EMERGO

The Dutch flood risk system since 1986

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Dissertation

EMERGO

the Dutch
flood risk system
since 1986

Dutch flood risk policy — from Delta Works to Delta Programme

Integrated flood risk systems analysis framework

Design of a graphic language to represent the development of national water systems

Ties Rijcken

Delft University of Technology 2017

EMERGO

the Dutch *flood risk system* since 1986

Proefschrift

ter verkrijging van de graad van doctor
aan de **Technische Universiteit Delft**

op gezag van de Rector Magnificus
Prof. ir. K.C.A.M. Luyben;
voorzitter van het College voor Promoties,

in het openbaar te verdedigen op
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Door
Ties Rijcken
Ingenieur Industrieel Ontwerpen
Geboren te Groningen

This dissertation has been approved by the promotors

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the Dutch *flood risk system* since 1986

Dissertation

for the purpose of obtaining the degree of doctor
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by the authority of the Rector Magnificus
Prof. ir. K.C.A.M. Luyben;
Chair of the Board for Doctorates

to be defended publicly on
Thursday, June 22, 2017 at 12:30.

By
Ties Rijcken
Master of Science in Industrial Design Engineering
born in Groningen, the Netherlands

Propositions

1. **The 80s marked the start of an increasing discrepancy between what is *said* about the Dutch national water system and what is *done* about it (this thesis).**

2. **The objectives of a water system can be organised in a hierarchy, similar to Abraham Maslow's (1943) hierarchy of needs (this thesis).**

3. **Dutch national flood risk policy since 1986 is primarily characterized by continuous investments in flood probability reduction, strongly supported by improved risk models, and furthermore by a struggle with the higher-order objectives in "Maslow's hierarchy for water infrastructure" (this thesis).**

4. **The future of the Dutch national water system is only partially determined by climate change and the spatial development of the economy; yet most of all by the value we assign to risk modeling and the higher-order objectives in "Maslow's hierarchy for water infrastructure".**

5. **Civil and geotechnical engineers are inclined to want to solve flood risk problems with civil and soil structures, landscape architects with river widening, spatial planners with multi-level safety, coastal morphologists with sand nourishments and disaster managers with disaster management.**

6. **The biggest challenge for a universal interactive graphic language for infrastructure development is handling *poor* and *missing* data.**

7. **When internet platforms in the public realm succeed to support research activities, design studies and political decisions by engaging users and analysing usage patterns, they strengthen democracy and improve well-being.**

8. **Photography and science have in common that the instrument of observation affects the observation.**

9. **Form is content.**

10. **The essence of *development*, not only of water and information systems, but also of social and personal development, is to share with others.**

Stellingen

1. Sinds de jaren '80 is een grotere discrepantie ontstaan tussen wat er *gezegd* wordt over het Nederlandse hoofdwatersysteem en wat er aan *gedaan* wordt (dit proefschrift).

2. De functionele doelen van een watersysteem zijn hiërarchisch te ordenen, naar analogie van Abraham Maslow's (1943) hiërarchie voor de menselijke behoeften (dit proefschrift).

3. Het Nederlandse nationale overstromingsrisicobeleid sinds 1986 wordt vooral gekenmerkt door continue investeringen in het verkleinen van overstromingskansen, sterk gedreven door verbeterde risicomodellen, en daarnaast door een worsteling met de hogere-orde doelen in 'Maslow's hiërarchie voor waterinfrastructuur' (dit proefschrift).

4. De toekomst van het Nederlandse hoofdwatersysteem wordt slechts ten dele bepaald door klimaatverandering en de ruimtelijke ontwikkeling van de economie; belangrijker zijn het vertrouwen dat we stellen in de systeemmodellen en de waarde die we toekennen aan de hogere doelen in 'Maslow's hiërarchie voor waterinfrastructuur'.

5. Civiel ingenieurs en geotechnici zijn geneigd oplossingen voor overstromingsproblematiek in kunstwerken en grondlichamen te zien, landschapsarchitecten in rivierverruiming, ruimtelijke ordenaars in meerlaagsveiligheid, kustmorfologen in zandsuppleties en rampenbeheersingsdeskundigen in rampenbeheersing.

6. De grootste uitdaging van een universele interactieve grafische taal voor infrastructuurontwikkeling is het omgaan met *gebrekkige* en *ontbrekende* data.

7. Als internetplatforms in de publieke sector er in slagen om onderzoeksrichtingen, ontwerpstudies en politieke besluiten te ondersteunen door gebruikers te engageren en gebruikersgedrag te analyseren, zullen ze de democratie versterken en de welvaart bevorderen.

8. Fotografie en wetenschap hebben gemeen dat het instrument van waarneming de waarneming beinvloedt.

9. Vorm is inhoud.

10. De essentie van *ontwikkeling*, niet alleen van watersystemen en informatiesystemen, maar ook van persoonlijke en maatschappelijke ontwikkeling, is met elkaar delen.

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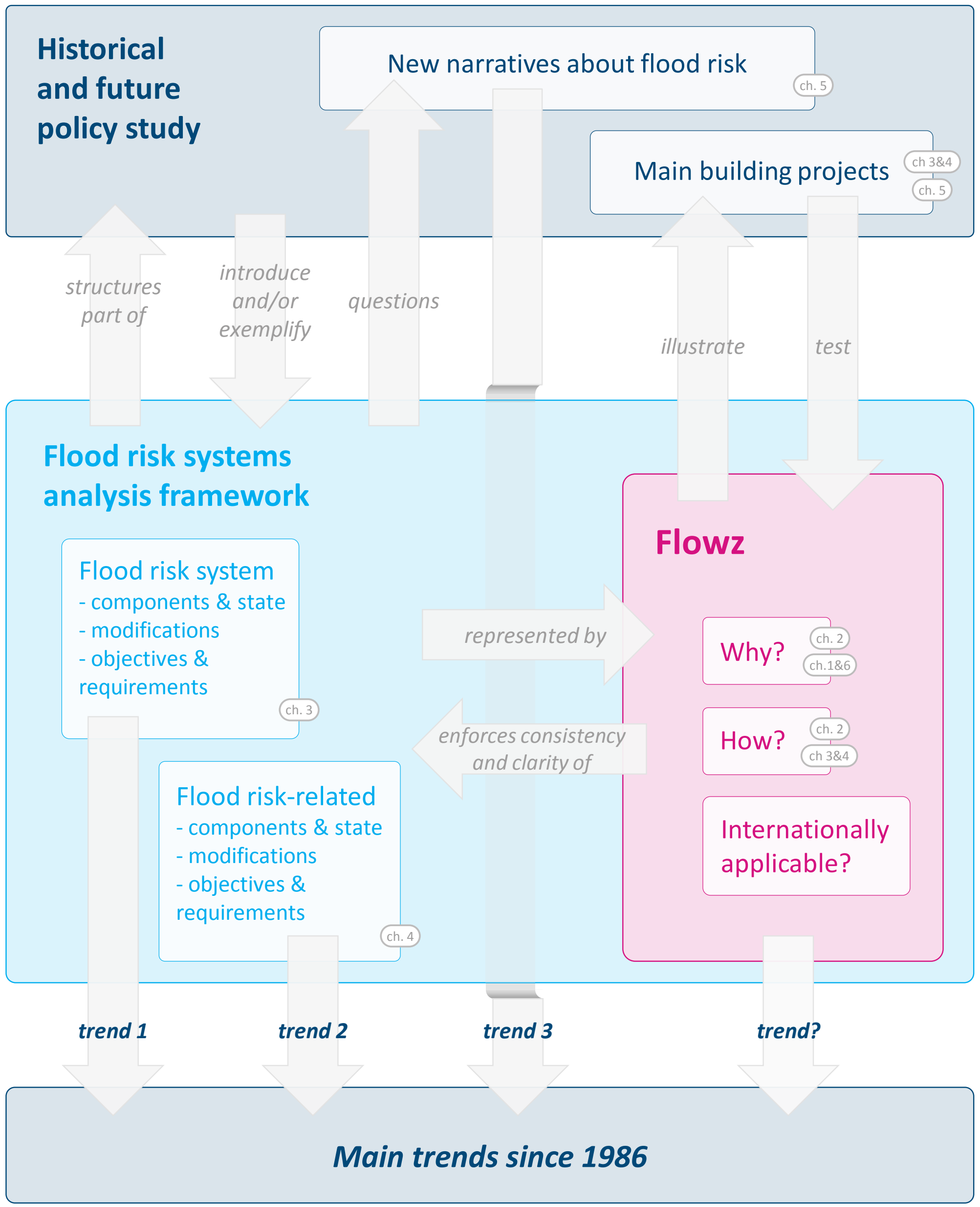

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PART III | STRUGGLING

DESIGNING FLOWZ
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HISTORICAL AND FUTURE POLICY STUDY

Summary

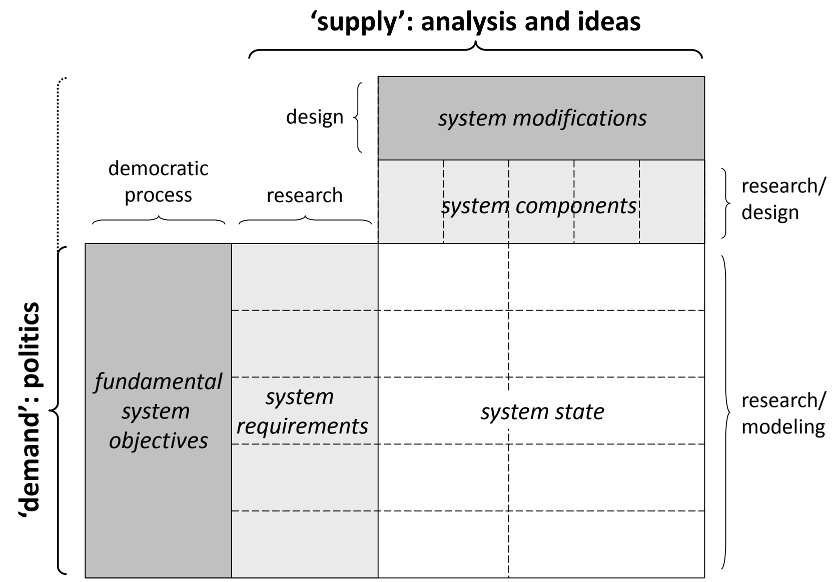
PART I | A RESEARCH AND DESIGN PROJECT ABOUT FLOOD RISK POLICY SINCE 1986

The period between the Dutch flood disaster of 1953 and the year 2016 can be divided into two eras, separated by the year 1986, when the famous Eastern Scheldt barrier was completed. The perspective of water professionals on flood risk policymaking during the three decades *before* 1986 was dominated by the reconstruction approach of the Delta Works and has frequently been studied. The three decades *after* 1986 have a less obvious general approach, which has not yet been studied in depth as a whole. This dissertation attempts to develop a coherent perspective on flood risk policy during the last 30 years.

This thesis's *research objective* is to develop a comprehensive flood risk and water systems analysis framework, to be used for two purposes. First, providing a historical interpretation of flood risk policy by answering the main *research question*: how can the development of the Dutch flood risk system since 1986 be characterised fundamentally? In the core of the thesis, three main historical trends are identified. The first trend results from a study of systematic approaches to flood risk through the years, the second main trend addresses the relevance to flood risk of additional flood risk-related water system objectives (freshwater conveyance, shipping, nature/ecotopes and landscape quality) and the third trend involves additional new ideas or *narratives* which have been influential during the studied period.

The second purpose of the water systems analysis framework is to meet the *design objective* of the thesis*:* to design an internet platform to represent the systems analysis framework and illustrate historical and future development of the Dutch flood risk system. The aim of the platform is to systematically organize and visualize the available studies and design projects, to educate about water systems, to inspire users to add contributions and monitor user behaviour to help indicate new research and design opportunities and support policy decisions. Acknowledged criteria for scientific and societal relevance guide the design throughout the thesis.

Chapter 2 introduces the platform, which was called *SimDelta* in 2012 and renamed *Flowz* in 2017. A brief survey of approaches to water system planning and 'serious games' concludes that a graphic interface to visualise technical-physical complexity and socio-political complexity (or: supply and demand of analyses and ideas) is increasingly recognised to contribute to effective policymaking.



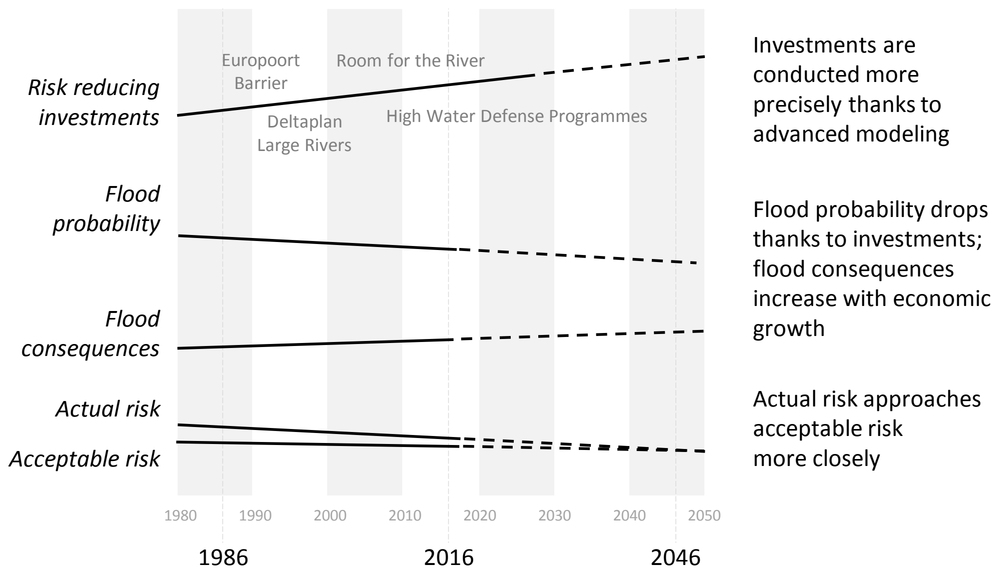
A structure for the platform is proposed, consisting of six stackable software blocks: the base block contains interactive maps generated in a systems model, the top block involves communication between stakeholders to make choices in a virtual problem-solution space. Usage over the internet makes it possible to record preferences, and 'crowdsource' corrections, improvements and new ideas. The extent to which the concept can contribute to policymaking can only be tested by developing it step-by-step. Chances for success will depend on how the platform relates to existing ways information is obtained and existing types of decision support.

PART II | AN INTEGRATED FLOOD RISK AND WATER SYSTEMS ANALYSIS FRAMEWORK

In this thesis, flood risk is approached as an integrated system of components which are more or less timeless, but for which analytical approaches have changed through time. *System components* are in some *system state* relative to *system requirements*, derived from *system objectives*, changeable by *system modifications*. Five system components are distinguished: embanked areas, flood defenses (embankments), unembanked areas, outer water and control structures. Each component is treated in turn, starting with definitions, general geometries and basic numbers for the Netherlands. The main question then is how scientific advances in system state 'measuring rods' have contributed to decisions to upgrade existing components or add new ones.

For flood risk systems the main flood risk objective has always been, somehow, to achieve *acceptable risks*: tolerable probabilities of casualties, damage and other undesired effects. This has been translated into requirements for dike height (before 1953), design conditions with specified exceedance probabilities for dike sections (1953 – 2016, brought under national Dutch law in 1996) and flood probabilities of dike trajectories (to be implemented in 2017). Other flood risk objectives have been to lower river water levels and to maintain a base coastline, objectives which are more strongly intermingled with other water system objectives than just flood risk reduction.

The common theme throughout chapter 3 is that more detailed modeling has enabled better expressions of risks and more accurate assessments of system component conditions. Increasing precision in identifying gaps between desired and assessed system states has been a major driving force for investments in flood protection, which have been conducted without interruption since 1986, except for the years between 1987 and 1992. This thesis's first main trend are *ongoing investments in flood protection, strongly motivated by improved risk and acceptable risk analyses*.



The type of investments depends strongly on synergy with flood risk-*related* water system functions: freshwater conveyance, shipping, nature/ecotopes and landscape quality.

In chapter 4, these flood risk-related functions are approached with the same systems analysis framework of *system components* in some *system state* relative to *system requirements*, derived from *system objectives*, changeable by *system modifications*. The core question is which role these other water system objectives have played since 1986, in general and in relation to flood risk.

The *freshwater conveyance system* consists of service areas, freshwater inlets, freshwater connections, storage areas, weirs, distribution structures, pumping stations and fresh-salt barriers. Investments in the Dutch freshwater conveyance system have been little since the 70s and relationships to flood risk were minimal. *Shipping* uses ports and hinterlands, waterways and locks and is affected by moveable high water barriers and flow distribution structures. Since 1986, major investments were made in ports, waterway expansions and lock upgrades. Interaction with flood risk has been important, mostly in the tidal rivers, which are not dammed but kept open with moveable storm surge barriers to facilitate shipping. The aquatic *nature/ecotope system* can be seen as an interplay between 'eco-served areas', aquatic and amphibious ecotopes, eco-gates, pumping stations, fish passages and distribution structures. The nature objective in itself and in interaction with flood risk has been on the rise since 1986. *Landscape quality* (mainly *facilitating non-water system spatial functions*, *identity/ cultural heritage* and *esthetics*) is always treated as a secondary objective under other water system objectives, but could also be divided in system components and assessed in itself. Landscape quality played a part in almost all flood risk projects over the last decades, even on a strategic systems level.

The general role flood risk-related systems have played in flood risk policy-making can be interpreted using Abraham Maslow's hierarchy of human needs (1943). Maslow's main idea was that higher-order objectives (self-actualization and esteem) are addressed only when lower-order ones (security and physiological needs) are met; not necessarily fully, but to a larger extent lower in the hierarchy. Stacking the objectives treated in this thesis in a similar order, flood risk and freshwater conveyance would be the most fundamental objectives, under freshwater conveyance, shipping, nature/ecotopes and with landscape quality as the highest achievable goal. Recent Dutch water infrastructure development can then be identified as a broadening of water system objectives and an *upward movement in 'Maslow's hierarchy for water infrastructure development'*, similarly to how human beings try to fulfil higher needs during their lifetime. This is the second main trend identified in this thesis.

PART III | STRUGGLING IN 'MASLOW'S HIERARCHY FOR WATER INFRASTRUCTURE'

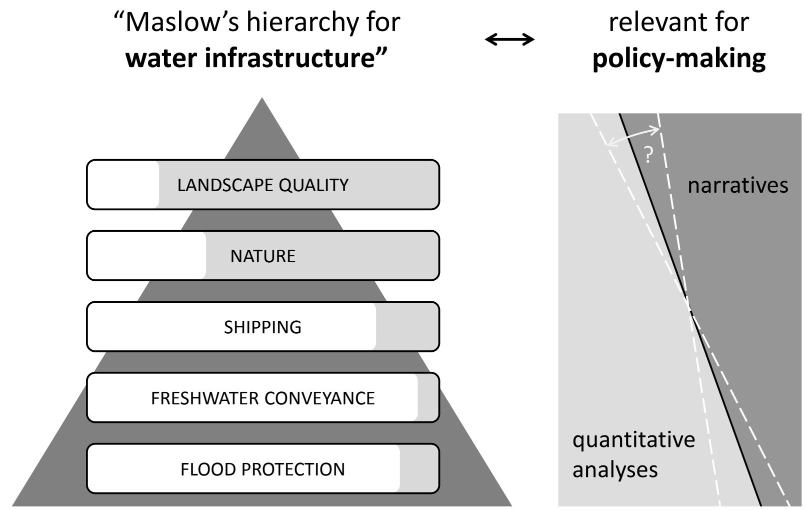
Studying historical flood risk policy documents also revealed several recent new ideas on flood risk which have a narrative structure and appear at odds with the systems analysis. Because these *new narratives,* like 'water should be leading in spatial planning' and 'rivers should not be squeezed in a corset', were found so frequently, they are considered important enough to be studied for a third main historical trend.

The three most popular new narratives are that 'water should not be our enemy, but our friend', that flood protection entraps us in a dangerous 'spiral of risk' which can be stopped, and that flood risk reducing measures should be 'natural' or 'follow nature along'. They are studied by scanning important Dutch documents, looking for illustrative quotes, to find common denominators.

Behind the new narratives lies increasing interest in objectives such as an attractive water landscape (Water as a Friend), fear of large-scale technological solutions (Spiral of Risk) and healthy ecotopes (Following Nature Along). Many quotes show a general aversion to higher dikes. The general critique to the new narratives is that they advance particular preferred measures as generally logical without having to systematically compare them to alternatives in particular situations.

One explanation for the popularity of the studied new narratives is that especially at times when new higher-order objectives in 'Maslow's hierarchy for water infrastructure' (nature/ecotopes and landscape quality) are added to the mix, it is tempting to follow a simple grand idea rather than to do the hard work of unraveling the concept of risk, grasping the interplay between the increased amount ot different objectives and systematically comparing alternatives. An additional explanation states that many Dutch water professionals are wary to take a stand for higher-order objectives, and feel more comfortable when a narrative somehow connects a new objective like nature development to a centuries-old lower-order objective like flood safety. The third main historical trend identified in this thesis is that *new popular narratives address objectives higher up and lower in Maslow's hierarchy* simultaneously*, but distort well-balanced analyses.*

Before combining the three main trends from chapters 3, 4 and 5 in a conclusion, the final chapter first takes a step back. The main events, policy documents and projects treated throughout the historical systems analysis of the previous chapters are placed into six policy frameworks: Delta Works, River Normalization, Flood Defenses Act, Space for Water, Dynamic Coastal Maintenance and Multi-Level Safety. It becomes clear that the Flood Defenses Act has been the most influential framework for investments. Subsequently, the main trends of this thesis are compared to several characterizations of the studied period by other water experts. This exposes a certain discrepancy between *what was said* with *what has been done.* For example, frequently presumed is a historical shift "from prevention by high dikes and dams to better managing flood risk by a wider spectrum of measures", including "sustainable spatial planning [in the embanked areas] and disaster management". Statements like these are heard frequently, but, looking at the hard investments, still between 80 and 84% of the projects built and planned between 1986 and 2028 are in flood prevention ("high dikes and dams"), 15 to 19% in river widening and only 1 to 5% in "sustainable spatial planning" and disaster management (the 4% bandwidth is the part of the Delta Fund not yet allocated).



The presumed paradigm shifts are interpreted as a *longing* for the upper regions of *Maslow's hierarchy for water infrastructure development*, expressed somewhat indirectly, similar to how the new narratives of chapter 5 were interpreted. The three main trends of chapters 3, 4 and 5, with the additional observed discrepancies between what is said and done of chapter 6, lead to the final conclusion that flood risk policymaking since 1986 can best be characterized by a confused and convoluted *struggle to get to grips with higher-order water infrastructure objectives*. The important role played by the improved risk analyses (thesis trend 1, chapter 3) can also be seen as part of this struggle. Implementing the scientific advances did not come easy and shipping, freshwater and nature/ecotopes have not achieved the same level as flood risk. The motivation to advance scientifically is not only more safety (below in Maslow's hierarchy), but also more knowledge and insight (high in Maslow's hierarchy). The intrinsic beauty of a water system being supported by an advanced scientific framework is a value in the top of Maslow's hierarchy.

Conveying this beauty to a broader audience is the objective of the *graphic language* for the water systems analysis framework as developed in this thesis. Representing the system *components*, *assessments*, *requirements*, and *modifications* in a consistent way for flood risk, freshwater, shipping, nature and landscape quality systems is possible, but higher up in Maslow's hierarchy, data are less readily available. Much work is still to be done. Moving up in the hierarchy of objectives probably has no end.

Chapter 1 in brief

The period between the Dutch flood disaster of 1953 and the current year 2016 can be divided in two eras, separated by the year 1986, when the famous Eastern Scheldt barrier was completed. The main coherent perspective among water professionals on flood risk policy-making during the three decades *before* 1986 was dominated by the reconstruction approach of the Delta Works and has frequently been studied. The three decades *after* 1986 are a period with a less obvious general approach, which has not yet been studied in depth as a whole. This dissertation is an attempt to develop a coherent perspective on flood risk policy of the last 30 years.

