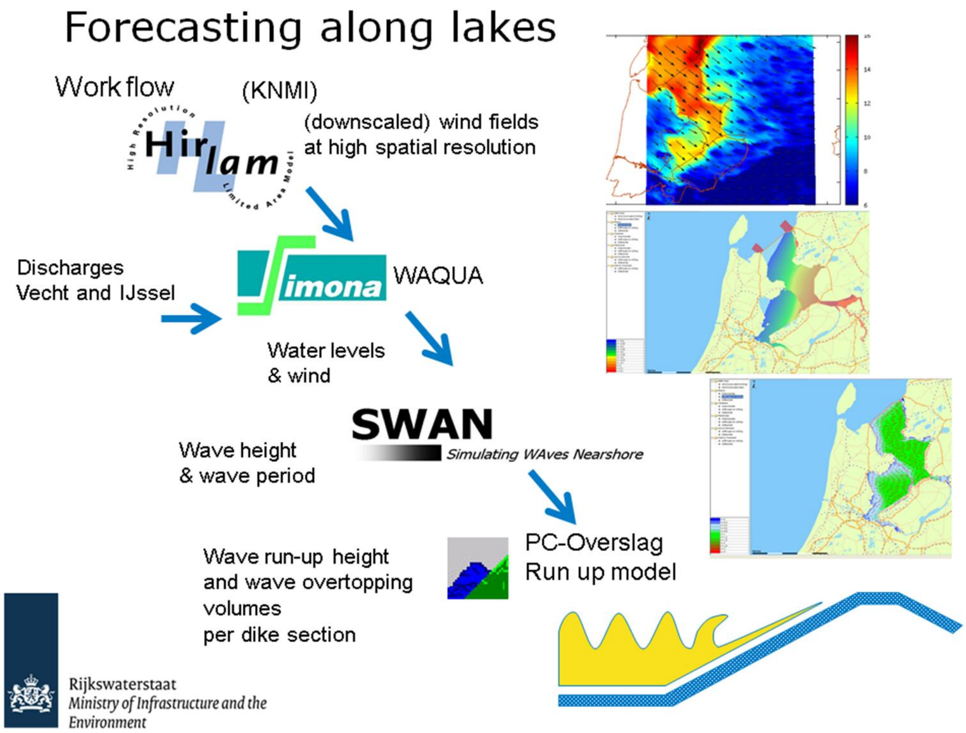

Figure 27. Workflow for flood forecasting along large lakes [Genseberger et al, 2013] and [Slomp, 2012]

8.3.4 *Interpreting data from flood forecasts*

Interpreting data from flood forecasts is cumbersome. There are 3600 km of flood defences. To simplify the production process and understanding flood alerts the focus has been on water levels. If a given design water level of a dike or structure is exceeded we may consider it is acceptable that it fails above this flood levels. Reality however is more complicated. In wind driven systems like the sea or large

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[43] HIRLAM is being replaced by HARMONIE

lakes height of a flood defence can be 10 meters or more above the design water level. Design water levels and design heights are usually not correlated (e.g. rivers) or partially correlated (Estuaries), [Geerse, 2011]. In the Netherlands the only exception is for large straight coasts like the Dutch dune coast with its large dikes e.g. Pettenmer- and Hondsbossezeewerng closing the former passages between the dunes [den Heijer et al, 2008]. Correlation between waves and water levels is very high.

Information on the link between probability of flooding and flood extent can be provided by policy studies.

How a breach will develop remains a second large question to answer. Some breaches widen very vast, other remain small (and can be rapidly plugged by a ship, e.g. in 1953) [Slager, 2010]. Other breaches deepen and widen at the same time leaving immense scour holes, impossible to fill during a flood event and almost impossible to block.

The size of the breach and the size and the layout of the area behind it determines speed and extent of flooding. Secondary dikes or (rail)roads or other high obstacles can slow the extent of a flood, but often increase the flow rates and rising rates of water levels and thus the number of casualties.

8.4 Information from policy studies and formal assessment of flood defences for flood forecasting.

8.4.1 Risk analysis

The main two national policy studies which provide the information on the consequences of flooding are WV21/DPV [Kind, 2010] and VNK2 [Jongejan et al, 2011]. The WV21 study (flood risk safety analysis for the 21st century) using the probabilistic WTI2011 tools (formal assessment tools of 2011) carried out a flood risk assessment for the Netherlands. The goal was to determine new flood risk standards to replace the standards developed since 1960. Climate change and economic growth were important variables in this study. Probability of flooding was determined using the failure modes overflow and overtopping, the Hydra-models. Simultaneously the VNK2 was carried out, a national safety analysis. The VNK2 study determined the actual flood risk for the situation in the year 2010. This is the situation before a number of large reconstruction projects (e.g. Room for the River and HWBPII (the national flood defence reinforcement programme 2011-2015) are completed. Flood probability was determined using a full probabilistic model and the main failure modes for flood defences. The failure modes are geotechnical failure (piping and inner slope failure), outer revetment failure (gras, asphalt and stone) and subsequently failure of the underlying layers, overtopping and overflow and subsequent erosion of the inner slope for dikes for dikes, dune erosion for dunes, overtopping, structural failure, non-closure, stability (and piping) for hydraulic structures. Flood damages in the WV21 and VNK-2 study were determined using overland flow models and flood damage curves.