Research objective: develop a flood risk systems analysis framework

Form a general theory on various policy-making perspectives, develop a comprehensive flood risk and water systems analysis framework, to be used for a historical interpretation of flood risk policy-making, flood risk reduction projects and narratives about flood risk, as well as for the design objective (below).

Main research question: how can the development of the Dutch flood risk system since 1986 fundamentally be characterised?

Which main trends can be identified in the development of and thinking about the Dutch flood risk system, as written down in policy documents and materialized in infrastructure upgrades, for the period between 1986 and 2016? The first trend results from a study of systematic approaches into flood risk through the years. The second trend addresses the contribution of flood risk-related water system objectives: freshwater conveyance, shipping, nature/ecotopes and landscape quality. The third trend is about additional ideas or *narratives* which have also been influential during the studied time span.

Design objective: design an interactive platform to represent this development

Develop a conceptual internet-based graphic language and user interface representing the systems analysis and illustrate historical and future development of the Dutch flood risk system. The platform should systematically organize and visualize the available studies and design projects, educate about the system, inspire users to add contributions and monitor user behaviour to help indicate new research and design opportunities and support policy decisions.

Chapter 1

This thesis

Publication type: chapter written for this thesis

1.1 Introduction

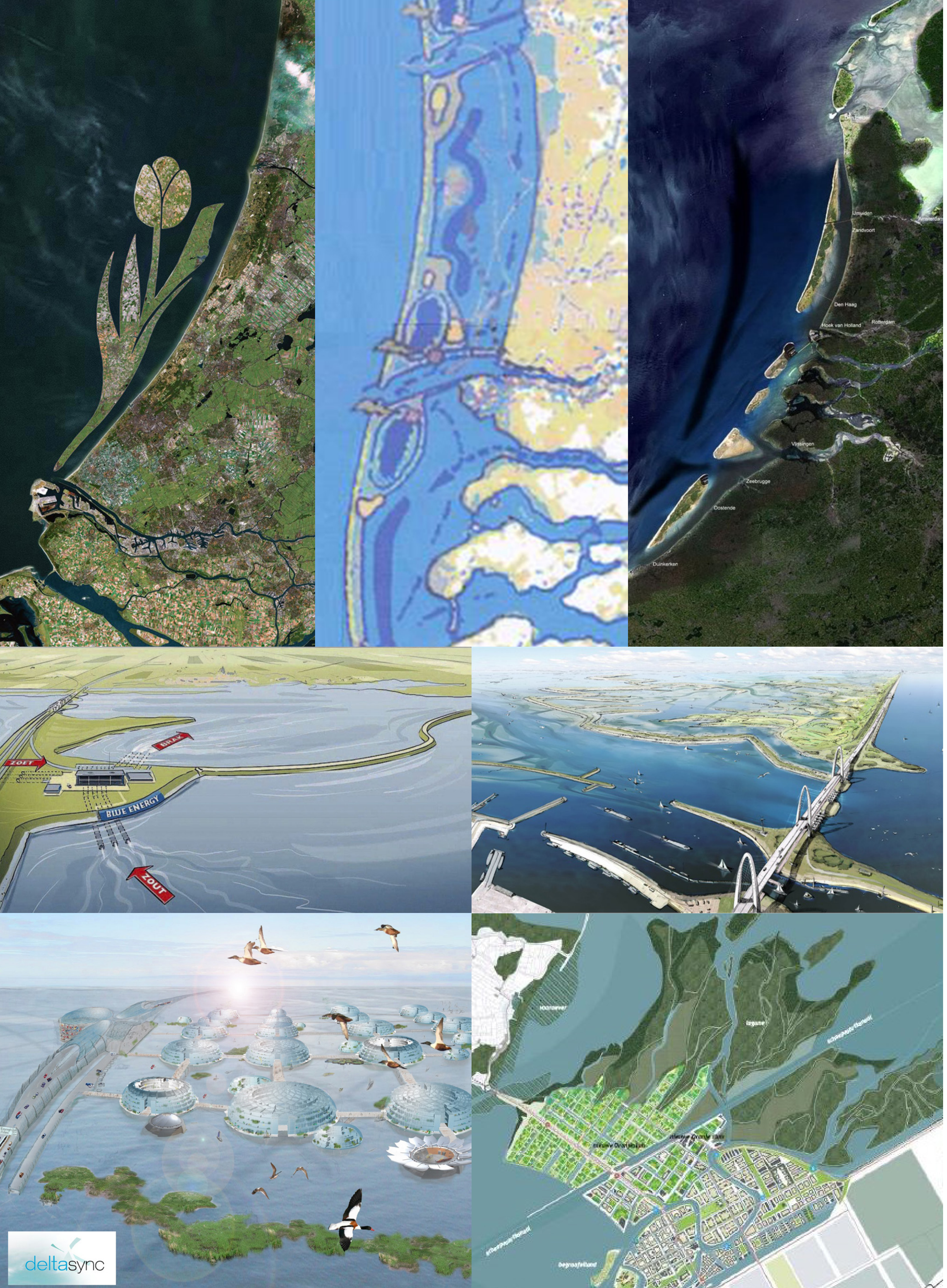
Thinking about flood risk after the Delta Works

1.1 The historic opening of the Eastern Scheldt storm surge barrier in 1986, with the minister of water management (left), the queen and the Rijkswaterstaat chief engineer (right).

On October 4, 1986, Beatrix Wilhelmina Armgard, Queen of the Netherlands, officially closed the Eastern Scheldt storm surge barrier and declared the Dutch province of Zeeland safe against floods. The same year, the Rijkswaterstaat Deltadienst (Delta Division) was relieved from service. After thirty years of building, the Delta Works were considered completed and the Dutch had established a firm position as the world's most capable tamers of the water. What happened since that day, did the Dutch flood protection and flood risk professionals recline and take it easy?

They did not. Flood defense maintenance was intensified, flood risk science expanded and different ideas and narratives about the water system appeared. The Netherlands were confronted with new problems and threats of the waters adjacent to the delta: the upper rivers and the sandy coast. At the same time, new societal opposition to system upgrades appeared in the public debate, especially in the river area. Between 1992 and 2009, five state commissions on flood risk issues were appointed; three for the large rivers and two for the entire water system. The national government kept spending the same average annual amount on flood infrastructure upgrades (excluding maintenance and operations), about half a billion euro (price level 2014) (MIRT 2014 and other

◄1.2 Some iconic projects built after 1986: (from top to bottom) Maeslant barrier, Noordwaard bypass, Dike relocation Lent, Sand Engine (Beeldbank RWS 2014 and other sources).



sources), and with the Delta Fund of 2012, this will continue.

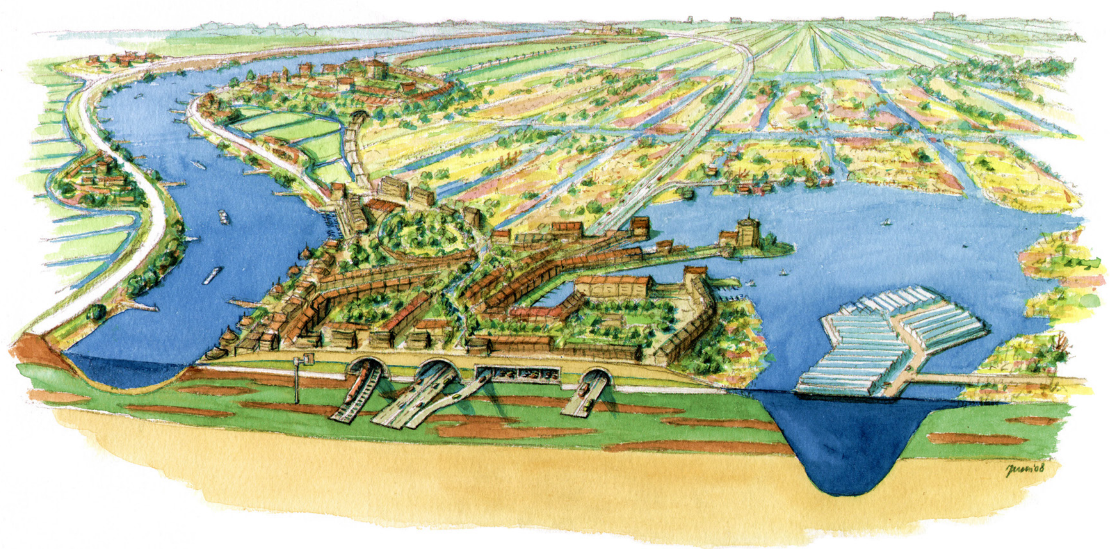
The thirty years of the Delta Works have been thoroughly documented in the quarterly newsletters (Deltadienst 1956-1986) and frequently described (de Haan & Haagsma 1984; Meijer 1998; van Evert 2014; DWO 2014, etcetera). During the thirty years after 1986, more documents about flood risk and the water system were written than ever before, but a general historical overview has not been found. Many historical studies start further back (Dubbelman 1999; van der Ham 1999; van de Ven 2003; van Heezik 2007; Rooijendijk 2009; ten Brinke 2009, etcetera), and/or focus on a particular part or aspect of the system.

This thesis takes a broad perspective and describes the development of the Dutch physical flood infrastructure system and the thinking behind it, between 1986 and 2015, and peeks far into the future. It covers the most relevant projects, policy documents and, most importantly, ways of thinking, modeling and representing. It is, however, not a PhD project as conducted on history faculties. The approach chosen is not chronological but structured around a flood risk systems analysis. Parts of the systems analysis and the historical policy studies are represented by standardized maps, a design project as part of this PhD project. The maps are part of an interactive web-based information system aimed at *historical* understanding and understanding of water infrastructure as a *system of interrelated components*, addressing flood risk and flood risk-related objectives.

Historical insight helps to understand the future. This thesis will present three trends describing the essential developments of the last thirty years, as the result of three analyses: unravelling flood risk as a system, with a certain condition (state) and with plausible modifications to meet objectives and requirements, singularly aimed at flood risk. Second, systematically thinking about the way the flood risk system interacts with other water system objectives, like fresh water supply and providing conditions for aquatic ecosystems. Third, thinking about flood risk in different ways, ways which appear to differ from the systems analysis and rather have a *narrative* structure.

The ultimate purpose of good thinking about flood risk is to invent good projects and make good decisions. This thesis is, however, less normative and more descriptive. The aim is to clarify links between decisions, objectives and ways of thinking. The period since 1986 has been a time of tough decisions to upgrade dikes against strong opposition

1.3 If it was up to hundreds of conceptual designers, scientists, artists, politicians and policymakers, the 1990s and 2000s would have left little of the Dutch water system in tact. On the left page: (top – North Sea sandy coast) the *Tulip Island* (Innovatieplatform), the *Haakse Zeedijk* (Rob van den Haak), *Blue Islands/Plan Geuze* (West 8); (middle – Afsluitdijk) Blue Energy (DeAfsluitdijk.nl), redesign of the Afsluitdijk *WaddenWerken* (Alle Hosper, DHV and others); (bottom – lake Marken) the *Floating City* in lake IJ (DeltaSync), new marshlands and urbanization *Markeroog* (West 8). Next page: (above) removal of dams in the South-western delta *Arms Wide Open* (World Wildlife Fund); (below) neighbourhoods on terps in deep polders (IvM).



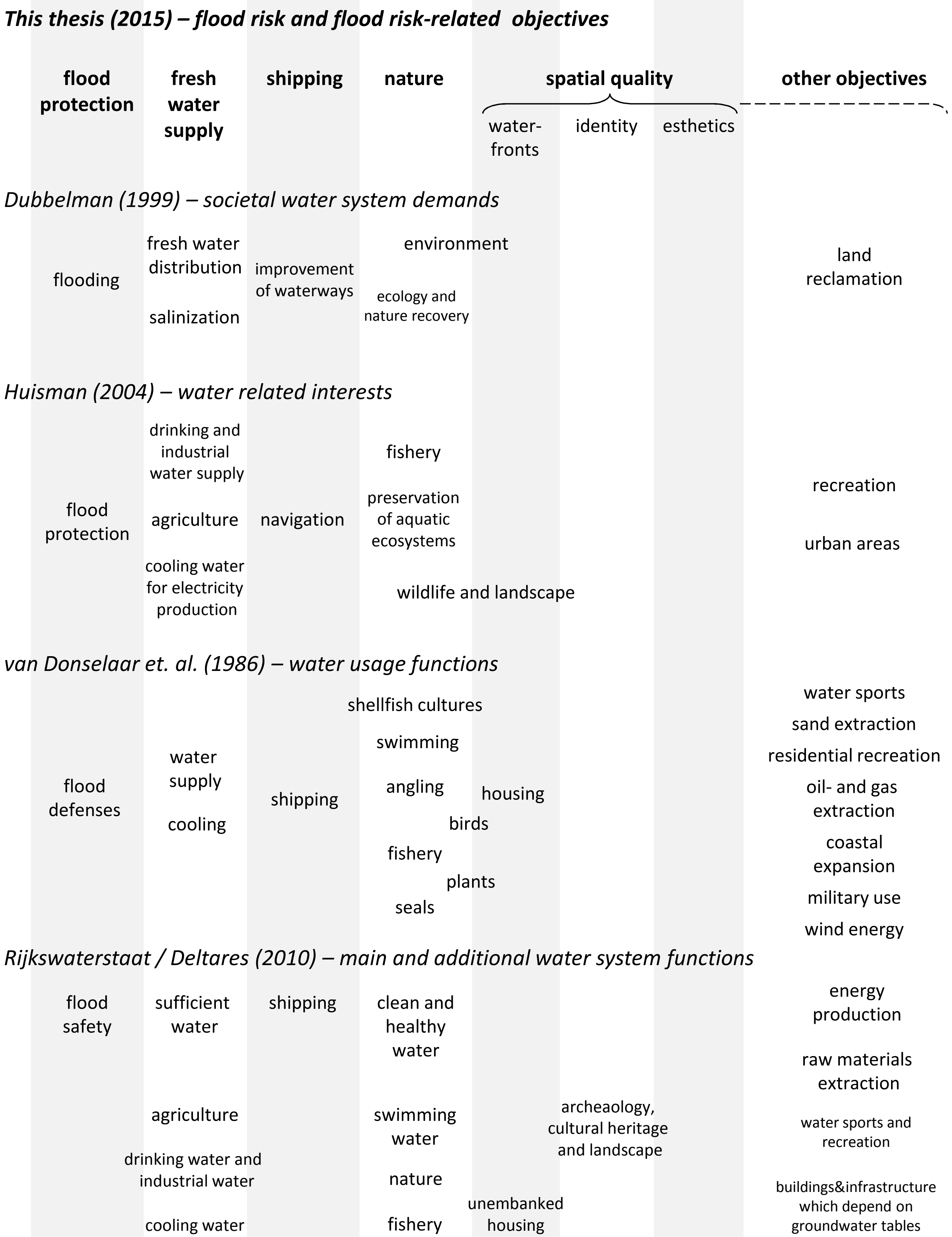
by local inhabitants, of diligent persistence to standardise and formalise maintenance, of building the largest and most complex sector gate barrier in the world, of environmental concern, greenification and growing resentment against higher dikes. It was also a time of dreams, particularly during the period between the mid-nineties and 2008; hundreds of bold ideas and extreme innovations were elaborated and discussed, but never made it into realisation (see some of these in figures 1.3).

The thesis aims to describe the main perspectives and ways of thinking, illustrated by the main projects and policy decisions. Some projects will be presented in more depth; the main cases for the thesis are located in the tidal- or lower rivers and the northern part of the Southwestern delta. This is the most complex part of the Dutch system, with branched rivers and half-open estuaries, comprising different water system types and areas with highly diverse flood characteristics – from elevated industrialised port landscapes and empty agricultural dike rings to dense neighbourhoods in the deepest polders of the Netherlands.

The flood risk system and flood risk-related objectives

What is a flood, and what is a flood risk system? This thesis builds on terms used within the Hydraulic Engineering group at Delft University of Technology (Vrijling 1997; Van Gelder 2000; Voortman 2003; Bezuyen et al. 2007; Jonkman 2007; Kok et al. 2008; Jongejan 2008, et cetera). Here, and in most contexts such as the daily news, floods are *unwanted*. Flooding means *harm*, caused somewhere by large quantities of water coming from large catchments elsewhere. Harm can be material or immaterial, and immediate or done over time. Water flowing over usually dry land causing little or no problems is sometimes also called flooding, but in this thesis this is referred to as high water, high tide, seasonal overflowing, et cetera. Flooding only caused by rain falling within a (small) system is considered *water nuisance*. *Inundation* is flooding intentionally caused by man.

Flood *risk* adds *probabilities* to the undesired events. The term flood risk *system* is unique to this thesis and has two main parts. First, (clusters of) vulnerable elements: people and material goods with a damage (or other harm) profile as a function of flood characteristics. Second, a natural system intertwined with man-made infrastructure, defined by geometry and materials, serving the objective of flood prevention of adjacent vulnerable elements. This second part of the flood risk system is, in this thesis, called flood protection *infrastructure*. Dikes are obviously infrastructure, but, according to this definition, a mound and a floodplain are as well; flood infrastructure is everything tangible which can be altered by man, aimed at reducing probabilities of vulnerable



entities getting flooded. The introduction to chapter 3 explains why the term *flood risk system* is chosen over terms like flood *management* and flood *protection.*

Physical flood infrastructure usually also affects other water-related objectives, like shipping, and non-water related objectives, like road infrastructure. A relationship with other objectives is created by the possibility that a measure to address a flood risk objective influences the extent to which another objective is met, or the other way around – throughout history, these relationships have usually strongly influenced decisions for solutions to flood risk problems.

The flood risk-related water system objectives as distinguished in this thesis, are informed by similar lists by several others. Hydraulic engineers Dubbelman (1999) and Huisman (2004) present, respectively, eight *societal demands* and ten (Dutch) *water-related interests*. In 1987, the Ministry of Spatial Planning took a broad perspective and listed over twenty *water usage functions* and investigated their mutual relationships (van Donselaar et al. 1986). Deltares (Marchand 2010) published the Delta Model evaluation framework for the current Delta Programme, using the four main *water system functions* of the 2010-2015 Management and Development plan for the National Waters (Rijkswaterstaat 2009), plus eleven remaining functions. See figure 1.4.

The variety of terms shows there is no agreed single perspective on the Dutch water system. In this thesis, two types of system objectives are distinguished. First, objectives which are uniquely and solely served by the water system, and for which there are commonly agreed methods to quantify and map the performance: freshwater conveyance, shipping and aquatic and amphibious nature (treated in sections 4.1-4.6) – these resemble the main water system functions of Rijkswaterstaat in figure 1.4. Many of the other demands, interests and functions in figure 1.4., can be seen as subsets; *agriculture* and *industry* for example, are land users who make use of *fresh water supply*.

The second group (treated in section 4.7) are objectives which are either of minor importance to the whole and/or not uniquely and solely addressed by the water system, and/or not commonly evaluated and mapped with a uniform unit. A flood risk system modification should, for example, rather not disturb existing attractive *waterfronts*, or could create a new attractive waterfront simultaneously with a dike upgrade. An attractive waterfront requires components which are not unique to a water system, such as houses, roads and benches. Furthermore, a map showing the performance of the Dutch waterfronts would be hard to make, because waterfronts are not judged against commonly agreed requirements. In figure 1.4, for this second type of objectives the term *spatial quality* is proposed, a term with multiple interpretations (to be elaborated in section 4.4).

◄1.4 Water system objectives used in this thesis compared to similar lists by other professionals.

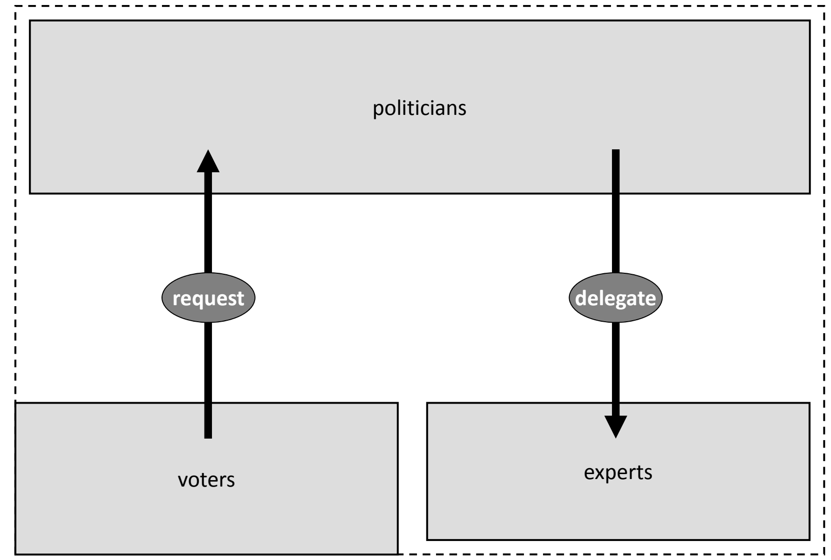
In a flood risk reduction project, some objectives have nothing to do with the water system. Two examples: solar panels may be desired to power a pumping station; to upgrade a dike somewhere, national health and building codes require that soil pollution by a former factory has to be cleaned. Some water system aspects have nothing to do with flooding, such as navigation at open sea. These two kinds of objectives are left aside in this thesis. The same holds for *political* objectives, like providing employment, and *process* objectives, like making sure proper procedures have been followed.

From content to process – context

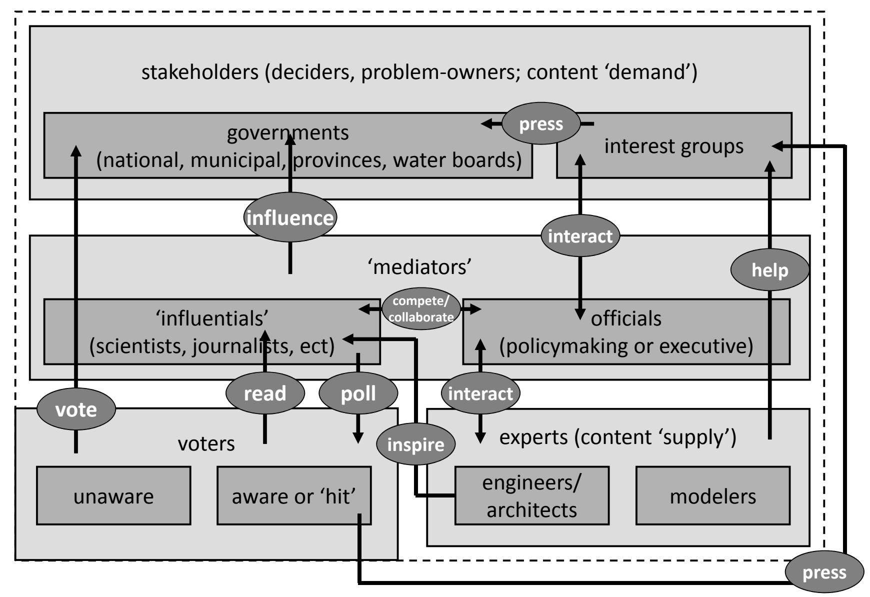
The historical and systematic overview of this thesis should be placed in the light of a particular over-arching issue during the time span studied: the shift in emphasis from *content* to *process* in management and communication. Several differences between the Delta Works (1953-1986) and the current Delta Programme (2009-2015), both the major national flood risk project at the time, support the notion that this shift has been happening.

At the times of the Delta Works, there was a close connection between national decision-makers and people whose main competence was knowledge of the flood risk system (content), like hydraulic engineers. In the *first* Deltacommittee (1953-1960), twelve of the fourteen members were civil engineers, the other two were an economist and an agricultural engineer specialised in freshwater distribution. The construction of the Delta Works (the phase between 1953 and 1986) was coordinated by the hierarchically organised Rijkswaterstaat Deltadienst (Delta Division), consisting of mostly hydraulic and other civil engineers. The top management had close ties to the national politicians (Yska 2009; Metze 2010; Hoogland 2009). The democratic scheme approaches the simple form represented in figure 1.5, where politicians are chosen by the Dutch people and consult the engineers directly.

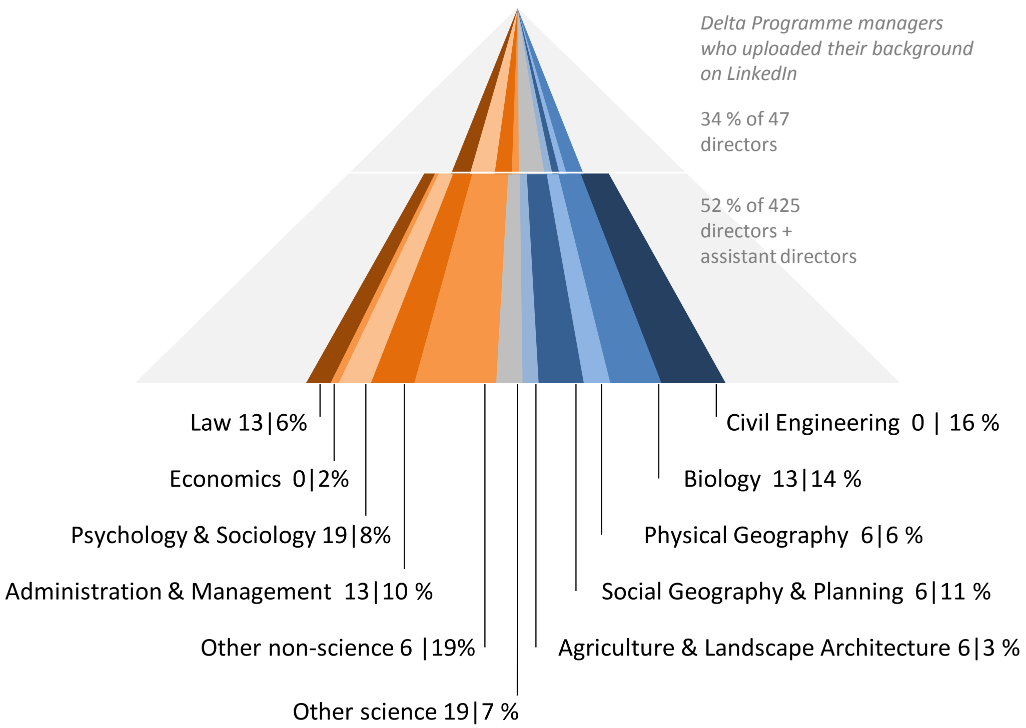
In the 21st century, engineers and politicians are farther apart. The *second* Deltacommittee (2008) contained one civil and one agricultural engineer and the majority of the other seven members did not have a particular reputation for knowledge about the national flood risk system. The Delta Programme (2009-2015), the multi-governmental organization to implement the recommendations by the Deltacommittee, has been structured in order to disperse decision-making over both national and regional governments and to consult many stakeholders (and other purposes; van Buuren & Teisman 2014). The wider spectrum of professionals and the (seemingly) less hierarchical structure explain why more emphasis than before is put on process management (*governance*), than science and content. The democratic scheme looks more like figure 1.6.



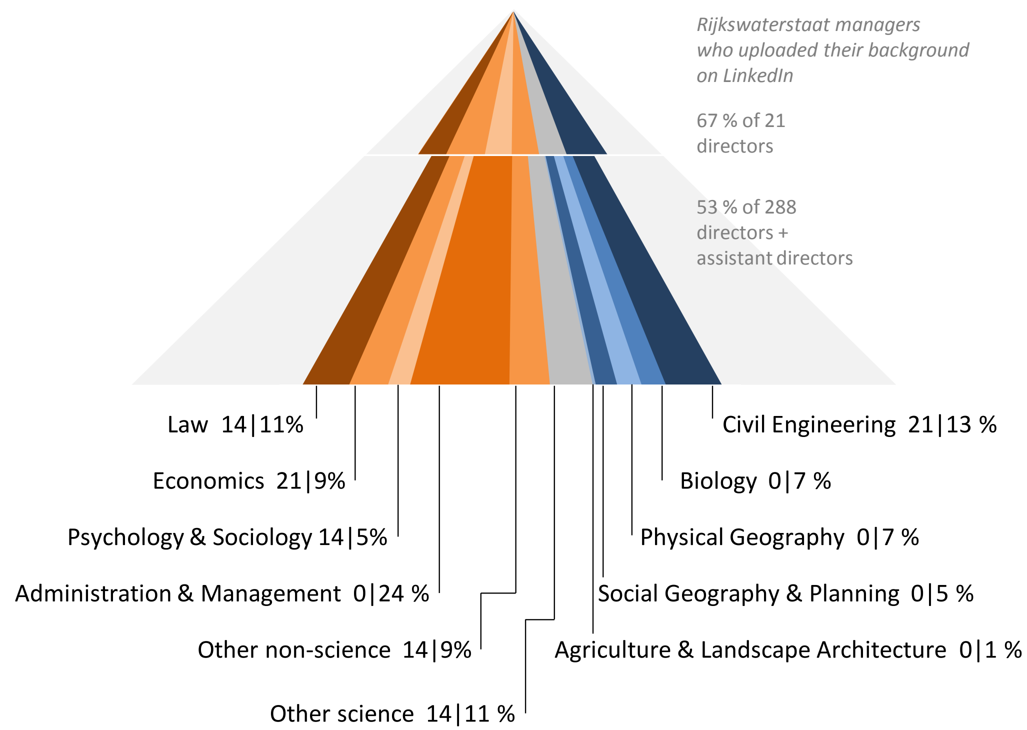
1.5 The simplest way to represent a democratic interaction between voters, politicians and experts (like hydraulic engineers). In this scheme, the politicians and experts are hierarchically organised.



1.6 Representation of a more complex democratic interaction around a theme like flood risk. The boxes are filled with hierarchies, but perhaps the organization as a whole is less hierarchical than as depicted in figure 1.5. On a scale between figure 1.5. and 1.6, the times of the Delta Works would be more towards 1.5; the current times rather fit 1.6.



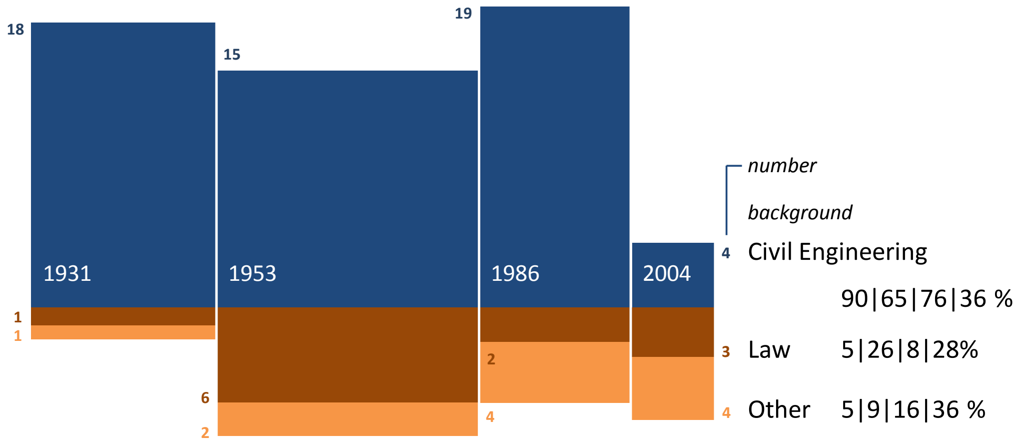
1.7 The educational background of the Delta Programme top management in 2012. Among the 34% of the directors who have filled in their LinkedIn profile, there are no civil engineers. More than half of the directors and assistant directors have backgrounds which have nothing to do with water.
Method: the names in the organogram by Aloserij (2012) were listed and grouped in directors and assistant directors (the Delta Programme consists of multiple steering groups and guiding groups, who were considered directors; the staff of the 'programmabureaus' were considered assistant directors). Doubles were removed. LinkedIn profiles were scanned for educational backgrounds. PhD replaces MSc, MSc replaces Ba. Discussion: the majority of the 66% of the directors who did not complete their LinkedIn profile are politicians (members of the political steering groups), most probably mostly non-engineers with a background in studies like law and economics.



1.8 The educational background of the Rijkswaterstaat top management in 2013. About 1 in 5 of the directors and 1 in 8 of the assistant directors are civil engineers. For both, less than 1 in 3 has a water or planning related background.
Method: same as 1.7, for the document RWS (2013), an organogram of Rijkswaterstaat with directors and assistant directors per division. Discussion: only 53% of the assistant directors filled in their LinkedIn profile.

Figures 1.7 and 1.8 show the results of a study into the educational background of the top management of the Delta Programme and Rijkswaterstaat (Adriaanse & Rijcken 2015). The blue colour range are people with a background in water-related studies, like water management, biology or physical geography. The orange colour range represent education during which students have probably never learned anything about water systems, water management or hydraulic engineering. A similar study on flood risk professionals at the time of the Delta Works could not be done, but from interviews it appears that nowadays more non-engineers and non-experts are employed in the professional flood protection sector, than within and around the Delta Works.

Figure 1.9 shows a second short study conducted for this thesis; the background (titles) of the Rijkswaterstaat chief executives since 1931 were counted. Since 2004, engineers are no longer the majority.



1.9 Rijkswaterstaat chief directors since 1931. Although the period since 2004 is short, a reduction in civil engineers can be observed.
Method: the Wikipedia page Hoogland (2015) lists all Rijkswaterstaat chief directors (directeur-generaal, hoofdingenieur-directeur, hoofdingenieur, administrateur, raadadviseur, directeur, hoofddirecteur, directieraadslid, hoofddirectielid, bestuurslid, chief financial officer), as collected by Jan Hoogland (see also the book by Hoogland (2010)).
All people mentioned on the website were listed (doubles were removed) and grouped according to their titles: ir. and dr. ir. (Civil Engineering), mr, mr dr, prof mr dr, mr ing (Law) drs, dr, prof dr, other (Other). The dates 1953, 1986 and 2004 are crucial reorganization dates. Discussion: it could be possible someone studied law but has no mr title, and it could be possible someone studied engineering, but not civil engineering.

The content-process shift can also be illustrated by a brief analysis (also conducted for this thesis) on how the Deltadienst communicated and how the Delta Programme communicates with the outside world. Four random newsletters by both organization s were scanned for articles about content or process: *content articles* summarise new knowledge or illustrate a technical or landscape design, a building project or an experiment, *process articles* explain when what will be done by whom, or highlight particular process steps that were taken or will be taken, like a meeting of a steering committee or the signing of an agreement. Figure 1.11 shows the results of this brief research.

Newsletters present what people in an involved community want to read, are expected to want to read, are desired to read and/or what is simply available. In case of the first option, it can be concluded that nowadays flood risk professionals are more interested in process over content, than before: the in total 40 Delta Works news items contained on average three technical illustrations per article and no pictures of people at all. Of the 92 items by the Delta Programme on the contrary, only one was accompanied by a technical drawing and one by a graph, and 34 by photographs of individuals or groups, attending for example a workshop or conference. Furthermore, the 92 Delta Programme

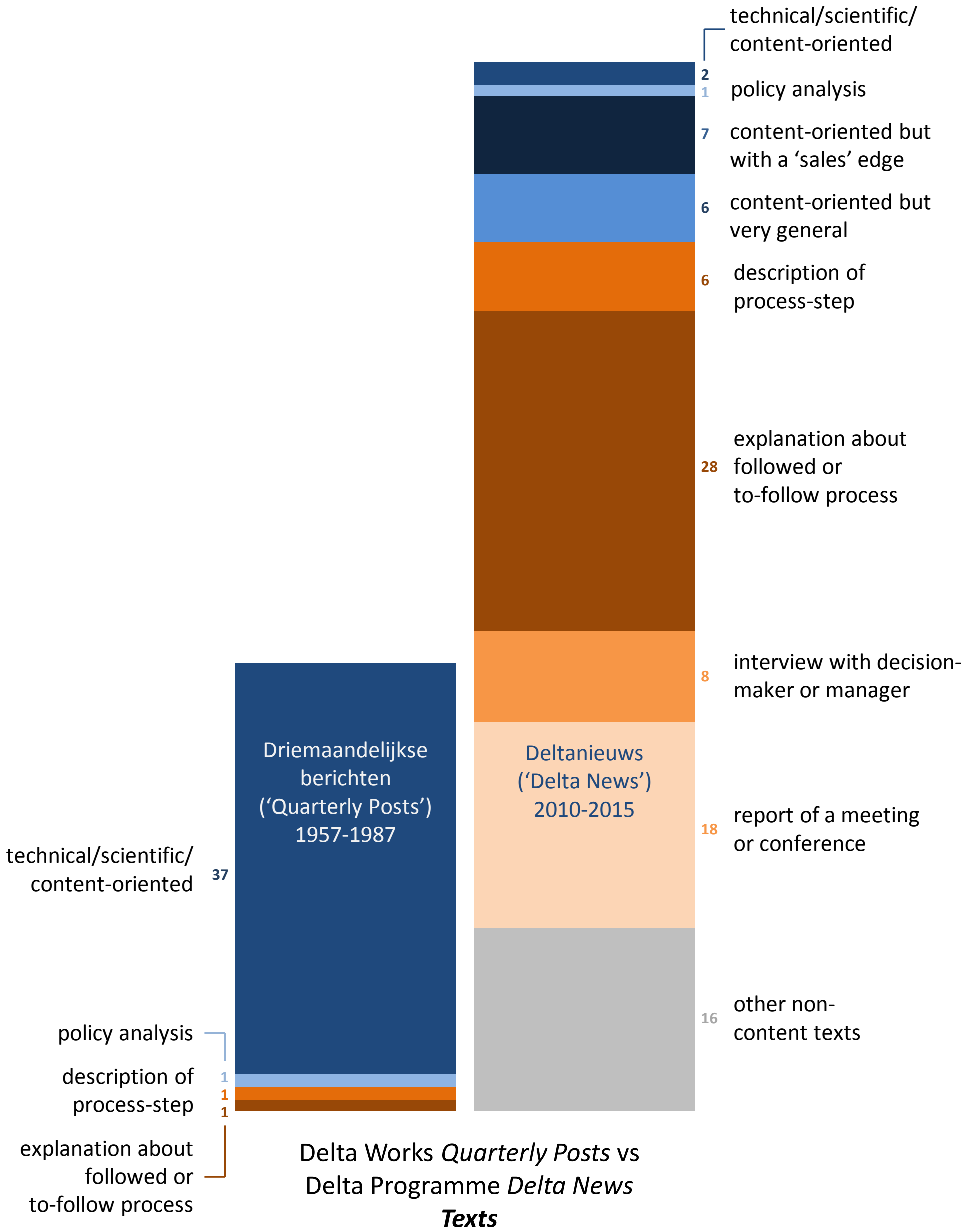
1.10 The Delta Works published the *Driemaandelijke Berichten* (Quarterly Posts) every three months between 1957 and 1988. The Delta Programme issued *Deltanieuws* (Delta News) every two months between 2011 and 2015.

news items mention in total 26 *numbers*, like water levels or costs (excluding years and dates); six of these 26 present new research results or design ideas. 83% of the scanned Deltanieuws articles contain no numbers at all.

The Delta *Works* contained policy-making, designing and building; the Delta *Programme* has just arrived at the building phase in 2016. Perhaps policy-making and designing put more emphasis on process than content, regardless of the spirit of the age, and this would explain the difference. Perhaps the difference is explained by the clarity of the task at hand during the Delta Works and a lack of clarity about the problem to solve for the Delta Programme. Other programmes parallel to the Delta Programme, like the High Water Defence Programme may be more content-oriented.

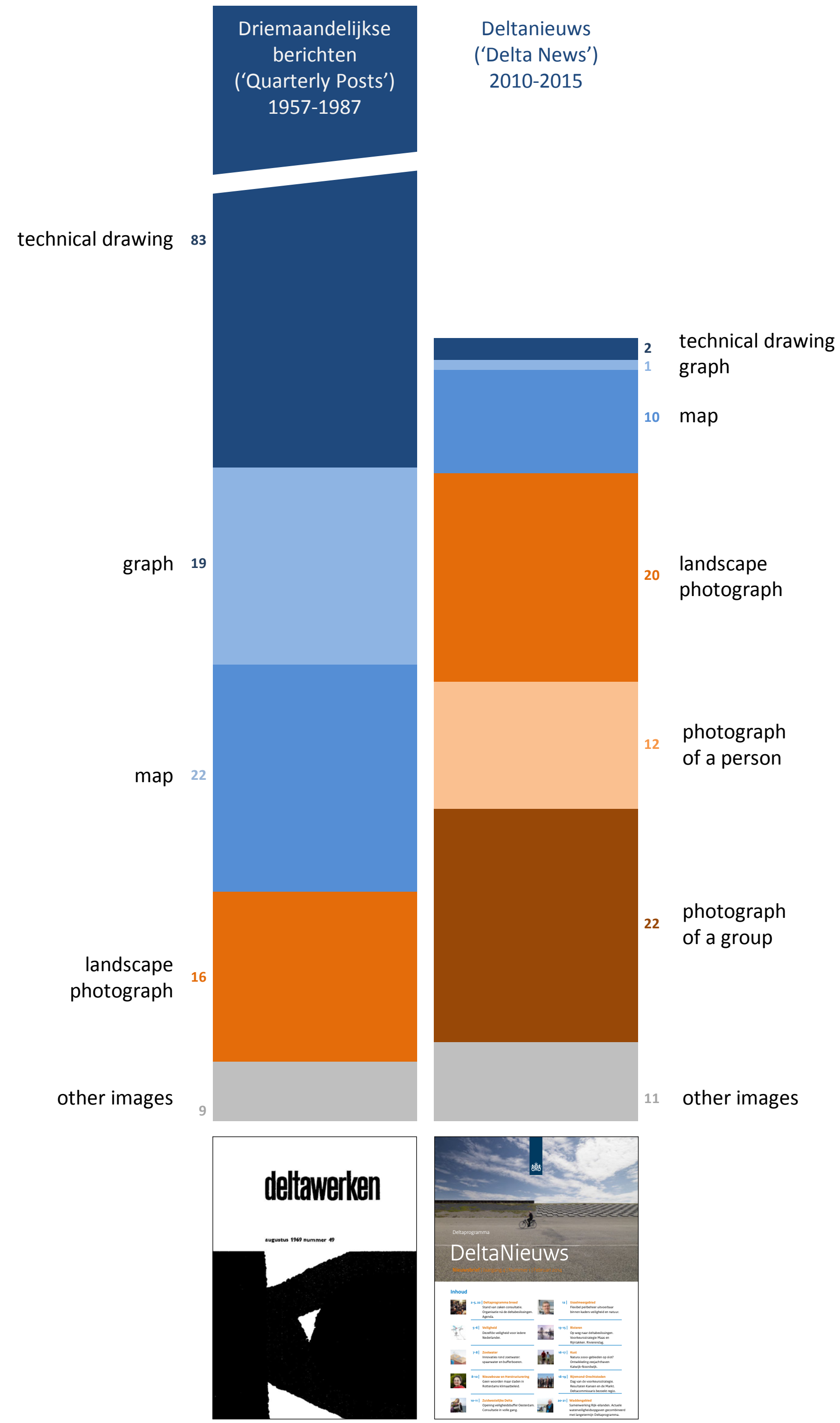
Either way, in each era and policy phase, content and process are intermingled and both will of course always be needed. Too much focus on content can lead to a lack of democratic legitimation or a tunnel vision, too much process to populism or a lack of efficiency.

The historical and systematic flood risk policy analysis in this thesis aims at representation of content-oriented findings, with clarity and precision, to bring more content into the process.



Delta Works *Quarterly Posts* vs
Delta Programme *Delta News*
Texts

1.11 ▸▸ The emphasis in external communication on content (blue) versus process (orange) at times of the Delta Works and the Delta Programme are diametrically opposed.
Method: four issues of the *Driemaandelijke Berichten* (Quarterly Posts) and four issues of *Deltanieuws* (Delta News), evenly spread over the periods 1957 to 1988 and 2011 and 2015 respectively, were analysed on types of text and types of illustrations (Quarterly Posts: November 1959, August 1969 and 1979, November 1987 – average number of pages: about 60), Delta Programme: September 2011, February 2012, 2013 and 2014 – average number of pages: about 20). Discussion: the articles were not all entirely read.



Delta Works *Quarterly Posts* vs
Delta Programme *Delta News*
Images

1.2 Towards the main trends between 1986 and 2016

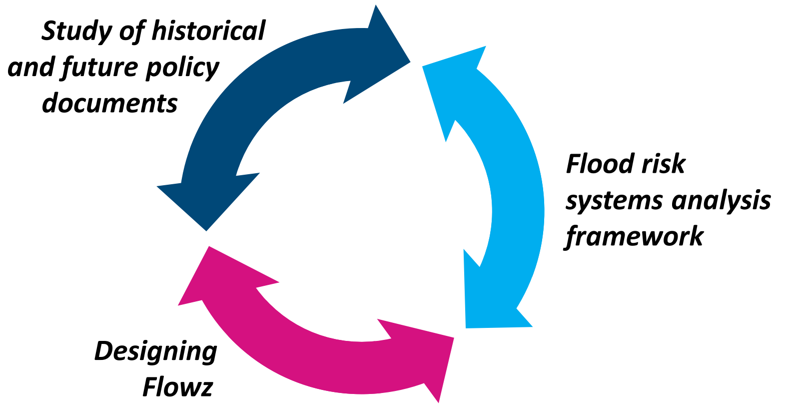
A historical systems analysis – research objective and research question

To contribute to shifting back from process to content, this thesis focusses on content: the lens through which the time span is studied looks at *what* has been done and *why*, rather than *by whom*.

The *research objective* is to develop a *flood risk systems analysis framework* for a *historical study into flood risk policy-making*, with special attention to *the relationships between flood risk and flood risk-related objectives* and *certain additional new ideas about flood risk*. This objective is the approach to answer the research question *how can the development of the Dutch flood risk system since 1986 fundamentally be characterised?*

In the term historical systems analysis, *historical* refers to the study of scientific work, policy documents and building projects in a certain timespan; the *systems analysis* is the way this study is structured. To represent the findings of the historical systems analysis, the thesis also has a *design objective*: *design a standardised systematic graphic language to represent the historical and future development of large complex water systems in interactive maps*.

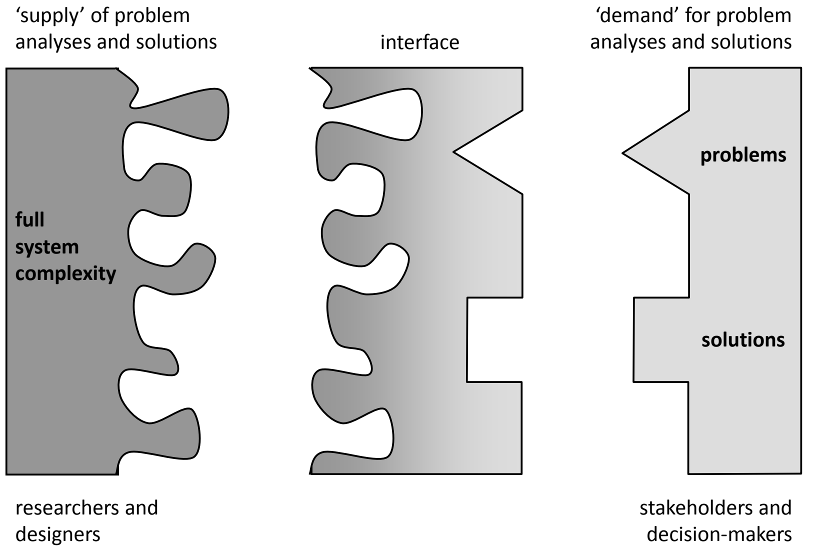
Figure 1.12 illustrates that throughout the thesis these three elements support each other.