8.4.2 Other policy studies

Other policy studies were often carried out in smaller area’s but can provide valuable additional information. This information still has to be filtered and added into the MEGO/LIWO database.

- The cross boundary flooding along the Rhine is an important issue not included in national flood risk analysis studies. This was separately investigated in a common project with the German federal state North Rhine Westphalia between 2005 and 2009 [Silva et al, 2009][44].
- The effect on flood probability due to the Room for the River and Meuse Works projects on the Rhine and Meuse rivers. Both projects have lowered the design water levels. This study uses fragility curves to determine the probability of flooding [VenW and BZK, 2006]

In 2007 and 2008 the National Risk Assessment by the ministry of Interior in the Netherland [BZK, 2008] was carried out. For Flood risk evacuations policies were assessed. It became clear that evacuating the population of the Western Coastal areas in the Netherlands was not possible [HKV and ORANJEWOUD/SAVE, 2008], [Brinke et al 2010] and [Slomp et al, 2011]. National Exercises were carried out using these tools in the TMO national flood risk Exercise [TMO, 2009]. [Kolen, 2013] shows that an evacuation strategy based on a mixture of horizontal evacuation (out of the area at risk) and vertical evacuation (to safe areas near or in your own residence) is more appropriate. In this study for each of the six worst credible floods (figure 22) a strategy was determined to reduce loss of life.

[44] Currently a new transboundary research project by Rijkswaterstaat, the regional government of Gelderland, and the regional water authorities Rijn en Ijssel and Rivierenland with the Government of North Rhine Westphalia is being set up to up-date this information

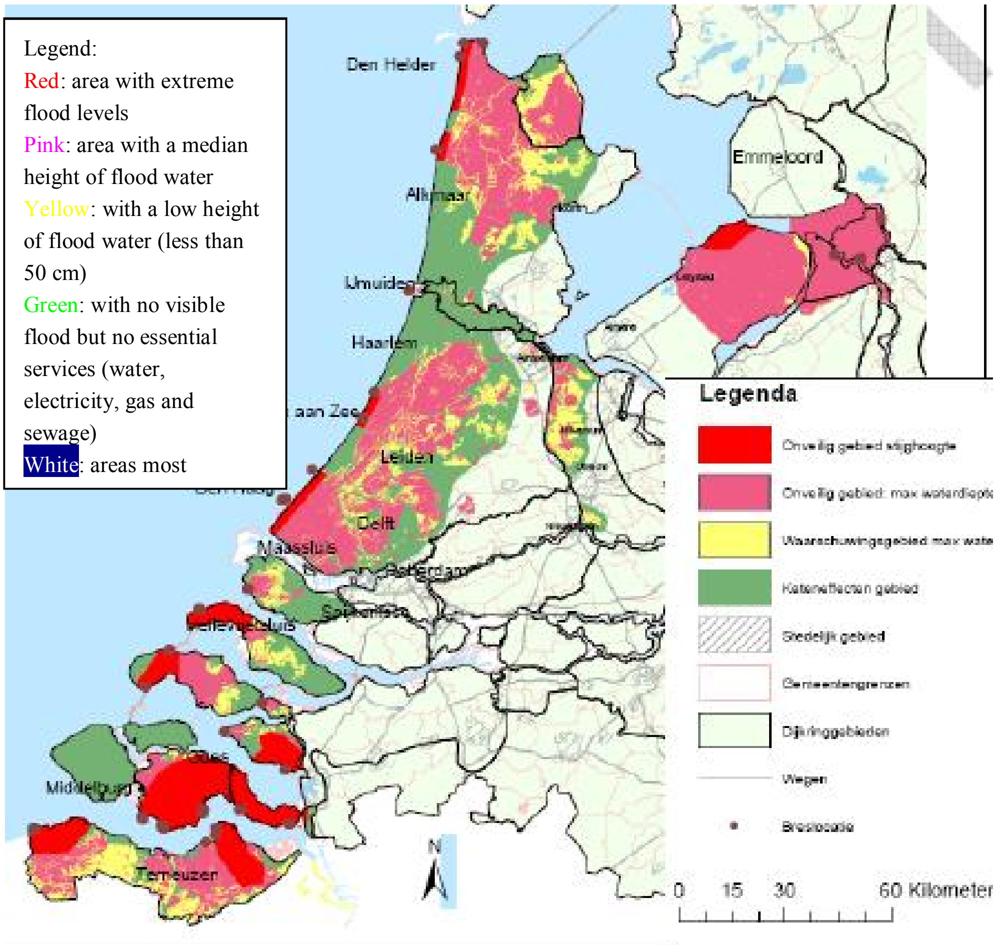

Figure 28 Division of the flood scenarios into areas with different flood heights or effects of the flood.