1.12 These three thesis components are intermingled throughout the thesis – see an elaboration in figure 1.15. The policy study and systems analysis combined are called a *historical systems analysis*.

The art of omission – design objective

The design ambition reflects the design and engineering background behind this thesis. For water professionals, the graphic language should provide fast and intuitive understanding of the Dutch flood risk system. For this thesis, designing a clear and precise system of symbols forces to expose the *essence* of the flood risk system: 'the art of omission' (see figure 1.13).



1.13 The interface to be designed in this thesis translates the essence of the complicated technical-physical flood risk system to a simple problem-solution approach.

The graphic language and web-based interface combined are the *design objective* of this thesis: *design a web-based information platform to educate and communicate about flood risk and water systems*. The interface, first called *SimDelta* and now *Flowz*, provides intuitive access to systematically organised documents and maps. The platform is approached as an academic design task: discussing fundamental aspects and alternatives to main design issues (these design deliberations will be done not in the body text of the thesis, but in the captions for the interface screenshots). The core concepts underlying the interface are inquired in the next chapter.

Part of the design objective is answering the question to what extent the five main water system functions (flood risk reduction, freshwater conveyance, shipping, nature/ecology and landscape quality) can be described and mapped at the same level as the flood risk system – see the next subsection. The underlying assumption is that when different systems are described and visualised with the same systematics, this leads to faster understanding, a more objective approach and better integration between the related system objectives.

1.14 The interactive interface should take full advantage of the possibilities of today's information and communication technology, like availability on multiple platforms, integration with other information systems and intuitive use.

Research method

Figure 1.15 shows how the three thesis elements (systems analysis, historical policy document study and designing the interface) relate to each other; the colour scheme in the table of contents shows how these elements are dispersed throughout the thesis.

The historical systems analysis first identifies a fundamental rational systems framework and then applies this framework to various moments in history by identifying methods of analysis (which evolve through time) and material manifestations (building projects). The framework is inspired by Keeney's (1996) *Value Focussed Thinking*, revolving around a *decision context* (this thesis: system components), *means objectives* (this thesis: system modifications) to achieve *system objectives* on various levels.

The general advantages of applying a systems analysis on a national level are: 1) problem analysis is separated from generating solutions (resulting in a better analysis and more varied solutions), 2) the entire system is assessed equally and with the best available national models, 3) national policy-making is better served, for example to benefit remote regions.

Inspired by these advantages, the systems analysis framework of this thesis first distinguishes:

- the *flood risk system* and
- water systems *related to flood risk* (freshwater conveyance, shipping and nature/ecotopes),

then identifies for both the flood risk and flood risk-related water systems:

- (physical) *system components*, in a
- *system* (component) *state*, to be *assessed* and changed by
- *system modifications*, based on
- *system requirements*, derived from
- *fundamental system objectives*;

then describes

- *relationships* between the flood risk system and flood risk-related systems, which occur when a system modification to one system also affects a related system.

These systems analysis framework elements are treated for *flood risk* in chapter 3 and similarly (but less extensively) for *freshwater conveyance, shipping* and *nature/ecotopes* in chapter 4.

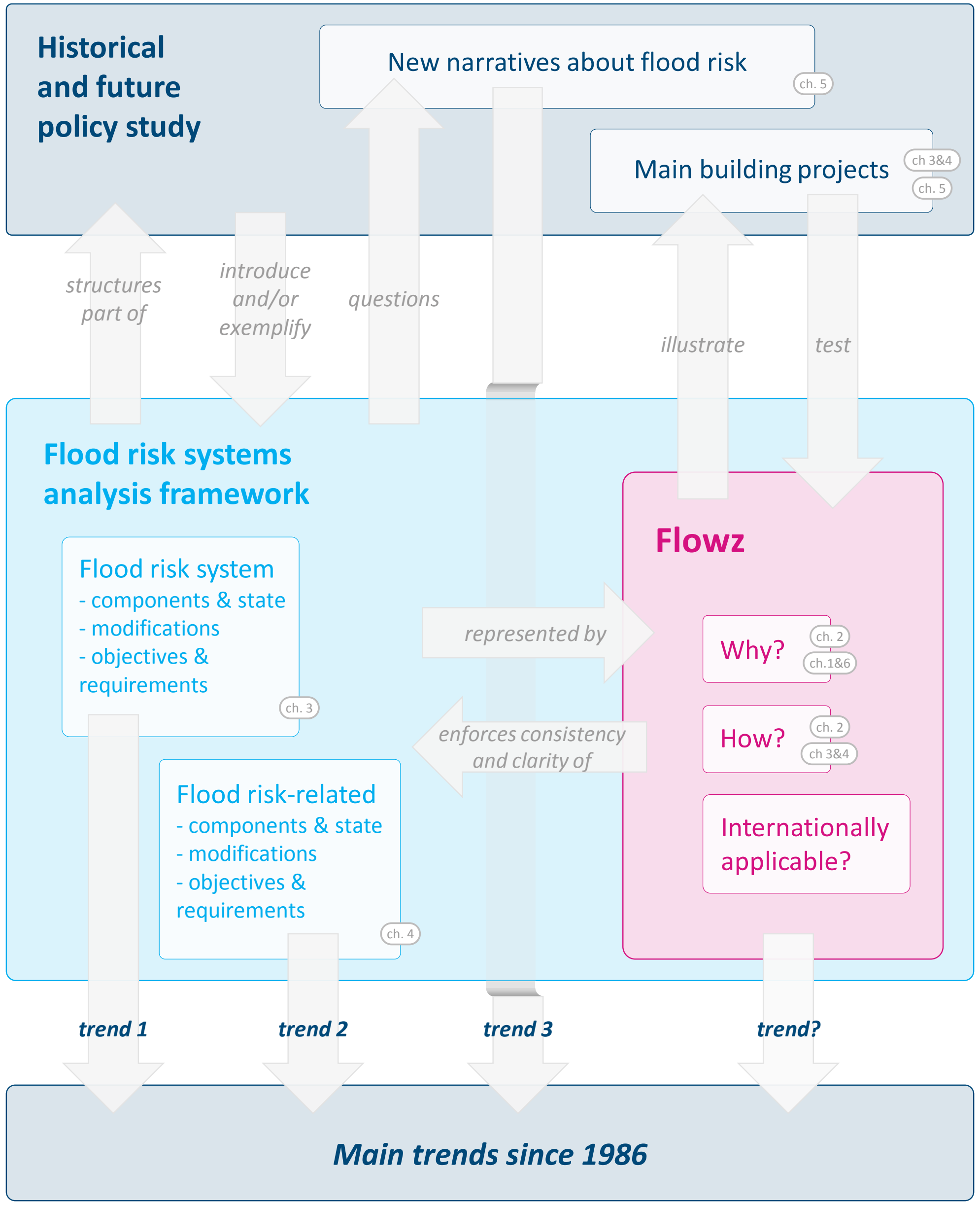
The *landscape quality* sections in chapter 4 and the *new narratives* of chapter 5 identify remaining *gaps* in the systems analysis framework.

Following this method, the research question *how can the development of the Dutch flood risk system since 1986 fundamentally be characterised* is answered by first formulating *three main trends*: the first addresses the flood risk system alone, the second refers to the integration between the flood risk system and other water systems, the third to the additional new narratives. Finally, the thesis' findings are compared to characterisations of the same time span by other water professionals and this leads to the final conclusion.

What is a main trend? A main trend has to express a shift relative to the policies and thinking during the times of the Delta Works. The trend should not be a particular occasion or brief transition, but an ongoing shift taking a decade or more. It has to be manifested in modeling (system descriptions, equations), in publications (reasonings, evaluations, values), possibly in legislation and finally physically (building projects). It should be noticeable in a large part of the projects and policy documents. The trend has to be recognised by professionals who have an overview over the period studied.

The chapters leading to the three trends (chapters 3, 4 and 5) each end with a discussion and conclusion. First, a methodological discussion of some crucial terms, choices and omissions in the historical systems analysis. Second, a reasoning towards a main trend. This reasoning starts with an exposition of the main investments, new theories and models developed. This leads to multiple subtrends and finally to a common denominator between the subtrends.

The policy studies referred to throughout the thesis often span the entire national system. When more detail is needed to introduce or explain particular system components or developments, the *geographical focus* is on the tidal rivers (also called the Rhine-Meuse estuary, or the lower river reaches), an area considered the technically most complex part of the Dutch national water system.



1.15 The flood risk systems analysis (in blue) is core to the thesis. The research question is to identify the main historical trends since 1986, as the result of a historical policy document study, structured by the systems analysis, which revolves around *system components* in a certain *state* relative to *system requirements* based on *fundamental system objectives* possibly leading to *system modifications*. Designing the interface enforces clarity and precision in the systems analysis. The interface is also used to illustrate historical cases and studies; representing different studies with the same graphic language tests the extent to which the interface can be universally applied.

Scientific design

The design process of the interface has a head, a body and a tail. Chapter 2 presents the birth of the interactive platform and explores past and future of interactive policy support instruments. The systems analysis chapters 3 and 4 show how the graphic language of the platform represents system components, state, requirements, and modifications. Screenshots are presented throughout the subsections; the captions explain design choices which have been made in iterative design cycles as taught by for example Roozenburg and Eekels (1995) and Brown (2009). The discussion at the end of chapter 5 and the final conclusion of chapter 6 relate the final design to the three main trends and the final conclusion of the thesis.

The design process of the interactive graphic model will use the guidelines recommended in the *quality assessment in the design and engineering disciplines* by the Royal Netherlands Academy of Arts and Sciences (2011). The quality of a scientific design project is sufficient if it has enough *scientific quality* and *societal relevance.*

Scientific quality:

1. the design and the design process provide generically applicable new knowledge;
2. the design and the design process are reviewed by scientific peers;
3. the knowledge eventually created by the design is publishable in peer reviewed journals and used by the scientific community.

Societal relevance:

4. the design is used and/or appreciated by stakeholders in society;
5. the design helps to spread scientific knowledge in society.

De Jong and van der Voordt (2005) edited an influential book on scientific study and design of buildings and public space. Their guidelines for scientific design match the ones listed above, when criteria like reliability, validity and scientific relevance are covered by the scientific community reviews in points 2 and 3. The thesis's policy study approach is along the line of what De Jong and van der Voordt call *typological research*: studying many flood infrastructure programs, projects and concepts (each the results of a design process) on their essential functioning in the water infrastructure system, to generalise (typologize) for a systems analysis and design of a standardised graphic language and user interface.

▼ 1.16 Part of the historical systems analysis of this thesis is to explain and discuss these water system components one by one; this will be done in chapters 3 and 4.
Throughout the thesis, *design considerations* will be marked under the Flowz map captions. Some considerations for the table on the next pages: the layer column indicates which elements are shown on which layer (scale level). One of the design goals is to have the thickness of each element (including 'negative spaces' between shapes, like a port) be equal in a single layer. Control structures pop up in the layer with the water body which they control. System component *sizes* are determined by the relative importance of the component and *locations* of the system components by the positions relative to each other, rather than by exact geographic geometries. Towns and villages are only shown when they are located near a water body.

	Land and urban areas	Flood risk	Freshwater	Shipping	Nature	SVG layer
	Water(front) village (>2.000 inhabitants)					*18 'villages'*
	"Freshwater town"		Small freshwater axis Small reservoir (<xx m3)		Nature axis 0,8 pt	*17*
	"Waterway II) town"			Waterway class II	Nature axis 0,8 pt	*16*
	Small unembanked area (>0,04 km2) Water(front) town (>10.000 million inhabitants)	Discharge capacity 1000 m3/s Small port and/or industry Small unembanked vulnerable area Detailed dike or dam	*Capacity* 10 m3/s Medium reservoir (xx m3)	Waterway class III Small port	Nature axis 1 pt Small tidal flats Small floodable nature Medium fresh/salt slufter	*15*
	Medium unembanked area >0,4 km2) City (>25.000 inhabitants)	Discharge capacity 1500 m3/s Medium port and/or industry Medium unembanked vulnerable area	*Capacity* 15 m3/s Medium reservoir (xx m3)	Waterway class IV Medium port	Nature axis 1,5 pt Medium tidal flats Medium floodable nature Large fresh/salt slufter	*14*
system components	Large unembanked area (>4 km2) Water(front) city (>25.000 inhabitants)	Discharge capacity 2000 m3/s Large port and/or industry Large unembanked houses, office buildings, marinas, public space and other vulnerable functions Dike (type c)	*Capacity* 20 m3/s Large reservoir (xx m3)	Waterway class Va Large port	Nature axis 2 pt Large floodable nature Major fresh/salt slufter	*13*
	Major non-floodable land above 100 m Major non-floodable below 100 m Major floodable land above sea level Major floodable land below sea level 'Major' urbanisation (> 0,1 million inhabitants)	River discharge capacity: *from <2500 m3/s* *to >12.000 m3/s* Dike or dam Dune Standardised dike cluster	Capacity *from* <25 m3/s *to* >120 m3/s Major reservoir (xx m3)	Waterway class Vb Waterway class VIa Waterway class VIb Waterway class VIc	Major beach Major freshwater Major floodable nature Major saltwater Major tidal flats	*12 'major'*
	'Max' urbanisation (> 0,5 million inhabitants)	River discharge capacity: *from 3.000 m3/s* *to 7.500 m3/s*	Capacity: *from 30 m3/s* *to >120 m3/s* Max reservoir (xx m3)	Waterway sea shipping 1-4 Waterway sea shipping 5-8	Mega fresh floodable nature (fresh amphibious ecotope) Mega tidal flats (salt amphibious ecotope)	*11 'max'*
	Mega non-floodable land above 100 m Mega non-floodable below 100 m Mega floodable land above sea level Mega floodable land below sea level 'Mega' urbanisation (> 1 million inhabitants)	River discharge capacity: *from 7.500 m3/s* *to >20.000 m3/s*	Capacity: *from 30 m3/s* *to >120 m3/s* Mega reservoir (xx m3)		Mega freshwater (fresh aquatic ecotope) Mega saltwater (salt aquaticecotope)	*10 'mega'*
		Capacity unknown Dike (type unknown)	Capacity unknown Freshwater aqueduct or canal) Freshwater pipeline	Waterway class unknown		
control structures	Control structure (type unknown)	Discharge distribution spillway Outlet Pumping station Outlet with pumping station Moveable high water barrier	Discharge distribution spillway Freshwater intake Pumping station Weir Fresh-salt barrier	Dam or weir with lock Dam or weir with lock, permanently open in summer Dam or weir with lock, permanently open in winter Moveable high water barrier	Eco-gate (two directions) Pumping station Fish passage	*any layer*
system modifications	Control structure modified in current year Optional control structure modification	Flood defense modified in current year Optional flood defense modification Unembanked area modified in current year Optional unembanked area modification River project conducted in current year Optional outer water modification	Freshwater reservoir modified in current year Freshwater reservoir modification Freshwater axis modified in current year Freshwater axis modification	Port modified in current year Optional port modification Waterway modified in current year Waterway modification	Amphibious ecotope modified in current year Optional amphibious ecotope modification Aquatic ecotope modified in current year Optional aquatic ecotope modification	

Chapter 2 in brief

Studying a flood risk system involves a large number of combinations between possible measures and effect studies. Having to deal with infinite options is intrinsic to any design task, but the size (space, time and people involved) of the national flood risk system justifies additional effort into how options are represented, communicated and discussed. The goal of a communication layer can be stated to connect *supply* and *demand* of content. This is a simple starting point, but pieces of content are intricately interconnected, and demand for content is intertwined with development of content in complex ways.

This chapter aims to enhance understanding of this process and to introduce a communication concept based on interactive maps used by internet communities, called *SimDelta* in 2012 and *Flowz* in 2016. A brief survey of approaches to water system planning and 'serious games' concludes that the graphic interface between technical-physical complexity and socio-political complexity (or: between supply and demand of content) is increasingly recognised to contribute to effective policymaking.

A structure for SimDelta/Flowz consists of six stackable software blocks: the base block contains interactive maps generated in a systems model, the top block involves communication between stakeholders to make choices in a virtual problem-solution space. Usage over the internet makes it possible to record preferences, and 'crowdsource' corrections, improvements and new ideas. Whether the concept works and the contribution it can make to current policymaking can only be tested by developing it step-by-step. Chances for success will depend on how the platform relates to existing ways information is obtained and existing types of decision support.

Chapters 3 and 4 describe the flood risk and flood risk-related water system components conceptually and with a historical overview. Designing Flowz sharpens the mind towards the essence of the water systems, and the Flowz maps serve to illustrate the historical policy studies.

Chapter 2

Towards an internet platform to support water system development

Original paper title: 'SimDelta' – inquiry into an internet-based interactive model for water infrastructure development in the Netherlands

Co-authors: J. Stijnen (HKV consultants), N. Slootjes (HKV consultants/Deltares)

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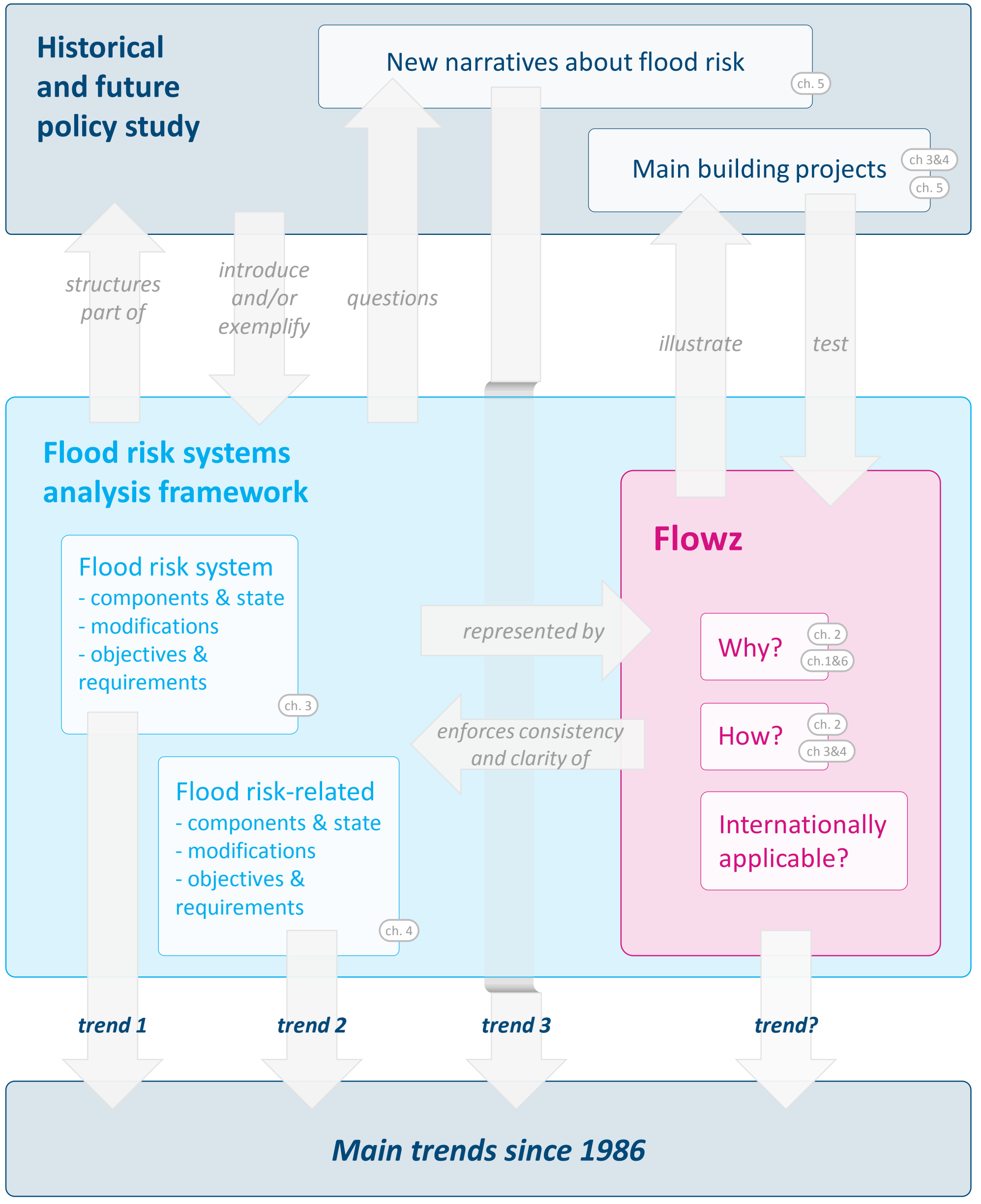
Modifications to the original paper: the subsection 'From SimDelta to Flowz' was added in June 2014, figure 2.13 was added in December 2016 (but made in November 2011).



2.0 This chapter completes this part of the thesis as explained in chapter 1 (figure 1.15 on page 40).

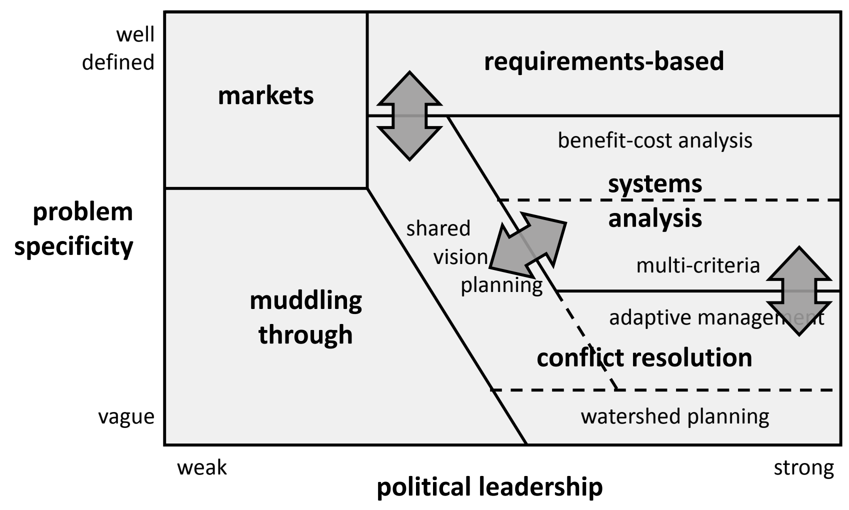
2.1 Water infrastructure development support

Water infrastructure planning and policy models

Spatial planning methods aim to solve spatial problems by identifying solutions, estimating their effects on various factors or functions, establishing criteria to judge these effects and getting value-based input from the relevant stakeholders, to support policy decisions (definition after Walker (2000) and Lund (2008)). This can be done with strong or little scientific support, depending on the resources available and the issues at stake.

The case for this paper is the Rhine-Meuse river delta, stretching about 200 kilometres from the Dutch western coast inland and 200 kilometres from south to north. Water management in the Netherlands is advanced. Hundreds of millions of euros per year are spent to maintain and improve the primary system (sea, large rivers and main lakes) (Deltacommittee 2008; Kuijken 2011), and several millions on policy support models (Subsection 1.1) and “serious games” (Subsection 1.2).

Most water resource planning efforts aspire to be rational and are therefore similar in their fundamentals (Lund 2008). Different approaches originate from different practical problems. Lund divides these along two major aspects: strength of leadership (perhaps better described as centralized *versus* locally dispersed power) and problem specificity (see figure 2.1).



2.1 Categorization of planning methods (Section 2.1) by Lund (2008). Serious Games (Section 2.2) could serve as communication tools (arrows added to the original diagram) to connect the planning methods of Systems analysis with Conflict Resolution.

Strong leadership and well-defined problems can result in easy-to-use legal requirements. When a detailed planning analysis is too expensive or impractical, projects often use previously established requirements or norms. The flood protection standards in the Netherlands were originally based on a benefit-cost analysis (van Danzig 1956), but since then have served as "simple" requirements the system has to meet, to whatever costs. Only rarely are new standards set, based on a new benefit-cost analysis. In the opposite corner of the diagram we find the policy of Muddling Through, a term introduced by Lindblom (Lindblom 1959).
In practice often few resources are available to dive deeply into a problem or there is no higher government to set standards. In the Dutch flood protection system, the way in which "multifunctional dikes" have been built and maintained has elements of Muddling Through. At this moment efforts are being undertaken to shift this to the planning methods of Conflict Resolution' or even Markets, supported by some building codes (Requirements), or Systems Analysis (see figure 2.1) (Stalenberg 2010; Vrijling 2010).