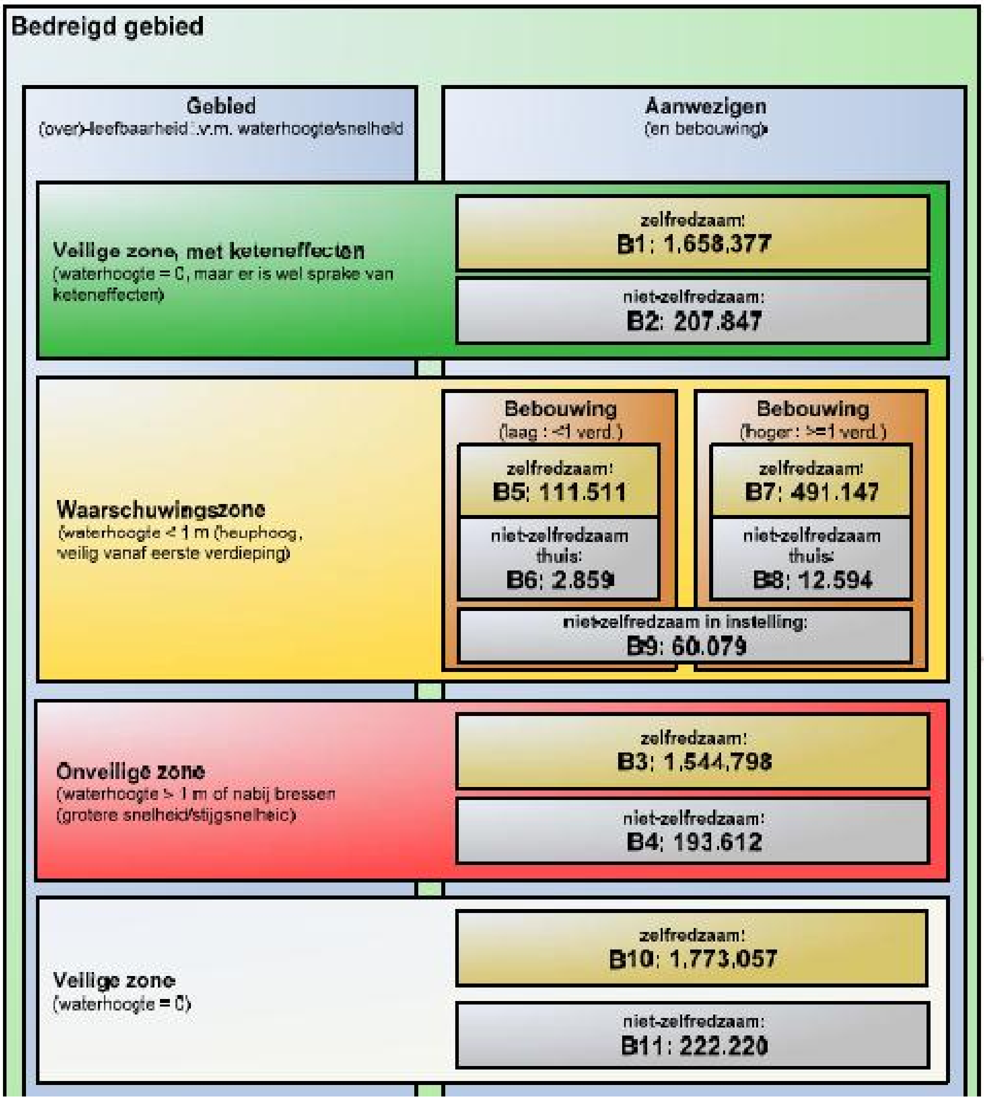

Figure 29: division of the number of people per category per area (of figure 6)

To reduce the maximum number of casualties all available resources have to be used most efficiently. Using the worst credible flood scenario the most important activities and capacities were identified and the number of necessary units of emergency services per region was calculated. Evacuation models were used to determine the flow of spontaneous and organised evacuation and the possibility to evacuate in a certain time frame. Flooding scenarios show which areas is the most vulnerable (figure 28). The population per area was determined and separated into self-reliant and non-self-reliant (figure 29). As measures both horizontal (removal from the area) and vertical evacuation (in the building itself or to nearby high ground or buildings) was considered. The tasks for the emergency services were focussed on reducing the number of casualties and promoting the self-reliant people to carry out what they can, to survive.