A multi-criteria analysis extends further than a benefit-cost analysis by adding non-monetary criteria and weights to the criteria, derived from values held by different stakeholders. Among the used tools are scorecards (Walker 2000) and utility functions to calculate trade-offs between different objectives (Keeney 1996).

Often enough, water systems are so far developed and political positions are held so firmly, that even when an "objective" systems analysis provides "evidence" for smart investments, still no action is taken, because of Game Theory-like stalemates, modeling uncertainties or communication and visualization difficulties. Lund writes: "where the water resource problem involves fundamental political conflicts among objectives, multi-objective analysis cannot resolve those conflicts, only make them clearer" (Lund 2008, p.4). In those cases, planners sometimes turn to a planning method that focuses on facilitating constructive negotiations. From this perspective, success is achieved when stakeholders come to agree on a decision, even one not qualified by systems analysis as one of the best. The national Delta Programme in the Netherlands has elements of Conflict Resolution in its organization. Regional sub-organizations have been formed to come up with long-term solutions in an intense dialogue with regional and local governments (Deltaprogramma 2010). These solutions, however, are input for the Delta Instruments (see later in this paper), established to determine the effects of the various solutions, in a typical Systems Analysis fashion (Deltaprogramma 2011a; Marchand 2010). These effects are brought back to the negotiation, and the future will tell whether the eventual decisions are made based on the outcome of the systems analysis, the negotiations among the stakeholders, or a mix of both. Merging the methods Multi-Criteria Analysis and Conflict Resolution requires particular communication tools, such as serious gaming.

The rise of serious gaming in policy support

Serious gaming can be defined as "experimental and/or experiential rule based, interactive (modeled) environments, where players learn by taking actions and by experiencing their effects through feedback mechanisms deliberately built into and around the game" (Mayer 2009, pp.825–826). It is still a question how serious gaming relates to policy making support methods and techniques from all corners of figure 2.1, such as modeling (systems analysis), stakeholder panels, workshops, and process management (conflict resolution, muddling through). Serious games are descriptive models instead of prescriptive; they reduce the central position desired by classical systems analysis in policy-making. However, exactly by taking this position, games might eventually provide more scientific support in the real political arena.

Serious gaming evolved behind the decision sciences: operations research, systems analysis, and public policy analysis. In the 1950s, economists and social scientists introduced social aspects in the decision sciences, but they remained predominantly mathematically oriented. In the 1970s, systems analysis models started to receive fierce criticism. In 1973, Douglass Lee wrote his Requiem for Large Scale Models, addressing fundamental limitations of computer modeling and naiveté of modelers about the world of politics and planning. Studies from political science, management science, and organizational behavior had demonstrated that policy-making was not comprehensive, rational, and linear, but rather bounded, political and incremental.
Lee's "seven sins" are useful to keep in mind (even though today's computers are faster than Lee imagined): "hypercomprehensiveness, data hunger and grossness, wrong-headedness, complicatedness, mechanical-ness and expense" (Lee 1973, pp.164–169).
These sins are particularly destructive when not only the modeling results are distrusted, but also the model itself cannot be understood by anyone but the modelers. Here serious gaming stepped in with the humble contribution of "making computer models more transparent" to policy-makers (Mayer 2009, pp.834–836).

In 1986, the RAND Corporation's Garry Brewer, who shared Lee's criticism of modeling in the 1970s, started to promote Policy Exercise, a tool with roots in early forms of serious gaming. Exercises and system simulations under various future scenarios advanced further with emerging environmental problems and climate change since the 1980s. Many environmental issues had an unprecedented large scale, high degrees of complexity and uncertainty, and needed new forms of communication to facilitate "a constructive negotiation among scientists and between scientists and policy stakeholders" (Mayer 2009, p.838).

It seems that serious gaming is an education and communication layer over a planning model, or a bridge between two models, for example multi-criteria analysis (usually preferred by scientists) and conflict resolution (comfortable for many politicians and stakeholders). Mayer suggests that policy gaming "integrates technical-physical complexity with social-political complexity" (Mayer 2009, p.852). Lund writes that "the objectives of a planning method are not limited to decision making, they also include education, documentation and reference, strengthening leadership, and fostering discussion" (Lund 2008, pp.12–13). These objectives imply communication and education. Serious gaming is not a planning method in itself, but can very well be a significant part of it.

2.2 Complexity in the Rhine-Meuse delta

The reviews of planning methods and serious gaming have shown that communication between systems analysis with the "real world" deserves special attention in policy-making. The third and fourth sections of this paper explore available advancements in information and communication technology to support this connection. The next section presents the Dutch Delta Programme, currently developing new policies for the interconnected rivers, canals, lakes and estuaries of the Rhine-Meuse delta.

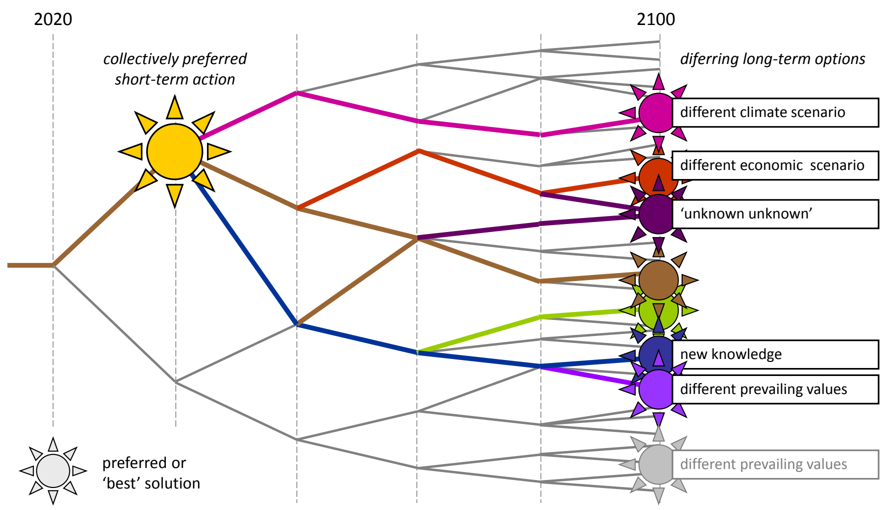
The objective: adaptive delta planning

At the end of 2007, a national committee was established to examine climate change threats and to unite and profile the Dutch water sector nationally and internationally. A year later this Deltacommittee presented several solutions for flood risk, fresh water supply and water related ecological problems expected in 2050 and 2100 (Stive et al. 2011). The report sparked a debate about the proposals, and alternative long-term plans appeared or were dusted off.

Around that time, various scientists in hydraulic modeling and policy analysis wrote about not only the need for more alternatives, but also for smaller time steps and more future scenarios. Not one single best solution, but "portfolios of flood management activities" will most effectively reduce risk (Aerts, Botzen, et al. 2008). Scenario studies should not only compare different strategies for different future states, but also consider pathways towards the future (Haasnoot et al. 2009). The Tipping Point approach investigated when the first problems would emerge under a particular climate change scenario, instead of focusing only on the years 2050 and 2100 (Kwadijk et al. 2010).

The Dutch government followed-up on the Deltacommittee in 2009 by launching the Delta Programme. The first publications of this large organization focused on the long term (Deltaprogramma 2010), similar to the Deltacommittee. However, in 2011 and 2012 the focus shifted to the shorter or mid-term (Deltaprogramma 2011b). To bridge the time spans, the Adaptive Management method is being investigated to have "a measure show up, way before it becomes urgent. This gets stakeholders acquainted with uncertainty and empowers the search for additional opportunities related to the problem or the project" (Deltaprogramma 2011b, p.31 (appendix)).

Adaptive Management as a planning method originated in the ecosystem sciences in the 1970s (Holling 1978; Lee 1999). Ecological models are explicitly acknowledged to have many flaws but are proposed to assist negotiation between different alternatives, as knowledge is improved. In Lund's diagram (figure 2.1) the method is therefore located in the Conflict Resolution corner. Its application in the Delta Programme seems to be more related to economic systems analyses. In government publications, adaptive management is tied to cost-efficiency (Kuijken 2011, p.9), for example by bringing in the mathematical Options Theory approach (Ingham et al. 2006). The advisory board for the Ministry of Infrastructure and Environment wrote in 2008: "adaptive policies evolve over time in response to new information" (Rahman et al. 2008, p.43). Walker's Dynamic Adaptive Policymaking is "a systematic method for monitoring the environment, gathering information, implementing pieces of the policy over time, and adjusting and re-adjusting to new circumstances" (Walker 2011, p.11). This is what the Delta Programme aspires to, but the question remains how to implement this ambition practically. Figure 2.2 illustrates how short-term actions relate to long-term options and uncertainties.



2.2 This conceptual "options tree" illustrates the objective for the Delta Programme as stated in this paper. A particular difficulty is how to relate the measures (or actions) to be implemented between 2020–2028 to long term options and uncertainties.

The recently adopted Delta Law establishes a Delta Fund in 2012. The fund will finance improvements to the Dutch water infrastructure with structural measures, such as flood defense modifications, altering or adding a river section, building or redesigning civil engineering works such as an operable barrier or a pumping station, improving fresh water supply by adding or modifying a canal, pipeline or storage basin, or non-structural measures, as changing building codes for unembanked areas, pricing fresh water or altering operations of a barrier or pumping station. Between the years 2020 and 2028, 2.4 billion euro is available for new projects, on top of 4 billion euro for maintenance and 3.6 billion euro for already allocated projects (Deltaprogramma 2011b; Kuijken 2011).

Which projects will be chosen for a given financial budget? In a democracy, public projects are selected based on a well-informed representation of a majority of the population. Combining this with adaptive planning, the objective for the Delta

Programme could be to determine which projects and policies for flood risk and fresh water supply, between 2020 and 2028, will be preferred by a majority, well informed on the wide range of options and scenarios on the long-term, and collectively willing to take the risks that come with each alternative.

This objective contains the technical-physical system, subject to uncertainties in long-term forecasts, and the social-political system, where the pros and cons of possible decisions have to be understood by the many stakeholders.

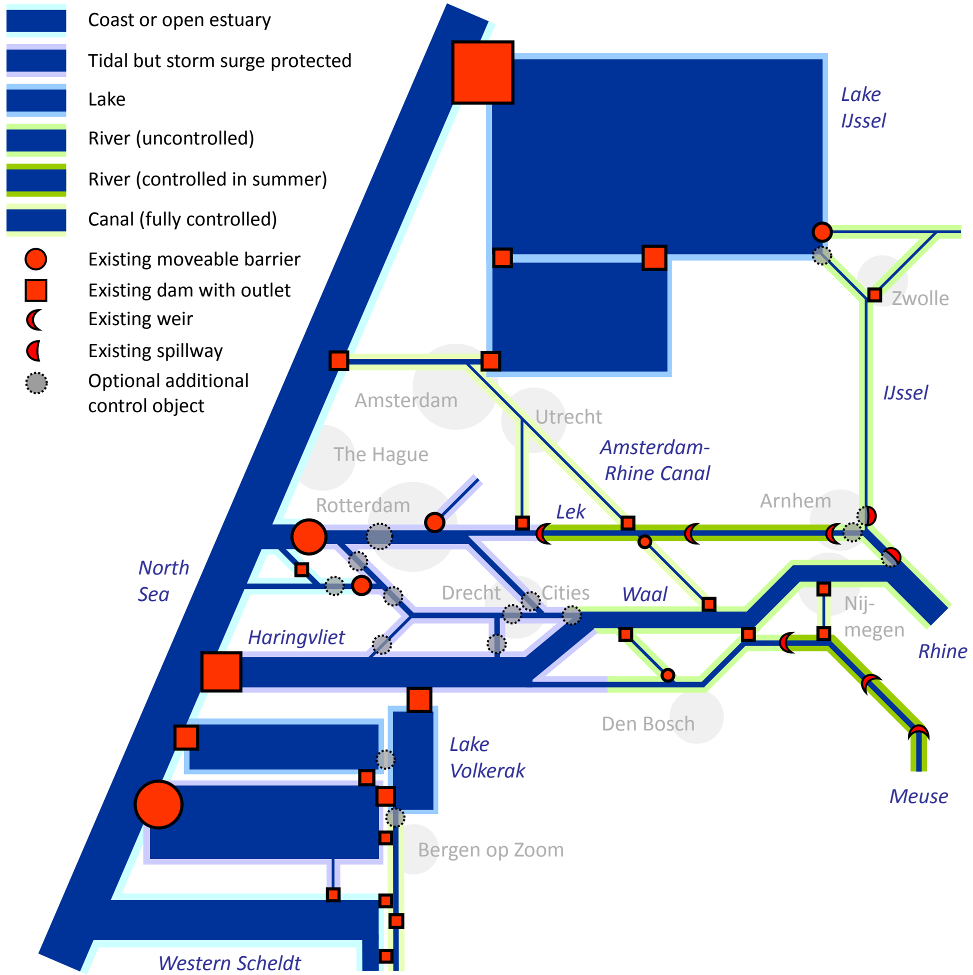
Technical-physical complexity (content supply)

Starting point for the physical Rhine-Meuse problem and solution space is the current three-dimensional geometry of the water system, including the operational regimes of control structures, such as dam outlets and storm surge barriers. Current available geo-information is vast and the operational regimes of the control structures are clear (van Overloop 2009); if computers were only fast enough, they could model water flows through the system accurately at given boundary conditions. However, hydraulic models have many sources of uncertainty, for example by simplifications in geometry (such as drawn in figure 2.3). Control objects may have clear operations policies, but these can be altered and moreover the objects can fail.

River discharge, storm surge characteristics and wind conditions interact with each other in complicated ways. Climate change scenarios add another level of uncertainty and complexity to the hydraulic boundary conditions. When we know the system geometry (including the operation of control structures) and probability distributions of the hydraulic boundary conditions (van Gelder & Mai 2008), hydraulic models will give us probability distributions of water levels, flows and water quality. A water behavior model is the core required to determine how well water system objectives will be met.

The Delta Programme and the Dutch water knowledge institute Deltares are currently developing the Delta Instruments, containing the Delta Model, a comprehensive model of the Dutch water system, effect modules and a comparative framework (Lamberigts & Marchand 2011). The project began by recognizing fifteen functions: flood protection, unembanked dwellings, clean and healthy water, shipping, agriculture, fresh water supply for drinking and industry, cooling water, energy production, raw materials extraction (such as sand and gravel), fishing, water and shore recreation, swimming, nature, archaeology, cultural history, landscape, and embanked (protected by primary dikes) buildings and infrastructure (affected by groundwater and flood risk) (Deltaprogramma 2011a; Marchand 2010). For now we can focus on four functions, which we re-phrase in terms of objectives.

Summarizing, the technical-physical complexity of the Rhine-Meuse delta lies in the water system modeling difficulties, the fragmentation and detail of the objectives, the interaction among the objectives, the uncertainties of future scenarios and therefore the exploding number of iterative cycles when projecting and designing into the future.



2.3 Scheme of the Dutch water system. The water types are classified by the possibility to control the water levels and flows. Coastal waters are beyond any human influence, inland canals can be fully controlled.

Theoretically all of this could be modeled and, in the face of uncertainties, a model user could pick his favorite path into the future. However, there is no single decision-maker; decisions emerge from contributions by a large group of diverse and dynamic stakeholders.

Socio-political complexity (content demand)

To the complexity analysis we started in the previous section, two socio-political elements can be added: First, non-quantifiable and hidden objectives; Second, the

	Flood protection	Unembanked flood protection	Fresh water supply	Shipping
Flood protection		A dam or storm surge barrier relieves both dikes and unembanked areas;	Raising the water level in a storage basin (eg lake IJssel) increases adjacent flood risk;	A dam or storm surge barrier disturbs a shipping route;
Unembanked flood protection	An unembanked area can be protected with a relocated dike; Etcetera		Raising the water level in a storage basin (eg lake IJssel) increases un-embanked flood risk;	A dam disturbs ships but protects the unembanked areas;
Fresh water supply	A dam can block sea water intrusion and create a storage basin; Etcetera	Re-introducing tide can increase unembanked flood risk and reduce fresh water supply; Etcetera		Raising the water level in a storage basin increases available water depth for ships;
Shipping	A new river can also be an added shipping route; Etcetera	Dismanteling a port can create new space for unembanked dwellings; Etcetera	A weir directs fresh water in a designated direction, but blocks shipping routes; Etcetera	

2.4 Some interactions between four main water infrastructure functions.

large number of active contributors, providing a large load of knowledge, ideas and preferences.

In policy-making reality, often an alternative chosen is not the best one according to a benefit-cost analysis. For example, some of the Room for the River projects provide safety in a more expensive way than dike enforcements (Ebregt et al. 2005, p.64). The argument goes that added “spatial quality” covers this, but it could also be possible that the chosen alternative supports elusive additional objectives, hard or impossible to quantify. Maybe landscape architects are more persuasive than dike experts. Perhaps the Dutch are tired of raising dikes and want to try something different. This was surely the case for the Dutch Delta Plan, developed in the 1960s. The Netherlands Bureau for Economic Policy Analysis (CPB) estimated that raising dikes along Dutch estuaries would have provided the same safety at 10% less costs than building large sea dams to shorten the Dutch coastline, but the government chose for the latter because of additional benefits, some of which were hard to quantify, such as knowledge development, international reputation and expected business development (Tinbergen 1961, pp.66–68).

In theory, non-quantifiable objectives can be modeled in a mathematical systems analysis. For example, the river dike improvements in the early 1990s successfully used “LNC-values” (landscape, nature and culture) in a multi-criteria analysis (Walker et al.

1994). Modeled or not, what is eventually needed is a way to shine light on them and make policy discussions as transparent as possible.

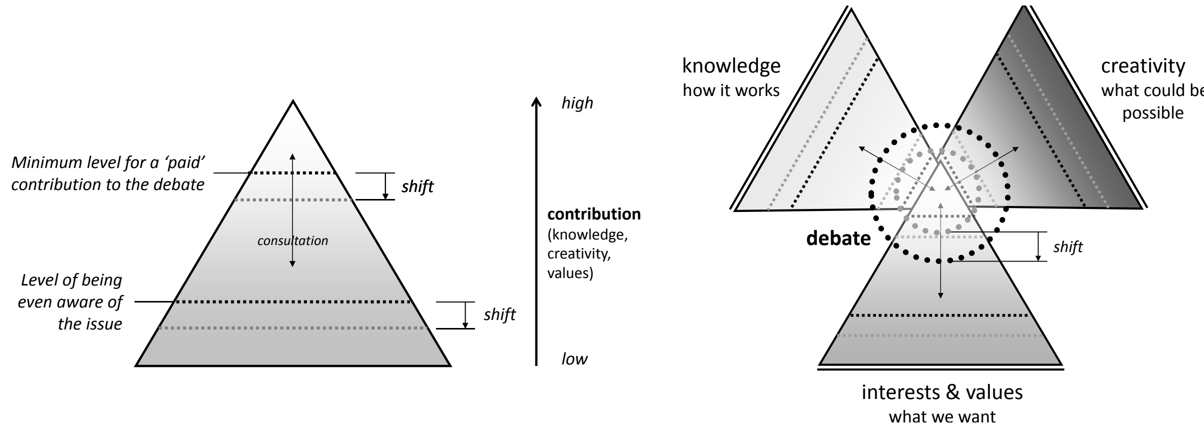
A second socio-political aspect is the many involved contributors to planning of the Rhine-Meuse delta. Influential scientists and politicians observe many relevant stakeholders and express the wish for still more involvement. Chairman of the Deltacommittee Cees Veerman says: “I believe in the power of the people, in bottom-up innovation”, and: “the whole decision-making-pyramid should be turned upside-down, we should put as much decision-power with the locally involved residents; that is modern governance!” (Deltares et al. 2009).

This inspiring vision has a downside. More participation can lead to high process management costs, higher chances for stalemates, a lower technical level of the discussions and confusion about roles. The Delta Programme for example sometimes invites high-school children to workshops. The question is whether they should participate with knowledge and ideas, or be asked about their values.

A centralized government could consult the public, but remain in charge, the way a company does consumer research, but not have the consumers manufacture their products. In the Netherlands however, not only deciding what should be done is being decentralized, also how to do it (Nota Ruimte 2004; Deltaprogramma 2010). This makes an integrated national water infrastructure policy harder. Han Meyer, director of the current research project Integrated Planning and Design in the Delta (IPDD), closely related to the Delta Programme, writes: “the large amount of interests and stakeholders and the withdrawn role of the central government make a clear policy extremely difficult.” (Meyer 2011, p.6).

These two phenomena float on a larger undercurrent described by the theory of Reflexive Modernization. In “modernized modern society”, the emancipation of the individual and the multiplication of possible forms of community weakened institutional boundaries, such as around the nation state and the central government (Beck et al. 2003). Necessary components to solve a problem (knowledge, creativity and values — see figure 2.5) become harder to bring together because they are not static and defined within a small number of institutions, but dynamic and dispersed. Modern process managers handle this by bringing as many people together as often as possible, but this is expensive, lowers the technical quality of the discussions and slows decision making.

Sociologists recognize this as a particular problem. Epistemologists Collins and Evans call it “the problem of extension”, which they try to solve by recognizing various levels of expertise in different corners than traditionally acknowledged (Collins & Evans 2007), but without stating that “everyone can become an expert” (Miedema 2011). Participatory decision processes become cost-efficient when it is clear who is eligible to contribute to which parts of a complex issue. In a workshop, high school kids can seriously disturb a discussion between experts. Then again they deserve to be asked what kind of future



2.5 Left: aggregated individual contributions to a public issue such as the Delta Programme can be represented as a hierarchy in a pyramid shape. Lower are more people, but with less input, such as voters, not even aware of the whole program. Up in the pyramid are fewer people, paid for their input and expected substantive contributions; right: Participatory design and decision processes stimulate interaction between creativity, knowledge, and values. This happens mostly high in the pyramids. Individuals can be on different levels in the pyramids: the mayor’s contribution can be high in the interests pyramid, low in knowledge and in the middle at creativity. The challenge for the Delta Programme is to facilitate the extensive interaction nowadays required, without delaying or flattening outcomes.

they want, and perhaps there could be a cost-effective way to retrieve their ideas and filter them for rare feasible ones, to be elaborated on by the experts.

Summarizing and concluding Section 2: the difficulty of the Rhine-Meuse delta adaptive planning is expressed in two axes of complexity. Physical-technically the system functions are highly interwoven and would benefit from an integrated approach on a national level by a limited number of people with a high level of expertise. Socio-politically there is a tendency in the other direction: more local participation and decentralization of decision-making. The question is how to bring these two together. As Collins and Evans put it: “democracy cannot dominate every domain—that would destroy expertise—and expertise cannot dominate every domain—that would destroy democracy.”(Collins & Evans 2007) Perhaps the answer lies in the framework used by the experts to provide local stakeholders with knowledge they need to express their preferences, and how their preferences and critique are then retrieved.

2.3 An internet community-based interactive model

The development of the Rhine-Meuse delta is complex, both technical-physically, because of the many different kinds of uncertainties, and socio-politically, because so many people are involved, often with hard-to-quantify and hidden objectives. A practical starting point to handle the technical complexity would be a water system model, producing outcomes for economic analyses and local concepts by engineers and architects. Starting point for the socio-political part could be to put a significant number of stakeholders in a well-informed position to choose between (and criticise) a significant number of alternative solutions to a number of problems. The Delta Programme is currently working on this by respectively the Delta Instruments, the regional delta programmes and the bridge between the Delta Instruments and the regional stakeholders, the Delta Portal. This paper claims that this bridge is crucial, and deserves innovations from the domains of serious gaming and internet communities.