9 Research results and goals

The WTI2017 program is a combination of long term and medium term research and the elaboration of new flood defence assessment tools. In the period 2017 -2023 research will be continued in a new program which will cater design, assessment (WTI2023) and maintenance issues. From 2017 onwards we have decided on a yearly update of the research program. Involvement of flood defence managers in each research project. Large scale research projects are too immobile and easily influenced by intuitional priorities.

In the Netherlands there are also other research programs for flood defences (for design purposes of primary flood defences[45]), for secondary flood defences by STOWA, the Foundation for Applied Water Research[46] and for coastal management (Kust Genese[47]) and river management (River Care[48]). The research part of the WTI project and the latter two projects are part of the National Research and innovation program for Water and Climate "Nationaal Kennis- en Innovatieprogramma Water en Klimaat (NKWK[49])". The NKWK program carries out matchmaking between research budgets and programs with a main goal to increase the efficiency of research and to speed up implementation of research. In July 2015 a workshop was held to collect and discuss new research subjects. The proposals were subsequently assessed by different groups between July and September. This is the first formal document to given an overview of the research proposals.

As mentioned in previous chapters, the Netherlands has adopted extremely high flood defence standards based on the failure (breaching of flood defences). This choice poses a challenge for the assessment and design of flood defences. As mentioned in the previous chapters both the assessment and design tools and rules are mix of common sense, research and choices made pragmatically. There is always room for improvement in elaborating assessment and design rules.

- hydraulic load models have still not been made completely consistent, so a fair comparison between regions is not really possible (the law assumes this consistency).
    - secondary issues (e.g. seiches, wave setup) may become more or less important in extreme situations (1 in 100 000 year event). This also has consequences for the level of detail for hydrodynamic models.
- for a number of failure modes we still use empirical models, we need process based models which describe the complete failure process per failure mode

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[45] http://www.centraalholland.nl/waarom/artikel/ http://pov-waddenzeedijken.nl/ http://www.pov-piping.nl/ http://www.povmacrostabiliteit.nl/
[46] http://www.stowa.nl/foundation_for_applied_water_research_stowa/
[47] http://www.wageningenur.nl/nl/project/NKWK-Kustgenese-II-1.htm
[48] http://www.ncr-web.org/rivercare/about
[49] http://www.waterenklimaat.nl/

- transitions between dikes and (hydraulic) structures, dikes and dunes, dunes and (hydraulic structures), or between revetments on dike are often places where flood defences fail. Adequate models for these phenomena are often still in a research phase or non-existent.
- Probabilistic models should be used to see where more research is needed. This is more effective when hydraulic load models are consistent and when the most important failure modes described in process based models.

9.1 Current research in 2016

In 2016 the focus is on making flood defence assessment rules and design rules less conservative.

Strength models

- The influence of time dependency of Hydraulic loads for geotechnical failure modes, piping and slope stability.
- Proven strength of dikes, e.g. in lake areas, which have resisted higher water levels (in 1916) then the current design water levels.
- The influence of thin successive layers of sand and clay renders the fore shore of Waddenzee dikes almost impervious.
- New information of the tables for evaluating non closure of flood defences.
- A consistent approach between wave overtopping and erosion of the innerslope and wave overtopping, infiltration, saturation of the innerslope and slope stability.

Hydraulic Loads

- An analysis of the influence of the chosen uncertainties in hydraulic loads.

9.2 The main research for Hydraulic loads

There is one main research question for hydraulic loads. How to determine water levels and waves at extreme return periods e.g. 100 000 years? Which processes are then relevant for failure of flood defences.
To determine extreme statistics long time series are generated for discharges on the main rivers Rhine and Meuse [Hegnauer, 2016]. For tidal movement and wind (storm surges and waves) statistical extrapolation is still used [Chbab, 2015]. [Brink van den, 2011] has shown it is possible to generate time series of 3500 years for wind driven systems and calculate extreme water levels. Longer time series are needed and wave information is also needed for estuaries, lakes and coastal regions. In upper river systems wave action is not correlated to river discharges, and yearly maxima are important (e.g. Beaufort 6 and 7).

Five large questions remain [Boers et al, 2014]

- How does wind drag react to high wind speeds [van Vledder, 2015].
- How are wind speeds and wind directions changed when the wind goes over multiple land and water crossings, this is important for deltas and barrier islands in front of a coastline [Verkaik, 2001]
- How does vegetation influence wave action? Currently formal rules do not account for the influence of vegetation.

- How can we calculate 50 000 or 100 000 years of wave data in an efficient way.
- How to provide more precise information on the duration and spatial distribution of hydraulic loads?

9.3 reliable measurements

Based on the plans for hydraulic loads and for strength models a consistent measurement program will be drawn up. Current long term wave measurements will be continued until at least 2023.

9.3.1 Hydraulic Loads

One of the long term goals are reliable measurements to calibrate Hydro-dynamic models, run-up models, ground water flow models. For water levels caused by storm surges [Dillingh et al, 1993] and discharges [Chbab, 2002] there is reliable information for a least 100 to 120 years and acceptable information for 200 years. A time-series of more than 30 years is often needed to be statistically reliable[50] and a long time series is necessary to validate current climate models which are used in in forecasting, climate research and the research for flood defences assessment and design tools.

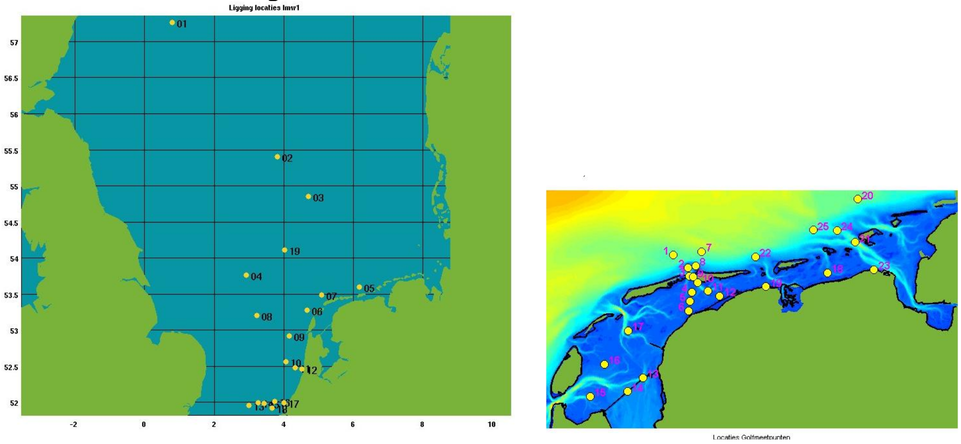

figure 30 Measurement sites for water levels, wind and waves (LMW and SBW[51])

Rijkswaterstaat has about formal 400 sites where water quality, wind, water levels, and waves are measured, an example is shown for the North Sea and project sites e.g. SBW "Sterkte Belastingen Waterkeringen" (figure 30).

There are a number of additional project measurement sites for hydraulic loads.

[50] Even then a time series of 30 years can be too short. I have covered this in 1988 when I compared 30 years of Rhine discharges to 100 years. A 30 year period showed a downward trend. A 100 year period showed no trend.
[51] To prolong the measurement period, the number of buoys were reduced to only one gap between islands instead of three. It is more important to cover more years than to have a better spatial overview. Currently there is funding to prolong the data set from 2006 up till 2023. After that we hope to integrate the former SBW measurement program into the LMW national program.

- Since 1997 wind, storm surge, wave and run-up measurements have been carried out in the large lakes (IJsselmeer and Lake Marken, see figure 23) [Bottema, 2007]. Both lakes are relatively shallow and react extremely fast to changes in wind speed and direction
  - Since 2006 a new long term measurement program, as part of the "Sterkte Belastingen Waterkeringen"[52](SBW), Strength Hydraulic Loads Flood Defences program was set up for the coastal areas. [Smale, 2011] discusses the research goals and achievements of 2006-2011 program. [Spelt et al 2012], [Spelt et al 2014] , [Wenneker and Smale, 2013] discuss the measurement program. In 2014 [Boers et a, 2014l] redefined the research goals for hydraulic loads. Based on these new goals, a new measurement plan will be drawn up.
  - Run-up measurements were carried out at Petten on the North Sea coast of Holland since 1994 [Wenneker et al, 2016]. Due to the reinforcement of the dikes at Petten by dunes in front of the dikes this site was discontinued. A new site is being set up in the Eems Estuary at Delfzijl[53]. These measurements can be combined with the measurements of wind, water levels and wave action from the WTI measurement program (mentioned above).
  - Wave measurement for short fetches
- As mentioned earlier vegetation reduces wave action on rivers, how to make this information available for flood defence assessment is the question. Part of the solution is maintaining the vegetation en inspecting its quality regularly. Determining how much vegetation is necessary to reduce waves on rivers with a maximum wave height of 1 meter is the question.