We will now try to answer two questions. First, which benefits over current policy-support methods would internet-based interactive software provide, and second, if anyone would want to build such a tool for the Rhine-Meuse delta, how to do this and where to start. For simplicity, we will name the proposed 'internet community-based gaming-like interactive model' from here on 'SimDelta'.

Benefits

The added value of SimDelta to current Delta Programme policymaking would be twofold. First: interactive maps can explain a complex system of scenarios, problems and solutions faster and more intuitively than reports and presentations. Second, many stakeholders can be served at lower cost more frequently using the internet than with workshops. Whenever they want and wherever they are, they can explore the Rhine-Meuse problems and solutions, leave comments, drop additional ideas or answer questions by other users.

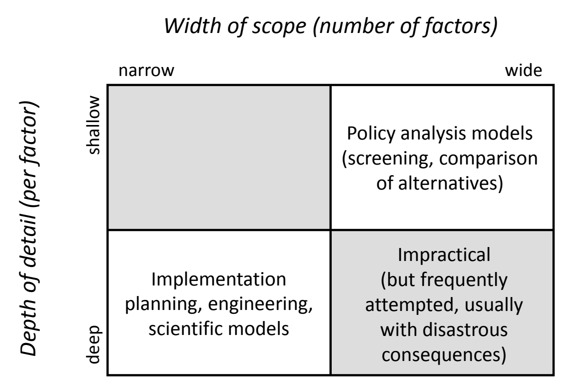
Let's recall this paper's objective for the Delta Programme. The planning question could be taken as how to match the supply of possible projects to the demand for them. The successful websites Google, Facebook and E-Bay do just that. These sites mediate supply and demand with a standardized language, easy access, filtered information, and processes that do not get lost after use, but keep improving.

Interactive maps provide both the suppliers (engineers, architects and other designers) and the consumers (the stakeholders) with sufficient understanding of the system to come up with feasible designs and to make well-informed choices. A project can then be chosen for two reasons. It can do well in the systems analysis (the "semi-objective" part), presented with interactive maps and supported by downloadable background documents. A project can also inspire by attractive visualizations, a good "story" and good marketing (the more subjective elusive part), similar to how products, companies and projects are nowadays promoted, increasingly effective over the internet.

Non-interactive communication such as reports, can only transfer and standardize a limited "cognitive load". The Delta Programme so far works with two years (2050 and 2100), two climate scenarios (35 and 85 cm sea-level rise), two economic scenarios and a limited number of alternative solutions. For stakeholders, ranging from members of Parliament to citizens near project locations, it will be hard enough to deal with this number of variables, however limited it is. For the Delta Instruments and for SimDelta it should be no problem to process many alternative-scenario combinations once the frameworks have been set up. When the model is working properly, the limits of the generated data are not set by the model itself, but by the maximum load that can be effectively communicated to the stakeholders.

Future pathways are often represented by decision trees (Haasnoot et al. 2009), such as made for the Thames estuary. A decision tree for the Delta Programme that would fit on an A3-sized paper however would probably not provide enough detail for good decisions. The Thames project leader Tim Reeder writes: "the approach to the Netherlands is more complex [compared to the Thames] (…), regional strategies in different areas, addressing different issues, need to fit on a national scale." (Jeuken & Reeder 2011, p.35). Under SimDelta lies not a single decision tree, but an entire forest. The way the Netherlands Bureau for Economic Policy Analysis (CPB) handles uncertainty is by presenting a deterministic analysis, and communicating the uncertainty orally, or else the message would become too complicated (De Vries 2010). In an interactive internet-based model, more scenarios strengthen the analysis, when enough users browse through the solution space to aggregate different reactions to different scenarios. For SimDelta, having many stakeholders is a prerequisite rather than a nuisance.

Of course, there are disadvantages and pitfalls. Lee warns of Large Scale Model Sins (Lee 1973) and so does Walker (see figure 2.6). The effectiveness of internet platforms



2.6 Policy support models have to be wary of incorporating too much detail—diagram from Walker and Haasnoot (Walker & Haasnoot 2011, p.18).

and social networks are a whole field of study (Oinas-Kukkonen et al. 2010; Ridings & Wasko 2010). A single gaming session is often not enough to make stakeholders understand a complex case (Zhou et al. 2012). Collins and Evans address the problem of "how to use science and technology before there is consensus in the technical community" (Collins & Evans 2007, p.8); lack of scientific consensus can be a problem for SimDelta. Of course, face-to-face contact will always be important. Internet-based gaming-like interactive modeling will never replace decision-making, but can help to streamline and aggregate input.

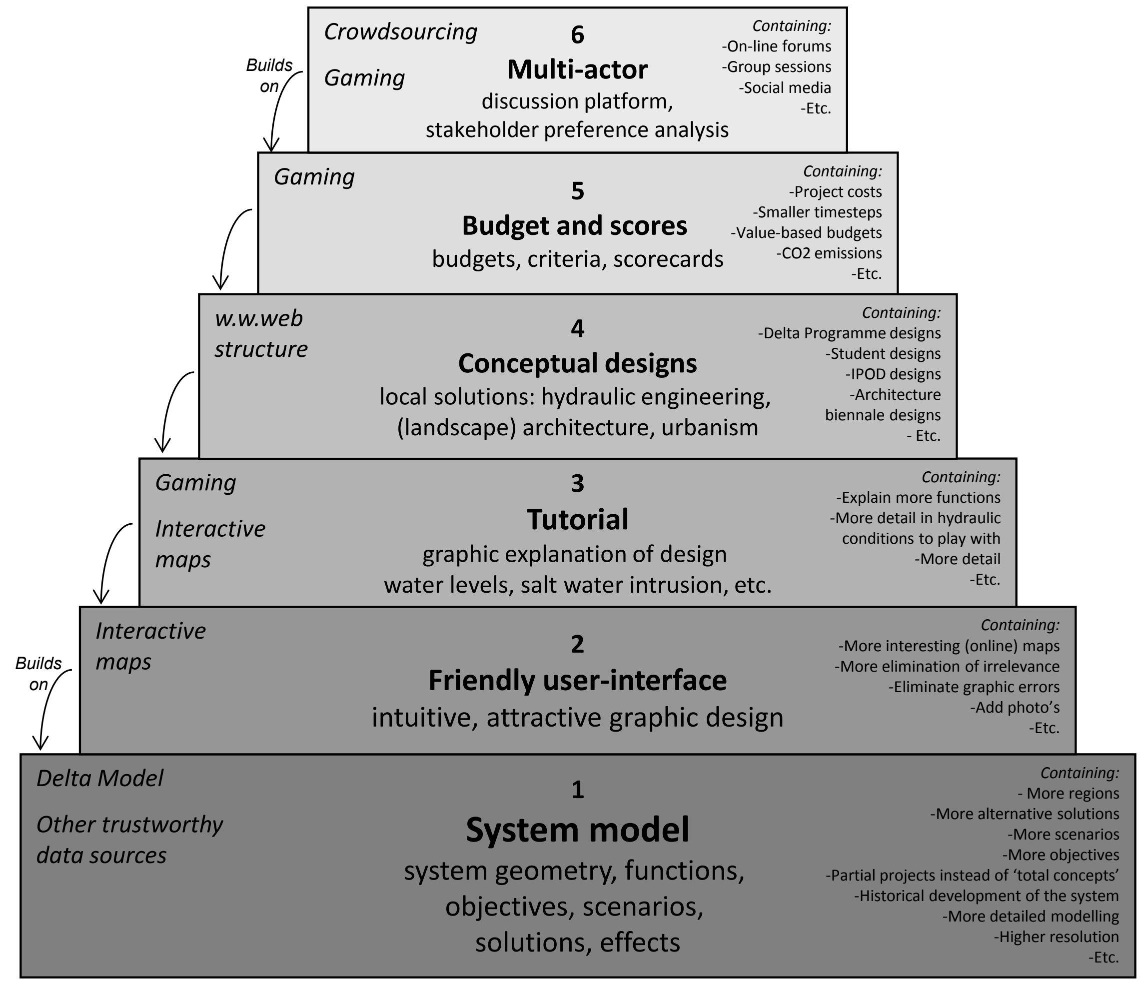
According to the book The Wisdom of Crowds, by James Surowiecky, "large groups of people are smarter than an elite few, no matter how brilliant—better at solving problems, fostering innovation, coming to wise decisions, even predicting the future" (Surowiecki 2005). Design theorists promote "crowdsourcing": "an online, distributed problem solving and production model. Crowdsourcing blends open innovation concepts with top-down, traditional management structures, so that crowdsourcing organizations can effectively tap the collective intelligence of online communities" (Brabham 2008). "The medium of the Web enables us to harness collective intellect among a population in ways face-to-face planning meetings cannot." (Brabham 2009). This collective intellect provides contributions in all three pyramids of figure 2.5: choices (interests and values), criticism (knowledge), and new ideas (creativity).

Features

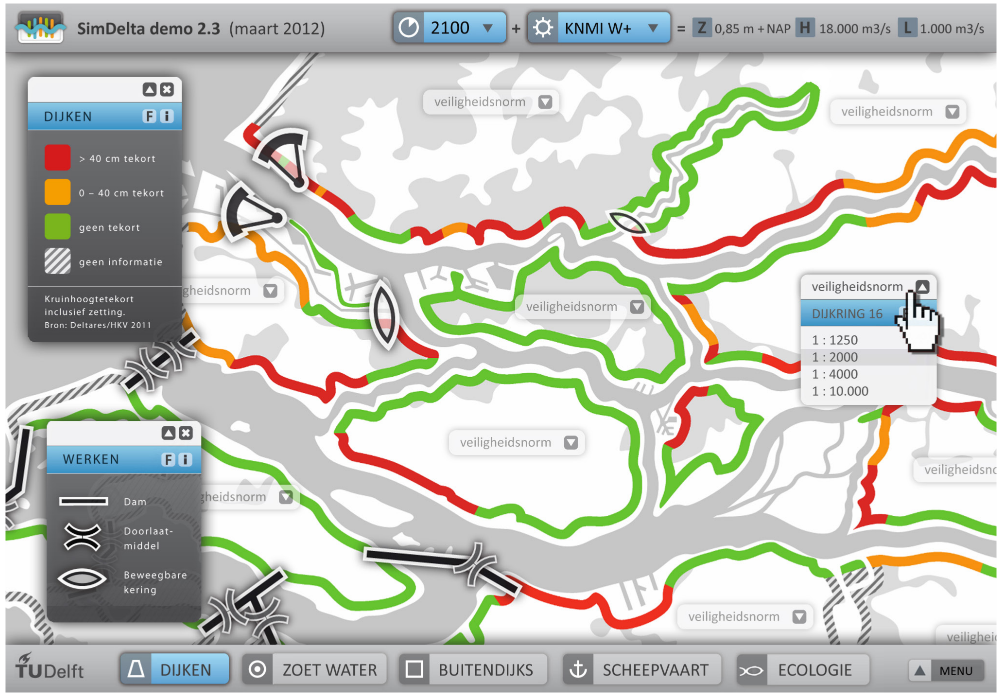
Building an intuitive and attractive interactive model in which stakeholders can pick their favorite projects designed by engineers and architects and see their estimated costs and effects, for a case as large as the entire Dutch water system, stretching far into the 21st century, under various climate and economic scenarios, is an extensive task. The ultimate goal, stakeholder preference analysis (to support democratic decisions on water infrastructure improvements to be implemented in the Netherlands after the year 2020—see the objective in Section 2.1), has to be built on a number of "blocks".

The base block contains the system model. Various general methods are available for complex systems modeling (Walker 2000; Keeney 1996). They relate objectives, functions, measures (alternatives, solutions, projects, strategies, tactics, and so forth), scenarios, effects, *etc.*, to each other. As part of the Delta Instruments project the Deltares institute is currently building the Delta Model (a several million euro project) (Deltaprogramma 2011a). The Delta Model is streamlining existing models, connecting different regional models, nesting models of various scales, developing new parts and setting up a data validation procedure. An ideal system model has an open structure, to be able to adopt data sets generated elsewhere. It could indicate various degrees of data validity (for example "class 1—Delta Model-approved", "class 2—expert guess"). The system model as well as the approved data sets can be continuously expanded by

more regions, measures, scenarios, functions, more detail and resolution, and smaller time steps. Particularly exciting would be to translate the historical development of the system into the systems analysis framework for the future. The Delta Model stops at determining the effects of measures under specific scenarios and passes the effects on to the Delta Program's regional sub-programs, more closely involved with the stakeholders (Marchand 2010, p.27). It is up to them to (supported by a comparative framework (Lamberigts & Marchand 2011)) value the effects and to determine to which extent their objectives are met by particular alternatives. This fits the sequence of blocks (figure 2.7), because in SimDelta all users together make their choices and give their criticisms, based on their values and understanding.



2.7 To retrieve statistical information on stakeholder preferences with SimDelta, five "blocks" of activities (interactive software development) have to be constructed on top of the Base Block, the system model.



2.8 Block 2—intuitive and attractive user-interface. Users can click on objectives and scenarios, build projects or change a policy and immediately see the state of "their delta".

Block 2 is an intuitive and attractive user-interface. Between 2005 and 2007, the Dutch project Room for the River developed a software tool, called the Box of Building Blocks (Blokkendoos—here "blocks" are spatial projects), to discuss all 600 possible Room for the River measures with the stakeholders. The software has excellent features, from sand extraction profit calculations to aerial photos. For many stakeholders however the user interface looks old-fashioned and will present too much information in a too technical way. Figure 2.8 shows an attempt to simplify the Rhine-Meuse system and to make it more attractive to use. It is made with visual design principles such as use of colour codes, icons and other semantics, schematization, simplification, layered information, "use cues", *etc.* (Mijksenaar 1997; Tufte 2001; Luyer 2004).

Some people might consider Block 2 just a layer of paint over a serious system model for which one would simply hire a graphic designer at the end of hard modeling work. However, a good user interface requires the difficult tasks of simplification and forcing oneself to identify with an inexperienced user. It takes much iteration to reach a really intuitive user-interface. The best interface designs are made by people who understand both sides the interface connects.

Stakeholders such as politicians do not need to understand detailed physical system complexity to be able to choose among alternative solutions. For example, the absolute

or relative design water levels are a step in between problems and solutions; only the flood risk and the pros and cons of safety-improving solutions really matter. However, using the model becomes easier and more fun when some of the underlying system is understood. When a good user interface is in place, this can be used to design a tutorial or "educational plug-in". The tutorial contains extra images and animations that explain, for example, the origins of the design water levels in the lower river system (which appears to be difficult to many stakeholders). Furthermore, the more users of the model understand some of the backgrounds, the more will discover errors or give suggestions for improvements.

Block 3 will be particularly useful for architects and engineers who contribute to Block 4: conceptual spatial designs, such as multifunctional levees, surge barriers and river expansions. In workshops and meetings where designers meet water experts, time often must be spent explaining how the water system works. Designers" energy can get lost on large scale solutions that are either obvious to water experts, or impossible. The contribution of the designers lies mostly in local solutions (visualized as in figure 2.9) or in out-of-the-box large-scale solutions with some sense of reality. Both contributions will be served with a tutorial that explains the system essentials.

2.9 Block 4—local solutions by engineers and architects: a flood barrier integrated with a hotel (by architect Anna Dijk).

2.10 Block 5 introduces the gaming elements "budget" and "outcome indicators" (here for example on safety, ecology and other scores).

The first four blocks serve to make the system understandable and show the many projects that could be built in the coming century. It is more fun to navigate through this space when there is a budget to build projects with, and when indicators measure ones performance on the model objectives (as illustrated in figure 2.10). The budget will also further sharpen user insight on benefits and costs, and it will be more interesting to monitor his choices, his "willingness to pay".

With budget and outcome indicators, SimDelta so far has seven of the nine characteristics of serious games described by Mayer and Zhou. It is "flexible and reusable, immersive, authoritative, transparent, fast and easy, integrative and communicative" (Mayer 2009; Zhou et al. 2012, p.4). The model starts to look like a serious game:
an "experimental and/or experiential rule based, interactive environment, where players learn by taking actions and by experiencing their effects through feedback mechanisms deliberately built into and around the game".

The two remaining characteristics are "dynamic" and "interactive". "Dynamic" here is defined as "able to show the performance of various alternatives in relation to preferences and behavior of other stakeholders". "Interactive" means that the model is "able to support the negotiation process among stakeholders" (Zhou et al. 2012, p.4). In other words: the model so far cannot connect various users to each other. The final Block 6 contains the ultimate goal, stakeholder preference analysis, to support decision-making.

Connecting stakeholders through serious gaming is often done by putting a group of people in one room, and have them play and discuss at the same time, happening a couple of times a year. On-line communities with physically separated users can serve more users more frequently and probably against lower costs per stakeholder. However, user input over the internet can get polluted by unserious users. This could be covered by a user admission procedure, or filtered in various ways (a possible filter could be the current 'Deltaweb', see figure 2.11). It then becomes possible to involve citizens and schools of landscape architecture, urbanism, civil and environmental engineering, nationally and internationally. Live group sessions and on-line communities support each other in various ways.

2.11 Block 6—multi-player usability with access through the Deltaweb (a), source: Deltaweb (Jansen 2011); and a discussion forum (b) to post criticism and new ideas.

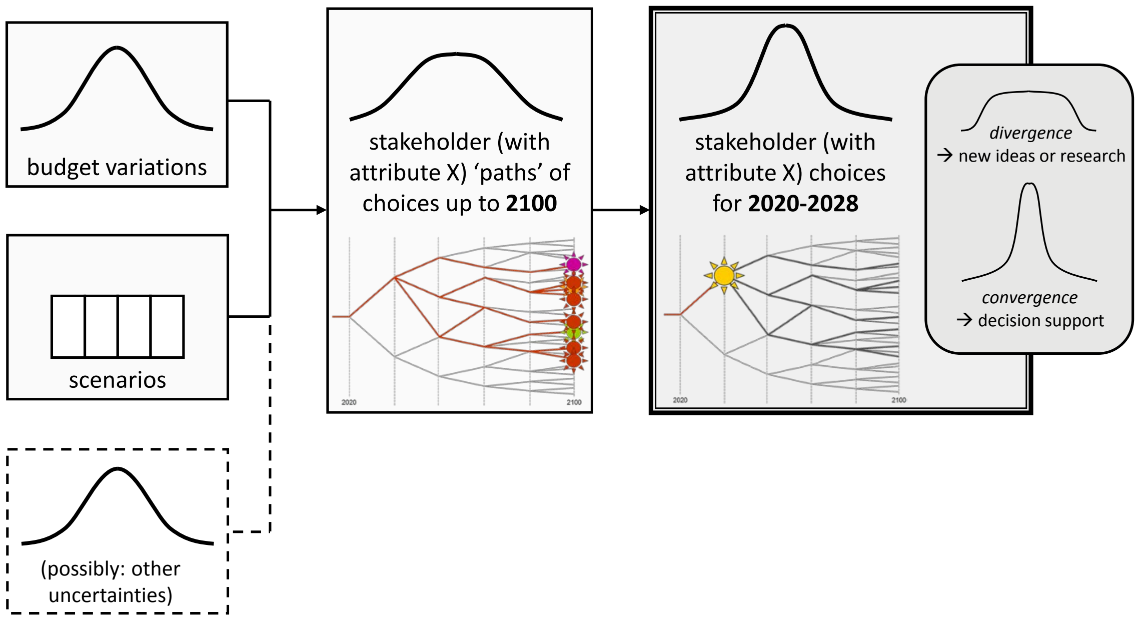
A mayor represents more than one vote from a particular location and an action group chairman represents a number of voices with a particular background. An advanced model could use user profiles to weight contributions of different users. Even so, SimDelta will never replace a representative democracy. It can only relate user backgrounds to user contributions and thus serve as an opinion poll. Furthermore the crowdsourcing mechanism will contribute to allocating additional design efforts and to determine research agendas.

Crowdsourcing in Block 6 contributes to the inevitable flaws and inaccuracies of Block 1. The accuracy and resolution of the underlying systems model is important, but not necessarily crucial. What ultimately matters are the choices, criticisms and proposed alternative ideas by all participants: each one with a particular level of knowledge, creativity and democratic contribution (see figure 2.12). These people are informed by the system model (block 1), through the layer that makes the system understandable for them (blocks 2 and 3), and possibly "seduced" by architects and designers into non-quantifiable benefits (block 4). They then choose based on their personal knowledge, "gut feeling", and choices of others (blocks 5 and 6).

If enough stakeholders join the pool, their aggregated contributions will result in either: (1) too much criticism or too many alternative ideas. Analyzing this will give suggestions for further research, development and design priorities; (2) too dispersed choices. This will lead to maintaining the status quo until new elements are introduced in the system, such as new ideas or new scenarios; (3) enough convergence to support the government to decide on a thorough investigation of particular short-term projects (see figure 2.12).

These three possible outcomes more or less correspond to the official government MIRT-research procedure outcomes (Marchand 2010, p.B-1). The idea of SimDelta is that the outcomes are statistically supported (instead of based on arbitrary conversations among politicians and stakeholders) and graphically understandable (instead of having to rely on a small number of supposedly objective knowledge people). The case will become clearer for more people.

Crowdsourcing is not only used to poll democratic preferences, but also to perpetually self-correct and self-improve. The original systems analysis attempt, to "depoliticize complex and highly political decisions" (Mayer 2009, p.828), is revitalized through the contribution of modern internet community technology.



2.12 In a SimDelta session budgets and scenarios can vary. Many user sessions together result in a distribution of chosen paths (series of choices) up to 2100. This long-term distribution will probably diverge. If short-term choices converge, they can support a political decision.

2.4 Chances for success

Decision support 'supply'

Technically it is possible to make SimDelta, combining technologies from systems analysis software, interactive websites and serious games. Feasibility might mostly depend on how the concept relates to other methods or groups providing decision support.

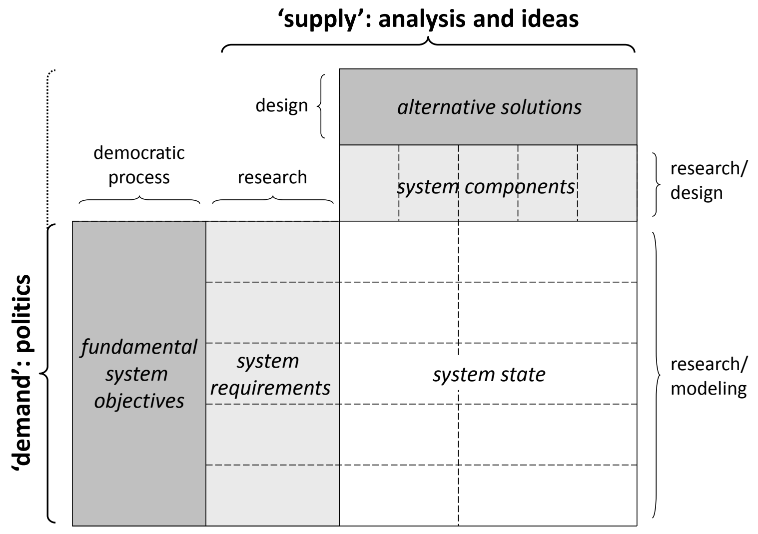
System engineering specialists model parts of the entire puzzle, such as determining economically optimal flood standards, flood risks or fresh water supply. This group will welcome integrating tools such as the Delta Instruments and SimDelta. They understand and appreciate the systematic thinking, and gladly see their part of the entire puzzle integrated in the larger extent. With an interactive user interface their contribution can be challenged by the comments of users with detailed knowledge of a particular geographical location. Specialists sometimes warn that integrating tools like SimDelta are too complicated and too much work.

Process managers believe that in a well-orchestrated process, with enough meetings among officials, stakeholders, specialists and designers, good ideas will eventually find their way to decision makers. Meanwhile, people get to know each other and do "joint fact finding", enabling a smoother transition from the conceptual phase to the subsequent planning and execution phases (Majone 1992). SimDelta will help process managers to understand the system complexity, providing them insight for discussions with specialists. The crowdsourcing of ideas and criticism shapes content, but can also replace part of the process manager's task of allocating design and development resources.