9.3.2 *Strength models*

For strength models a number of full scale experiments have been carried often financed by Rijkswaterstaat or the ministry of Economic Affairs.

- To evaluate the failure mode piping and slope stability for dikes surrounding the Eastern Scheldt, in 1985 [Vergeer en Kuiter, 1968] the storm surge barrier in the Eastern Scheldt was closed for more than 24 hours. Changes in water pressures under en behind dikes were measured using piezometers.

- For slope stability "up lift" at Berg Ambacht, a redundant dike was tested until it failed [Koelewijn, et al 2003] and [Van, 2001].

- For piping, in the IJkdijk project a full scale dike was built, undermined and breached to observe the full process of the piping phenomenon[54].

- To test the erosion resistance of boulder clay, a redundant dike at the Wieringermeerpolder was cut up into blocks of $1m^3$ and rebuilt in

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[52] This project has been continued in the WTI2017 and WTI2023 programs.
[53] This is still a research proposal without formal documentation.
[54] http://www.floodcontrolijkdijk.nl/en/

wave flume in the Voorst. Currently a larger flume has been built in Delft.[55] This was part of the SBW research 2006-2011.

- For slope stability on peat soils, a full scale dike was built and loaded until it failed [Zwanenburg and Jardine, 2015].

- For research on erosion of the outer and inner slopes of dikes due to wave action a number of machines were developed (figure 31)

figure 31 Waveovertopping simulator, Wave runup simulator Waveimpact simulator [Van der Meer, 2014]

9.3.3 *Quick Reaction Force*

Measuring waves on rivers and in estuaries is difficult and expensive. Important wave action is rare. Wave direction is important. A mobile team is being set up to measure water levels, waves and wind in these areas.

The team will also look into strength issues e.g. piping and slope stability during floods. This can be done using the piezometers installed by the flood defence managers.

[55] https://www.deltares.nl/en/facilities/delta-flume/

9.4 Integration and consistency between Hydraulic Load models

Integrating all probabilistic Hydraulic Load models is important. Only if the models are consistent with each other can results from different regions in the formal assessment of flood defences be properly compared. Currently the integration probabilistic Hydraulic Load models is first done in Hydra-NL (for a proof on concept) [Duits, 2015] and then in Hydra-Ring [Roescoe et al, 2016], the model which combines strengths and hydraulic loads in the formal assessment tool Ringtoets (see figure 16). Hydra-NL uses numerical integration as a solver and therefor is more precise than Hydra-Ring, furthermore Hydra-NL contains diagnostic tools to analyse input, output and each step in the probabilistic analysis. Hydra-Ring is more complex since it combines more stochastic variables and cannot use numerical integration as the main solver. It also does not have the diagnostic tools to verify the necessary input for a probabilistic model.

- Currently the hydraulic boundary conditions for dunes are not derived using hydrodynamic models. They are derived using statistical techniques. The WTI2023 will need to use techniques to run and analyse large number of hydrodynamic calculations in a probabilistic setting as developed for Estuaries [Slomp et al, 2002]. The Hydra-B model [Duits, M.T. 2004], takes into account two storm surge barriers, discharges from two rivers, storm surge water levels at Hoek van Holland and wind action (storm surge and waves) in the Estuary. Currently this technique is being expanded in the Eastern Scheldt [Stijnen et al, 2015]. The Eastern Scheldt is the most complex coastal area with a closed off estuary behind a storm surge barrier. The new project will provide the blue print for determining hydraulic loads probabilistically for the whole coastline.
- For systems behind two storm surge barriers placed in a serial system the Hydra-BS model [Duits, 2013] was developed. The Hollandse IJssel discharges into the Rhine-Meuse Estuary near Rotterdam (figure 15). It is protected by both the Algera Stormsurge barrier and the Maeslant barrier.

9.5 Integrating research for hydraulic loads and strengths modelling

Determining which failure mode is not sufficiently modelled is essential before investing money in research. Probabilistic models can give insight in which failure modes are important. Probabilistic models however often use simplified model description for failure modes. Integrating research for hydraulic loads and strengths modelling is therefore necessary. Research

9.6 The main research for Dune erosion.

The main research for Dune erosion, aside from the development of the full probabilistic load model for dunes (mentioned above) is the development of the strength model Xbeach in a probabilistic setting. Xbeach can evaluate dune safety including hard objects in dunes e.g. dikes, retaining walls and bunkers. The model has not been calibrated yet for a 2 d setting and the model Xbeach uses many parameters (a problem for probabilistic tools). Running the x-beach model in probabilistic setting will need very powerful tools, this has been investigated by [Bieman et al, 2014]

9.7 The main research for Piping

9.7.1 *piping models*

[Sellmeijer, 1988] describes a small part of the failure process (the transport capacity in the pipe) and is too conservative (as mentioned in paragraph 2.2). It does not describe how many sand particles get detached to be transported [van Beek, 2015]. The transport capacity is larger than the number of particles which will detach themselves. Information from [van Beek, 2015] is needed to determine a more precise definition of failure for piping. It will take a number of years to develop a working model.

Moreover the Sellmeijer model describes a homogeneous subsoil. Such a homogeneous subsoil does not exist in the Netherlands. Therefore a more conservative approach was used in the direction of the dike (a length factor of >100) [Vrouwenvelder, 2006], but the subsoil is also non-homogeneous perpendicular to dike (this provides extra safety). This extra safety is not accounted for since it can currently not be quantified).

9.7.2 *Subsoil description*

WTI uses one dimensional model to describe the subsoil for piping. Piping for dikes and structures is a 3 dimensional phenomenon. A better description of the subsoil has to be used.

9.7.3 *Measures to reduce/eliminate piping*

A large percentage of upper river dikes (along the Rhine Branches and the Meuse) will need reinforcements due to piping. Traditional measures are often berms. These take up a lot of space. Geotextile, Sand filters and sand piles are being experimented on.

9.8 The main research for Slope Stability[56].

Together with extremely high flood risk standards the focus is on the ultimate limit state (ULS) for flood defences. Describing this ULS and determining which deformations are still acceptable and do not cause other failure modes.

The choice of the length factor is conservative approach

ULS and SLS of sheet piles in dikes

9.9 Asset management and Maintenance

Risk based asset management and maintenance. Using risk analysis to determine how maintenance program should be carried out.

Improving daily monitoring. Making this information available for all different processes. Making use of big data techniques, the development of new data

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[56] The most important improvement is not a research issue but is part of the implementation program, schematisation of the dike and subsoil. There is still too much variability between different people carrying out the schematisation. This has been covered in the previous chapters.

collection and data management strategies. It is possible to collect and store immense quantities of data on flood defences. A lot of question have to be answered: What is necessary? What is already available? How to manage this data flow? How to keep essential information available over long periods of time? How to keep this data management affordable? How can we combine this information to get more insight in flood defences?

A new focus on failure modes which have to do with maintenance and which have become more important due to higher flood defence standards and the fact that flood defences will be assessed for ultimate limit state and not for the usability state. Secondary failure modes may become more important (also see paragraph 9.16).

There are also many issues to tackle which have to do with being prepared. Crisis management – for drought (drying out of dikes (often peat soils) and subsequent stability issues), being prepared for floods (extreme water levels and waves) and other issues (exploding/leaking pipes in dikes which can cause slope failure.

9.10 Earthquakes and dikes

Earthquakes can cause a number of failure models:

- liquefaction of layers under flood defences, and subsequent deformations of the dikes
- slope failure due to the earthquake
- failure at transitions, e.g. where a hydraulic structure is built in a dike (often built on piles), or a retaining wall, reinforcement of a dike (built with sheet piles) in the longitudinal direction of a dike. Both vibrate differently due to an earth quake, this leaves cracks and deformations between the structure and the dike.

9.11 The main research for revetments

- a process based description of the erodibility of the topsoil and subsoil.
- remaining lifespan of asphalt revetments
- traditional structures between revetments
- deciding on where to put which revetment. When is grass sufficient and can an asphalt or stone revetment stop

9.12 The main research for Hydraulic Structures

9.12.1 Eurocodes

Eurocodes (building codes) are based on the failure probability in the design life of the structure. Formal assessment rules and Design rules are based on the probability per year. This is often stricter, however this is not always the case. This has to be addressed.

9.12.2 Piping

For Hydraulic structures Bligh and Lane are still being used to evaluate for the piping at structures. A finite element model is available to assess flood

defences (Dgflow) [van Esch, 2013] in advanced assessment. This is not yet available for regular formal assessments.
The subsoil at structures is often disturbed. Adapting the soil data (from chapter 4) for assessment in a three dimensional model will remain an issue.

9.12.3 The structural integrity of Wooden flood gates

There are no manuals for the design and maintenance of wooden flood gates. Essentially

9.13 Transitions, between revetments and between structures and dikes

Transitions often cannot be modelled in the current strength models.

9.14 Pipelines, cables, non-water retaining structures in and around flood defences.

Due to higher flood risk standards for flood defences and the choice for the ultimate limit function state flood defences large deformations will be allowed. Current Pipelines, cables, non-water retaining structures have not been designed for large deformations. Assessment rules and design rules for pipes and cables crossings flood defences will have to be rewritten.