Spatial planners, landscape architects, engineers, urbanists and architects are obviously better skilled in visualization and generally more creative than modelers and managers. A visual model explaining the water system will help designers to understand the system better, so more could come up with creative alternative solutions in the basic system model block (such as an entire new river where no specialist had thought of before). Second, they will produce better conceptual local designs (figure 2.9 and Block 4 in figure 2.7) when they understand the overall system better. The part of SimDelta that democratically supports ideas is typically feared by designers to lead to conservative or populist decisions.

Decision support 'demand'

Decision support is traditionally offered to politicians and other stakeholders, such as companies or interest groups with a single objective like port development or ecology. This primary user group of SimDelta will contribute with the most exciting choices and



2.13 The entire professional domain of water infrastructure development can be considered an interaction between the supply of analyses and ideas by professionals and the demand for meeting public policy objectives by politicians and decision-makers.

comments. Politicians and interest groups are interested in the citizens they represent and to whom they have to explain their decisions, so involved citizens could just as well be asked to use SimDelta. Furthermore, while the specialists, managers and designers browse SimDelta to supply ideas and comments, they are at the same time Dutch citizens with interesting opinions.

The more users SimDelta will have, from any corner of society, the more valuable the gathered information will be to the primary stakeholders. In contrast to participation workshops, for SimDelta, serving more stakeholders is hardly more expensive (one of the web 2.0 competitive advantages (Oreilly 2007)).

SimDelta provides stakeholders and citizens insight into scenarios, problems and solutions, and

also in other stakeholders. This should make them more cooperative, better able to formulate criticism and to present alternative ideas. Politicians believing in Veerman's "decision-making-pyramid turned upside-down" (Deltares et al. 2009) are expected to welcome statistically sound stakeholder preference analyses to support their decisions, similar to companies being interested in market research to support the launch of a new product.

At the supply and the demand side, some people will believe that the current planning process and our current shared understanding of the system are already clear enough, transparent enough and effective enough. Others are more critical. Some will welcome the process to be demystified, others will feel threatened. For each, SimDelta would not replace current practice, but add to it. E-Bay and Facebook are successful, but flea markets and pubs still exist.

2.5 Discussion

General discussion [from the 2012 paper]

A water infrastructure system is never finished. Natural border conditions as well as wishes in society may change, and so do the tools to measure and models to interpret these conditions and wishes. Planning support instruments also evolve over time, but the fundamentals will probably remain the same. The comprehensive Dutch *Delta Programme* is supported both by the methods of *Systems Analysis*, modeling technical and economic aspects on a national level, and *Conflict Resolution*, to address the many local interests. *Adaptive Planning* is introduced to deal with changing circumstances. An instrument combining these three methods would model the interaction between scenarios, problems and solutions, be highly open to changes and improvements, and easily accessible by a large group of participants.

Advances in serious gaming and internet communities spark ideas for interactive software to compose one's own delta, similar to the game *SimCity*. A *SimDelta* would start with the current Dutch water system, and then present feasible solutions to problems showing up under various future scenarios. A click on a solution presents more detailed designs by engineers and architects, to involve hard-to-quantify additional benefits, like landscape quality, innovative technologies, or smart combinations with other public functions. SimDelta could be used by single users or groups, and would have forums for discussion.

Ideally, all knowledgeable and creative people in the field deliver SimDelta content, and all relevant stakeholders make their choices very seriously. If every participant completes his background profile accurately, SimDelta can provide decision-makers with statistical relationships between stakeholder properties, and their criticisms and preferences. In reality however, such an instrument will never be complete, nor will it be flawless. It takes time to become widely known, and still many people will not want to participate for many thinkable reasons. Interest groups might try to abuse SimDelta. Data accuracy will always be a subject of discussion.

In current policy making, different decision support activities compete with each other. This appears messy, but could also be seen as a democratic balance of power or a healthy competitive market. A new instrument like SimDelta will have to gradually gain support and evolve. A first step to take would be to limit the number of scenarios, problems and solutions, the geographical region to focus on, and the number of stakeholders to engage.

From SimDelta to Flowz [subsection added in 2016]

Since the 2012 SimDelta paper, insights have evolved mainly after discussions with potential clients and end users. This subsection describes some major developments and conceptual changes and briefly presents the current business propositions.

The concept has evolved towards an *interface only*: generating new water system data is explicitly not part of the business model. The interface represents data freely available 'out there', generated by possibly a large variety of institutions. If the most recent data are only open only to a small 'elite' but not to a broader professional audience, this is accepted as the current status (sensitive data could also be protected by passwords).

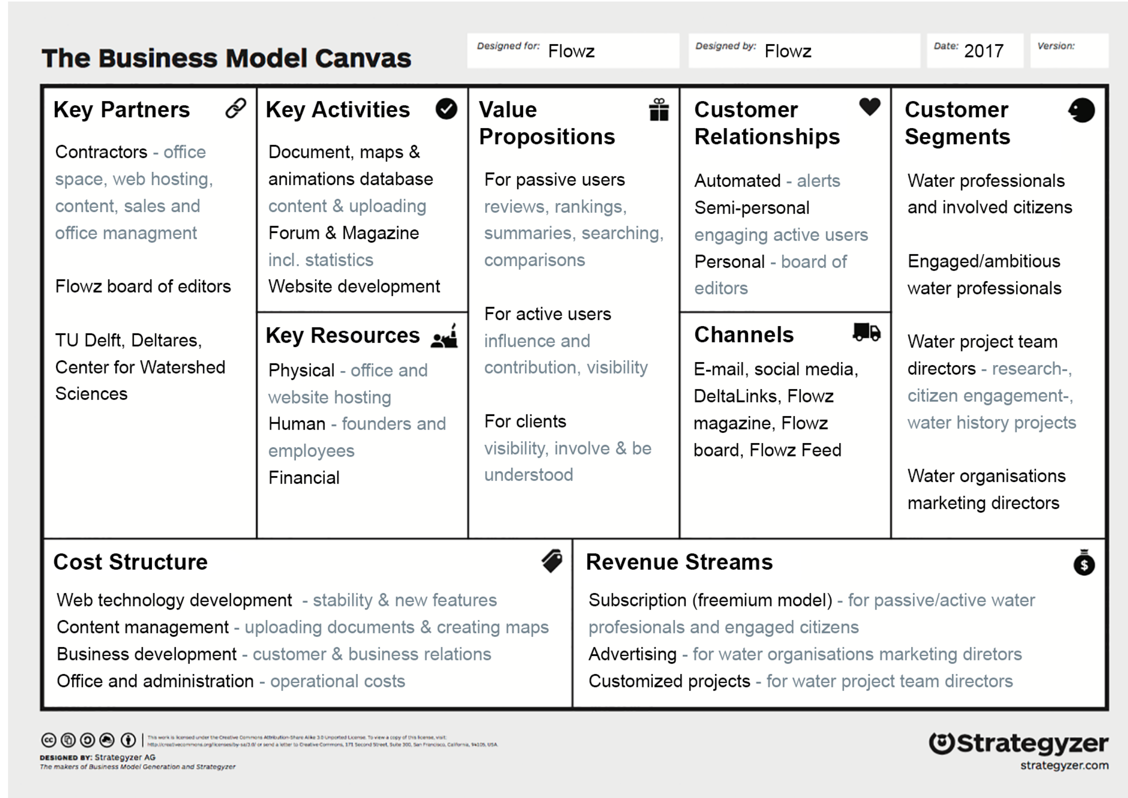
The platform first aims at showing different maps (which are only blocks 1 and 2 of figure 2.7), in five types: *background* maps, system *property* maps, system *requirement* maps, system *assessment* maps and system *modification* maps. These maps are like branches on a tree, on which new branches can grow and from which hang all documents published about the water system, from thorough reports with modeling results to short newspaper articles discussing new policies (this could be seen as block 4). The maps structure the relevant documents by water system function (each function has a different map) and geographic location. Other dimensions to structure or *filter* documents are topics (tags), publishers, publication date, document type, et cetera – see also the figures on the next pages. It appears it already is a large effort to build this basic structure and it will take some time before being able to take a step towards having users 'play' with costs and benefits of water system modifications (blocks 5 and 6 of figure 2.7).

There have to be triggers for users (water professionals) to be directed to the platform. This is outside the scope of this thesis and thus here only the main two triggers are briefly mentioned: automated e-mails (filtered by user preferences) mention that new documents or maps have been uploaded (like a *news feed*). Furthermore, part of the business case is a professional magazine (like DeltaLinks). The magazine articles are published on the website and the articles contain links to other items on the platform.

The business propositions are taken from the CANVAS business model (a.o. Banks 2013). In this thesis subsection only the value propositions, customer segments, key activities and revenue streams are elaborated.

The platform creates the following *values* for users: 1) updates and overview of documents produced in the water sector, 2) interpretation and evaluation of documents (by journalists, the Flowz board of editors and random users), 3) redrawing, interpreting and combining maps in a standardized graphic style to make them more intuitively readable and better comparable to each other, 4) visibility for the authors (individuals and organisations) of the documents and maps and 5) aggregated feedback about user preferences, data gaps, critique, et cetera.

Customer segments are knowledge professionals (consultants, scientists), policy professionals (officials, politicians, managers, stakeholders), students and other unexperienced



2.14 The CANVAS model for business cases, applied to *Flowz* (completed as a result of the STW Take-off project in March 2017).

(learning) professionals, and 'engaged citizens' (folks involved in water projects, not random citizens). The value of the platform is different for each of these groups.

Key activities are uploading documents (text, images, tags), redrawing and uploading maps, evaluating documents, writing popular-scientific articles and blogs. In a later stage, tutorials and animations educate on certain complex aspects of water systems.

There are multiple *revenue streams*: 1) end users pay to access certain parts (the *freemium* model) of the platform and for the magazine, similar to a newspaper or website subscription, 2) firms pay for visibility (like advertising), 3) local and regional governments or interest groups pay to have their problems, projects, sector, region or organisation elaborated and presented, 4) national governments sponsor the entire platform because they feel a responsibility for knowledge transfer and overview, 5) combinations with consulting.

In 2016/2017 a new name emerged: *linking*Flows or simply Flows, relating to flows of water, ships, nutrients, etcetera, as well as knowledge and information flows and even flowing human creativity and energy. The z hints to the Dutch words *ziel* (soul) and *zingeving* (give meaning).

The **List view** shows the available items (documents and maps) as a list of item summaries, in a sequence according to the Flowz ranking algorithm.

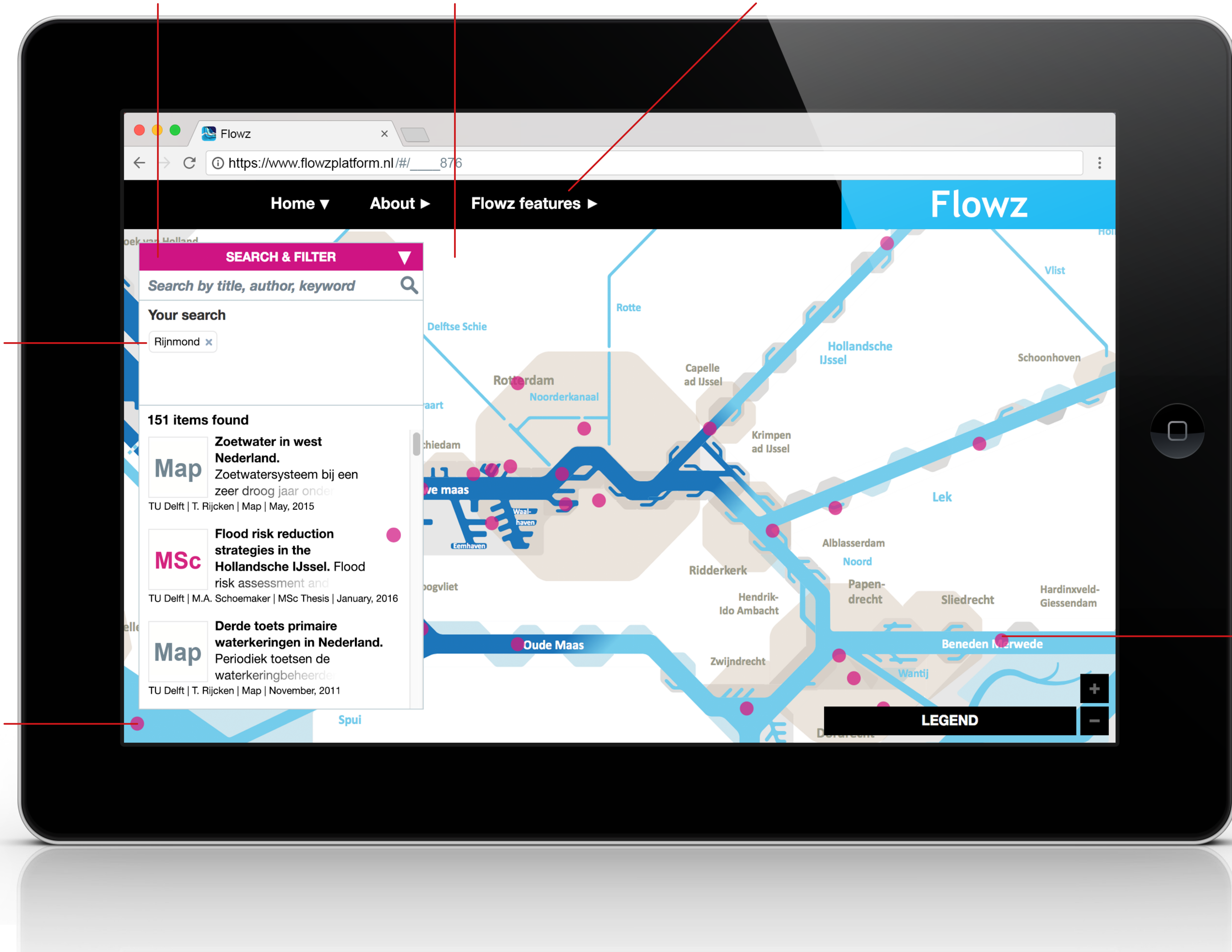
The **Background map view** shows documents as pink dots on the map. Larger dots reveal a list of documents, prioritised by a ranking algorithm based on item type, date, popularity, reviews by members of the editorial board and preferences set by the user. Zooming out clusters the dots.

Special projects contain pre-set selections of maps and uploaded documents for a particular client who seeks attention for a certain project, problem, region or historical development.

Flowz applies the *freemium* model: basic functionalities are free, some are only available with a subscription. **Users statistics** can be viewed by subscribers only and present rankings and other customisable relationships between user behaviour and publishers, companies, reviews, popularity or publish date.

At some point, thousands of documents (from books and reports to blogs and news items) will have been uploaded, accessible via even more pink dots on the map. A user can make a selection by applying **filters** (preset by him personally or suggested based on his professional profile), like theme, document type, publication date, publisher, language, or reviews by esteemed professionals.

One **dot** can link to multiple items and one item can link to multiple dots



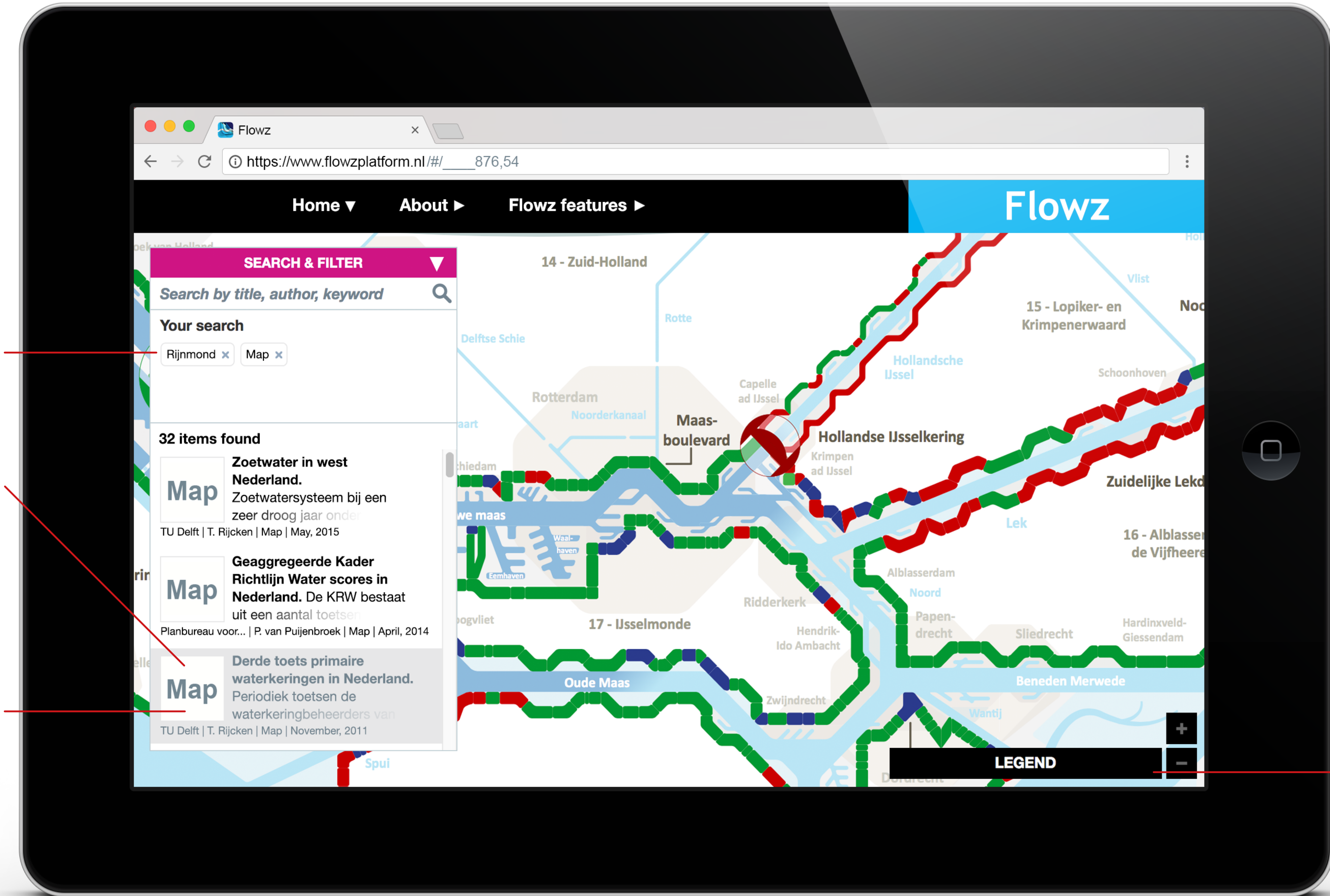
Documents are **uploaded** in multiple ways: by the Flowz content managers and board of editors, by subscribers (in return for a lower subscription fee) or by random users. Uploads may or may not be reviewed by a Flowz editor, content manager or subscriber. They can be freely available or link to a paid site. More thorough uploading and expert reviews give a document a higher ranking.

Items are location-specific, generic, or both, when a generic item contains cases. A document can be accessed through the **Map view** or the **List view**.

A **regional filter** (like *Rijnmond*) zooms in; applying the **Map filter** removes non-map items from the selection and thus the pink dots from the screen.

Clicking on a map item shows a **system map** on top of the background map.

Clicking **again** on a map item reveals **map information** and links to one or more source documents used to draw the map. Maps can also be accessed through the source documents (one map can link to multiple documents and one document can link to multiple maps).



The Flowz graphic language can show highly detailed information next to large data gaps without appearing unfinished by the use of **masks**: greyblue transparent shapes with holes (see for example page 92 of this dissertation).

The **legend** can be retrieved as a list of all system components, of only the system components in the current view, or displaying only the system component over which the mouse hovers.

There are Flowz maps available for different **years**, for the main **water system functions** (flooding, freshwater, shipping, nature/ecotopes) and **map types** (background, property, assessment, requirements or modifications). For future studies, different **scenarios** yield different system assessment or property maps. Years, themes, map types and scenarios can be applied as **filters**.

Additional functionalities not in this screenshot: 1) Even the highest quality maps contain errors: map **error message** boxes can be activated to be processed by Flowz. 2) When there are many relevant maps, maps and map views can be **pinned** (temporarily saved) for mutual comparison. 3) A **snapshot** exports a particular view as a high resolution image.

Chapter 3 in brief

The previous chapter introduced the standardized graphic language and user interface (Flowz). In this chapter, flood risk is approached as an integrated system of components which are more or less timeless, but for which analytical approaches have changed through time. The Flowz 'graphic language' is designed parallel to the historical systems analysis which serves to find the main trends in the development of the Dutch flood risk system since 1986 (the objective of this thesis).

The chapter describes how *system components* are in some *system state* relative to *system requirements*, derived from *system objectives*, changeable by *system modifications*. Five system components are distinguished: embanked areas, flood defenses (embankments), unembanked areas, outer water and control structures. Each of these is treated in turn, starting with definitions, general geometries and basic numbers for the Netherlands. The main question then is how scientific advances in system state 'measuring rods' have contributed to decisions to upgrade existing components or add new ones.

For flood risk systems the main flood risk objective has always been, somehow, to achieve *acceptable risks*: tolerable probabilities of casualties, damage and other undesired effects. This has been translated into requirements for dike height (before 1953), design conditions with specified exceedance probabilities for dike sections (1953 – 2016, brought under national Dutch law in 1996) and flood probabilities of dike trajectories (being implemented in 2017). Other flood risk objectives have been to lower river water levels and to maintain a base coastline, objectives which are more strongly intermingled with other water system objectives than just flood risk reduction.

The common theme throughout the chapter is that more detailed modeling has enabled better expressions of risks and more accurate assessments of system component conditions. This has been a major driving force for investments in flood protection, which have been conducted almost without interruption since 1986. This thesis's first main trend is *continuous investments in flood protection, strongly motivated by improved risk and acceptable risk analyses*.

The type of investments depends strongly on synergy with flood risk-*related* water system functions: freshwater conveyance, shipping, nature/ecotopes and landscape quality: the subject of chapter 4.