9.15 Hybrid structures/innovations.

At this moment there is a manual how to introduce innovation in design of flood defences. The designer has to prove the design is appropriate and can meet the standards for flood defences [Knoeff et al, 2013]

10 Concluding Remarks

10.1 General conclusions

The formal flood defence assessment is essential for managers of flood defences since national funding for reinforcement is based on this assessment.
The current flood defence assessment tools [VenW, 2006] are based on a mixture of probabilistic and semi-probabilistic tools. To simply the transition for the 2017 assessment tools we first introduce the changes in the assessment using current methods for semi-probabilistic assessment, and then make the managers and consultants familiar with fully probabilistic analysis methods to compare strength of flood defences and hydraulic loads. The formal assessment result is primarily based on the full probabilistic analysis.

Together with the new risk based safety standards, based on flood impact, this probabilistic flood probability assessment will allow for safety assessments and prioritisations of reinforcement measures that are done in a risk-based and therefore cost-effective way.

Insufficient height of flood defences has often been the main reason for failure. This can be seen in many recent floods abroad in New Orleans in 2005 [Kok et al 2006], in France in 2010 [Kolen et al, 2013] and in Thailand in 2011 [Jonkman et al, 2012]. Focussing on height in the Netherlands for more than 70 years, means some other failure mechanisms have been neglected [Jongejan et al, 2011]. We have prepared for the past disasters, we now have to prepare for the future. We hope that the use of the new tools will make decision making for funding of flood defences more transparent and more efficient. The scarce resources for flood risk management primarily have to provide safety and a reduction of potential damages. Tackling this issue properly, is something every society has to address. For this purpose in the past 70 years we have developed a large number of assessment and policy tools. These tools have been improved over time due to scientific knowledge but also because more and more information is available on flood defences. The cost to use the new tools and available information together has been reduced significantly. Assessment of flood defences can be carried out with approximately the same effort as in the past.

Implementing new policy, rules, tools and practices at the same time remains a very ambitious goal. In the past we have had subtle changes, every 5 to 6 years. In 1996 probabilistic methods were formally introduced for Hydraulic loads. Semi-probabilistic methods are slowly being replaced by probabilistic approaches. Over the past 20 years the VNK project (2001-2014) its predecessors and similar policy studies e.g. WV21 (2005-2012) have prepared the Dutch flood professional community for a more risk based approach. To facilitate all these changes on January 1st 2017, a large number of accompanying programs and projects have already started in 2015 and will continue during the transition period 2015-2019

10.2 An overview of important changes in flood defence assessment

A summary of the major changes is given below:

- a more complete set of risk based flood defence standards, they are based on risk assessments, but the end result is a political choice, confirmed by parliament. For the assessment these risk based flood defence standards are therefore non-negotiable. In the design phase other choices can be made, if the desired individual risk is attained. The new Water Act provides this possibility [IenM, 2016a]. For small protected areas with relatively low flood risk standards additional safety can be attained by improving resilience (building on mounds) or by reliable evacuation strategies. Room for the river measures remain possible to reduce design water levels and therefore prolong the design life of flood defences. A tool was developed to facilitate this process [Thonus and Wolters, 2012].

- the use of ultimate limit state instead of usability limit state, and therefore the inclusion of uncertainties in hydraulic loads and strength parameters.
    - Knowledge uncertainties for Hydraulic loads were never included in formal assessments of flood defences. This was a political choice.
    - A consequence of the choice for ultimate limit state is that height is no longer a formal assessment parameter for dikes and the freeboard for assessment is no longer used. For design purposes the freeboard is still necessary to account for settlement.
    - Another consequence is a separation in direct and indirect failure modes. Indirect failure modes often have to do with maintenance and regular inspection. If an indirect failure mode remains important for direct failure modes (e.g. erosion of the foreshore) than scenario's are used and each scenario is accorded a probability.
    - New research has provided more insight on the ultimate limit state, where this was considered to be validated it was taken into account.

- consistency between assessment layers. Where new research was available probabilistic models were used to determine semi-probabilistic assessment rules.
- the use of climate models with generated time series (3500 to 50 000 years) to determine statistical data for discharges and uncertainty data for coastal water levels.
- providing formal software tools where in the past only formula were provided.
    - this is a large change for piping and slope stability
- a more efficient use of readily available techniques for data management
    - a standard geologically correct set of subsoil information
    - use of digital terrain models
    - GIS as a data carrier in between the source data (at each organisation) and the formal models.

What does not change is trust in engineering judgement. It is possible to deviate from formal rules in the advanced assessment. If this applicable has to be shown the person carrying out the assessment. Formal assessment tools have had extensive quality control. In the advanced assessment the responsibility for the quality control is given to the flood defence manager. The national inspection (ILT), mentioned previously, responsibility is to verify the process of flood defence assessment.

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