Chapter 3

The Dutch flood risk system

Publication type: chapter written for this thesis

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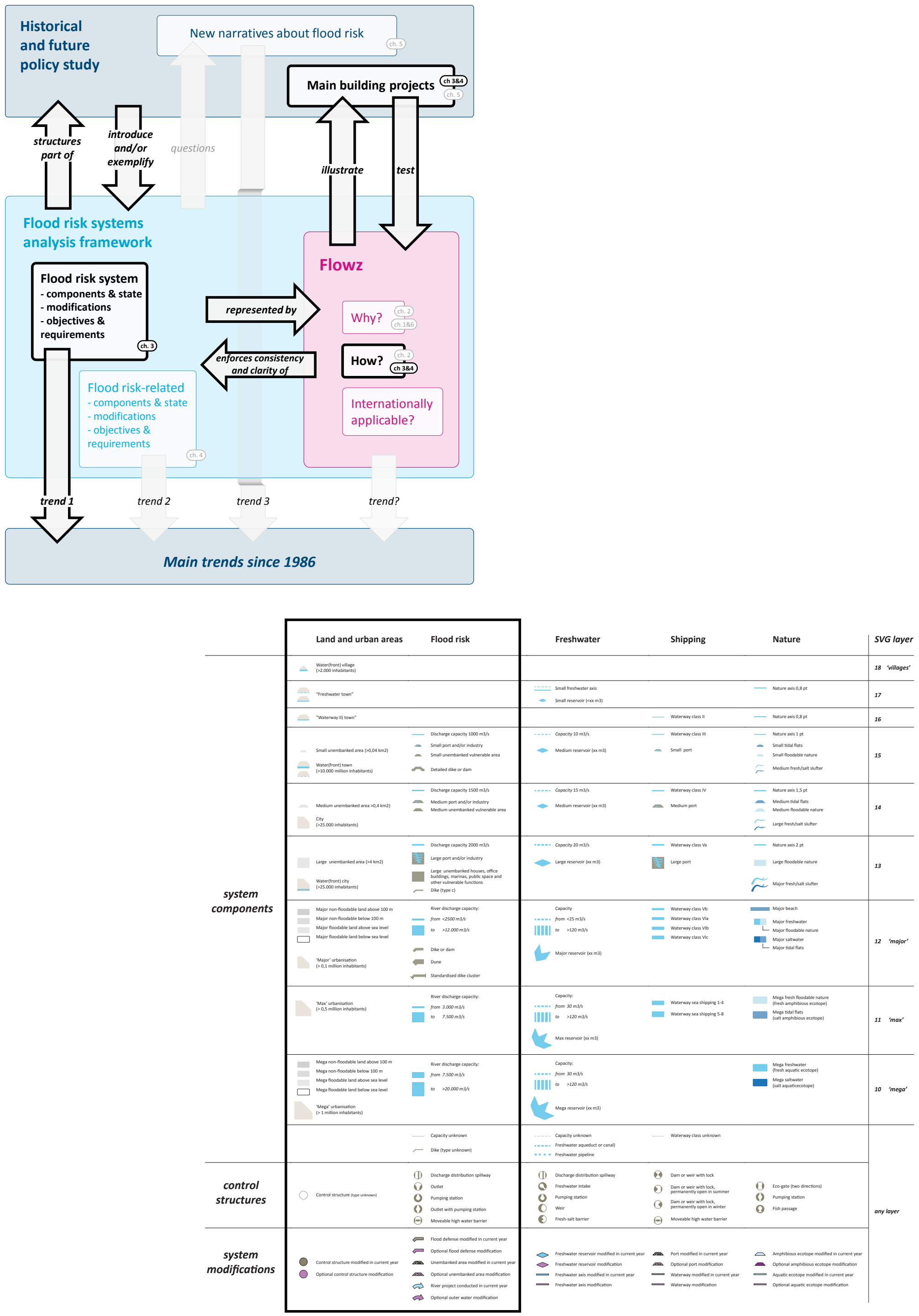


3.1 This chapter completes this part of the thesis as explained in chapter 1 (figures 1.15 and 1.16 on pages 40 and 42).

Flood risk chapter outline

The objective of this chapter is primarily to arrive at the *first historical trend* regarding Dutch flood risk policy-making since 1986 – see figure 3.1. The second goal is to design a universal graphic language to describe flood risk reducing water systems. Both these goals are approached by a *historical systems analysis*: describing the development of flood risk policymaking as the development of the physical system by describing one by one all *system components* (section 3.1) and the governing *system objectives* (section 3.2).

Section 3.1 treats five system components in turn: embanked areas, flood defenses, unembanked areas, outer water and control structures – see figure 3.1. Each component is described by:

- definitions, essential geometry and related core processes,
- basic numbers for the Netherlands as a whole,
- the historical development of the parameters and models to characterize the component and describe the *system component's state* (with a focus on the tidal rivers),
- the essential aspects of *system modifications*, the main historical projects in the tidal rivers and the issues currently under debate.

Each subsection is illustrated by Flowz legends and screenshots. The screenshot captions illustrate what is shown on the map, and may treat some Flowz design choices. If one is interested in the design considerations for Flowz, all screenshot captions should read like an explanatory story.

The system description is focussed on the Netherlands, but it should be able to represent foreign systems with the same universal graphic language. See Rijcken & Christopher (2013) for an exploration into the international applicability of the Flowz (SimDelta) graphic language and interface.

Again, *system components* perform along system state measuring sticks and can be modified by *system modifications*. Section 3.2 explains how system modifications are commonly justified by *system requirements*, which are derived from *fundamental system objectives.* The core questions of this section are how fundamental flood risk objectives have been expressed over the years and how these fundamental objectives have been operationalized. It appears that two major changes have taken place: the *level* of flood protection has been increased, and the *unit* in which the requirements have been expressed has changed.

Similar to the systems components section, these questions are illustrated by Flowz screenshots, for which the captions at the same time serve to illustrate Flowz design choices.

Section 3.3 first presents a methodological discussion of some terms, choices and omissions in the historical systems analysis and finally arrives at the main trend in system modifications and changing attitudes about flood risk since 1986.

The flood risk system

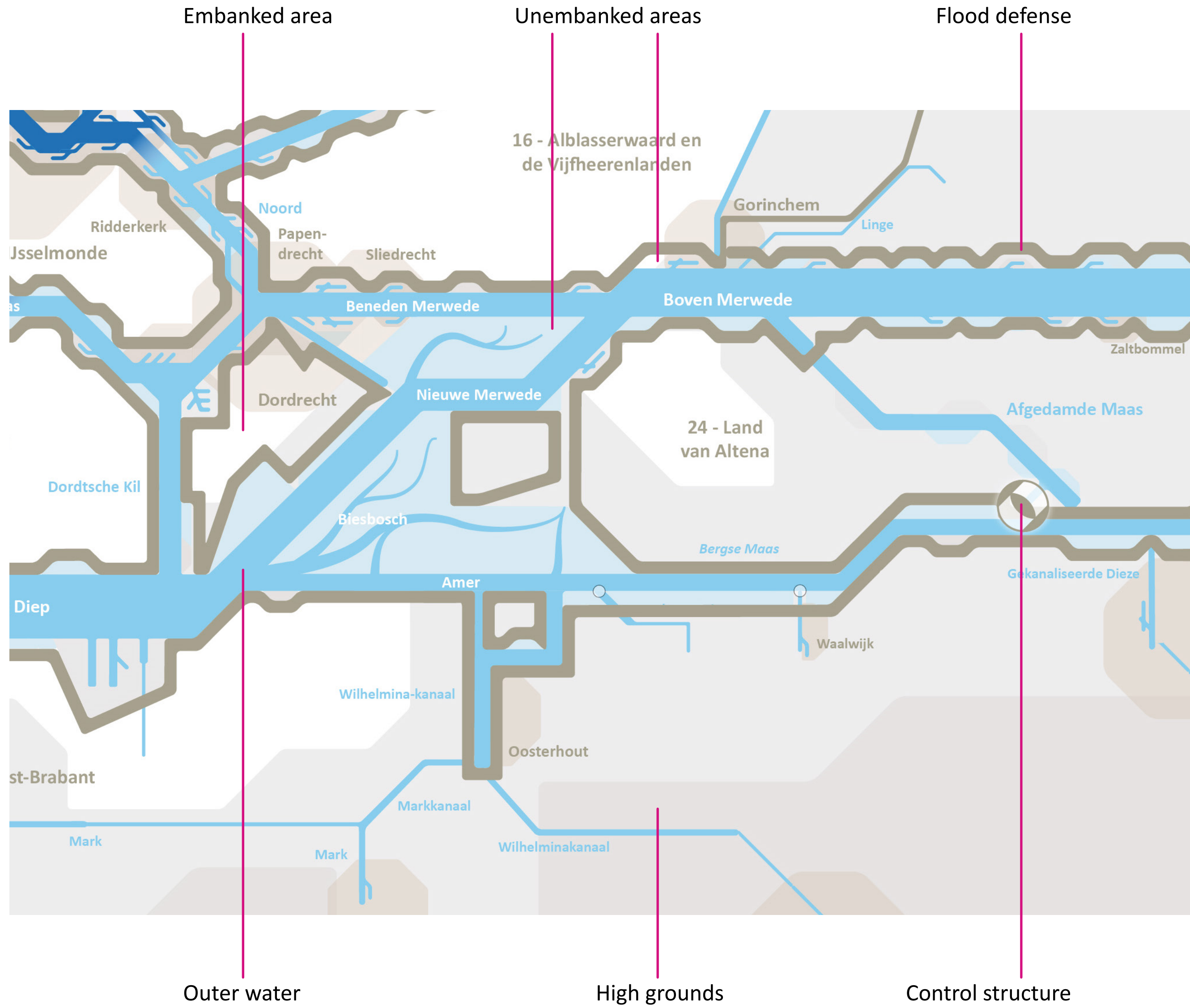
This chapter revolves around the concept of a *flood risk system* – a term not found in the flood risk literature so far. The well-known term *flood risk management* is chosen not to use, since in many contexts this term relates more to disaster management than flood protection. The term *system* is crucial to the approach of the thesis and of Flowz; why not use the common term *flood protection system*? A focus on flood *protection* would be the opposite of a focus on flood *management*: it would discard measures like evacuation management and local flood-proofing measures. Since the purpose of a system is crucial in defining it (Meadows 2008), the term *flood risk optimization (or minimization) system* would be the most appropriate. Since this is quite a mouthful, it is shortened to *flood risk system*.

As mentioned in the introduction, this thesis is not about local flooding caused by excessive rain, and also not about regular floodings which do no harm. Flooding means that *damage* is done by water which *rarely* enters an area (or system) from *outside*. This thesis looks at this on the Dutch national scale. Conditions at the boundaries of the Dutch system are tides, storm surges, river influx, wind and rain. These conditions prescribe how external water enters and how it leaves. By definition, boundary conditions are without the reach of our control, but the way the external water is distributed within the system, can be controlled to some extent: by modifications to the system geometry (not instantaneous), and by operations of control structures (instantaneous).

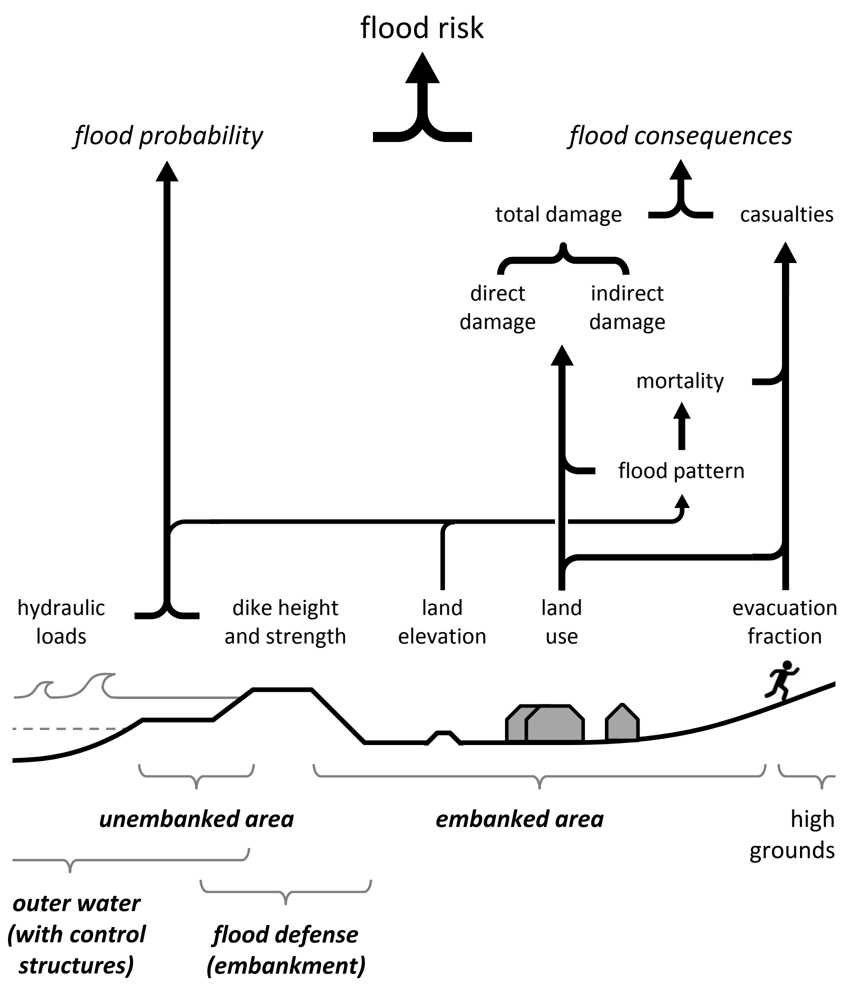
Dutch water professionals distinguish flood *probabilities* and flood *consequences* (DGW 2009; de Wit et al. 2010, et cetera). The way this is often done can be debated; for example, building on a mound is seen as a consequence-reduction measure, but it could just as well be considered reducing the *probability* that the building on the mound gets flooded. Either way, in the current Dutch language, the term flood probability reduction is used for *national infrastructure* (like flood defenses and control structures) and flood consequence reduction aims at *all other* flood risk-reducing measures, often on the *local* level.

Figure 3.2 shows the most essential flood risk terms used by flood risk professionals in the Netherlands. The system components in the systems analysis of this thesis are the physical elements in this scheme (in figure 3.3 in bold italics): 1) embanked (protected) areas, which are demarcated by 2) embankments or flood defenses, which are often bordered by 3) unembanked (usually dry) areas. The volume between the flood defenses, the unembanked areas and the water beds is 4) outer water, which can be controlled to a certain extent by 5) control structures.

A computer model with the geometry and material composition of a configuration of these components, including the operations of the control structures, generates



3.2 The five essential flood risk system component types in this thesis and in Flowz, plus high grounds (see also figure 3.3).
Design considerations: curved lines are straightened and stick to 45-degree angles. The '45-degree-rule' can only be surpassed for very characteristic shapes typically recognized by users. Advantages of this approach are that existing maps can be traced rapidly, it is easier to blow up certain parts of the system, the result is calmer to the eye and it creates a unique identity which resembles hydraulic flows schematics.



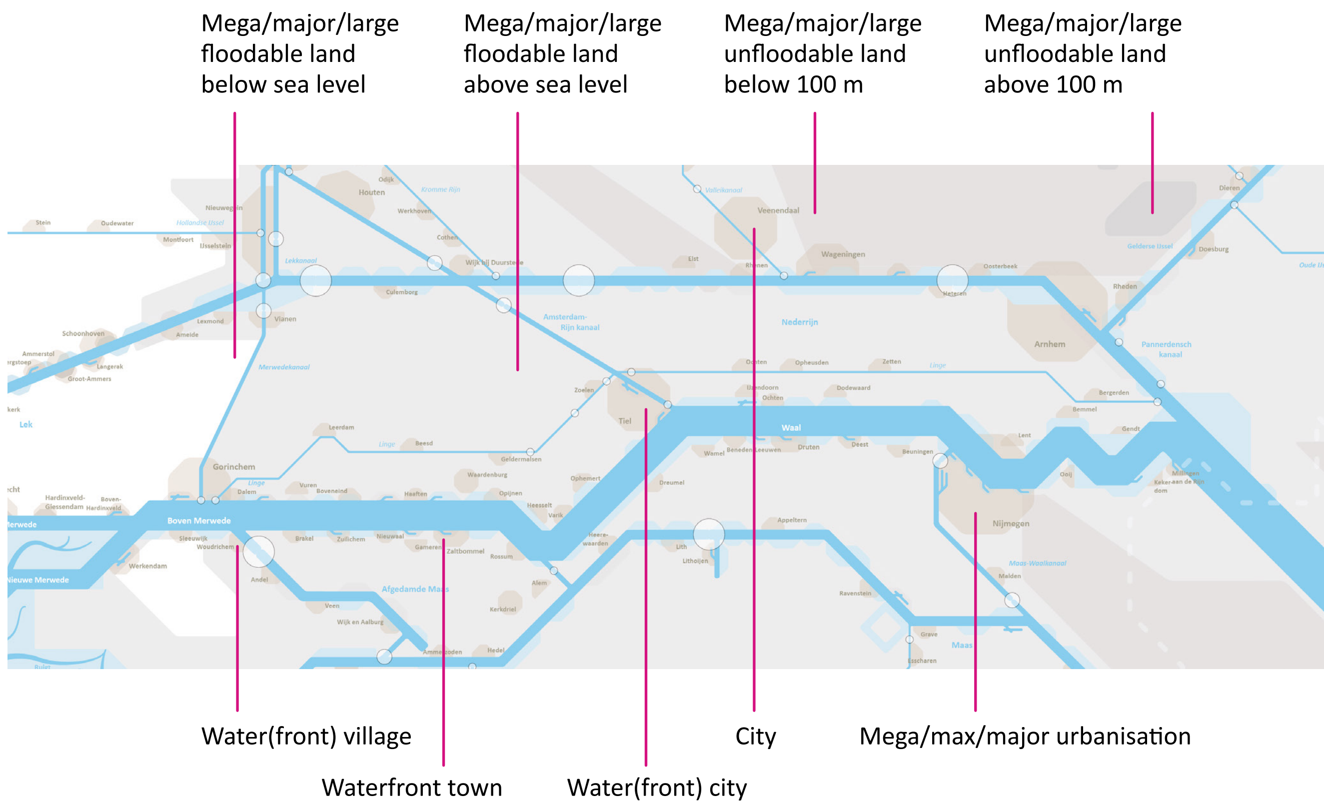
3.3 Essential flood risk terms, modified after Deltares & HKV (2012). An arrow means that proper (geo)data for one or more elements can be modeled towards the next. In ***bold italics*** the five system components essential to the systems analysis of this thesis. Note that for an average Dutch embanked area (dike ring), the part to the right of the dike is easily 20 times wider than the part to the left.

hydraulic loads throughout the system (internal model output), given the conditions at the outer boundaries of the system (external model input). The output conditions have an effect on land users, like a house, a tunnel, a park or a person, located wherever in the system. The extent to which these effects are disliked can be translated into how a system component performs: the system state. In practice, such a model is composed of multiple sub-models, made by multiple organizations, knitted together by policy-makers. This is elaborated in the next sections.

3.1 Flood risk – system components

Embanked areas

This flood risk systems analysis starts with what is primarily at stake: the *embanked areas* or *dike rings*. These are usually flat or soup plate-like and often slightly tilted surfaces, protected from inundation from outside water bodies by a closed ring of dunes, embankments, structures and/or high grounds. They are sometimes called



3.4 Ideally, the embanked areas in Flowz would be represented in a damage or risk map, which would change through the years and which could be modified by a variety of measures (from modifying a dike to modifying a city). Currently, only the location of cities and the elevation of the embanked areas is provided in the background.
Design considerations: the background has unsaturated colours and shades of grey to provide a clear view of the foreground (system state and system requirement maps), which are in bright colours. All cities with more than about 100.000 inhabitants are shown. Smaller water(front) cities, towns and villages are only shown when they are located nearby water or dikes.

polders, especially by foreigners, but in the Netherlands polders usually refer to smaller controlled areas, of which there are often hundreds located in one dike ring.

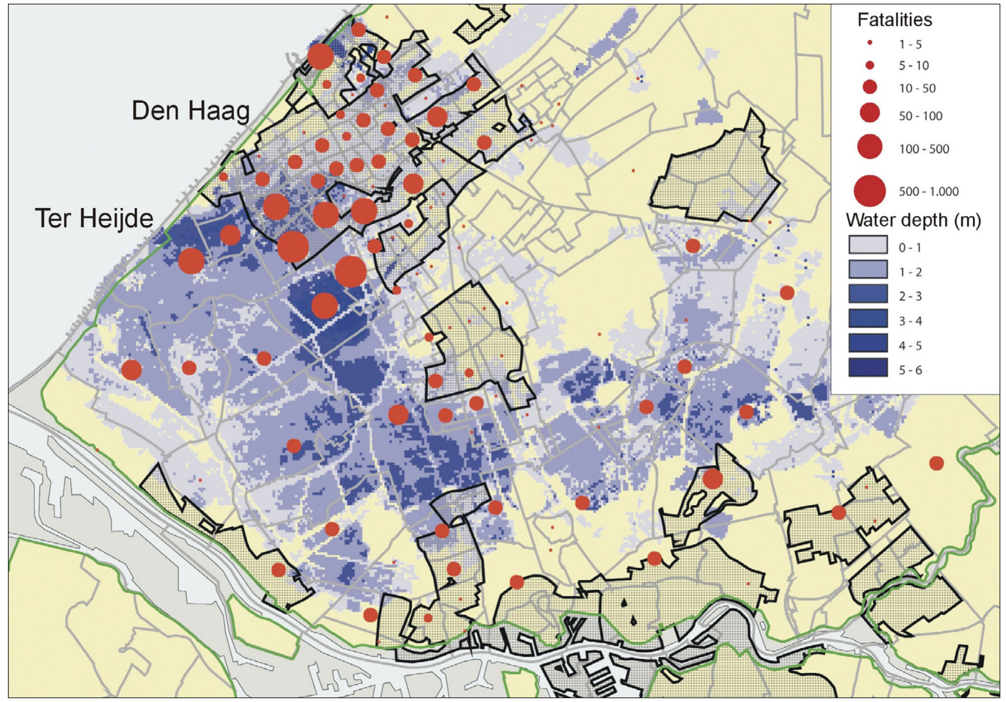
In 2007, the Netherlands had 53 dike rings, plus an additional 41 small ones in Limburg (the Southeast). The 40 largest dike rings have a total size of about 2000 km^2, accounting for 55% of the Netherlands (V&W 2007). In 2017 and onwards, the Dutch Water Act (Waterwet) does not refer to dike *rings* anymore, but to dike *sections* (REF); yet, for an understanding of embanked areas as flood risk system components it is important to realise they have to be closed rings.

An embanked area can be characterised by terms like surface area, dike length and inhabitants, and by parameters at the right of figure 3.3: land elevation and land use (like urbanisation; see Flowz map 3.4). From the perspective of flood risk, an embanked area is most directly represented by possibilities and probabilities of unwanted effects caused by possible floods: monetizable damage and imponderable damage, direct and indirect damage (also called societal disruption) and casualties and fatalities. A damage *possibility* is for example an upper limit: the highest possible damage, number of casualties or plausible societal disruption a flooding scenario could cause in a dike ring. Damage *probability* requires additional information about the other flood risk system components.

Looking at the historical approaches to quantifying the Dutch embanked areas in systems analyses, we see a development from coarse to fine. A first approach supposes that one ore more breaches, located wherever, result in complete inundation of an entire dike ring and a loss of a percentage of all goods and habitants. The 1961 Deltacommittee (van Danzig 1960) assumed 100% loss of goods and 1% casualties for any flood in their calculations (interestingly, Jonkman (2007) estimated a similar 1% casualties under a coastal flood after more thorough modeling). These percentages can be changed when we know, for example, which parts of an embanked area are above inundation level, or by whether we are dealing with a sea or river flood.

To many objects and plants, salt water is more damaging than fresh. A flood from sea is usually accompanied by a storm and comes with less warning time in advance. Furthermore, tides make it harder to close breaches. Floodable lands below sea level, mostly located near the sea, have to be drained by pumps when the outer water has returned to its normal state. These considerations played a part during the decision-making for the Europoort barrier between 1986 and 1990 (TAW/TNO 1989; Huisman 2004). It is now disputed whether sea floods are, in general, worse than river floods. High river discharges last longer and up the river the absolute water levels are higher than storm surges; an upstream dike failure can flood large areas in the downstream direction many meters deep for weeks and even months on end. Figure 3.5 was one of the first maps showing that a breach in the sea defense does not lead to complete inundation.

Until 2016, the official policy (the Flood Defenses Act / Water Act – more in section



3.5 One of the first inundation maps: South Holland after breaches near Den Haag and Ter Heijde. The red dots are casualties per neighborhood (which were determined using data from the Hurricane Katrina disaster in New Orleans) (Jonkman 2007).

3.2) has revolved around rough characterizations of the areas to be protected. Over the last decades, flood patterns and flood consequences have been modeled in more and more detail, and after 2017 the new modeling possibilities will finally be operationalized.

How does finer modeling work? Advanced studies of embanked areas combine different models to represent flood characteristics of point A or patch B by a probability distribution of inundation depths and other flood conditions like flow velocity, salinity and inundation speed. This distribution is a function of:

- the outer water loads adjacent to the dike ring (provided by models such as the Hydra models, probabilistic hydraulic computing of statistical boundary data (Geerse et al. 2010)),
- the distributions of various dike failure locations and types (produced by geotechnical modeling),
- the elevation of the embanked patch and the geometry of the embanked area (such as available at the AHN-database (Waterschapshuis 2013)), which determines how a flood flows from a breach to the patch (calculated by hydraulic models such as Delft-

FLS (Hesselink et al. 2003), Sobek 1D/2D REF and, recently, 3Di (Stelling 2012)).

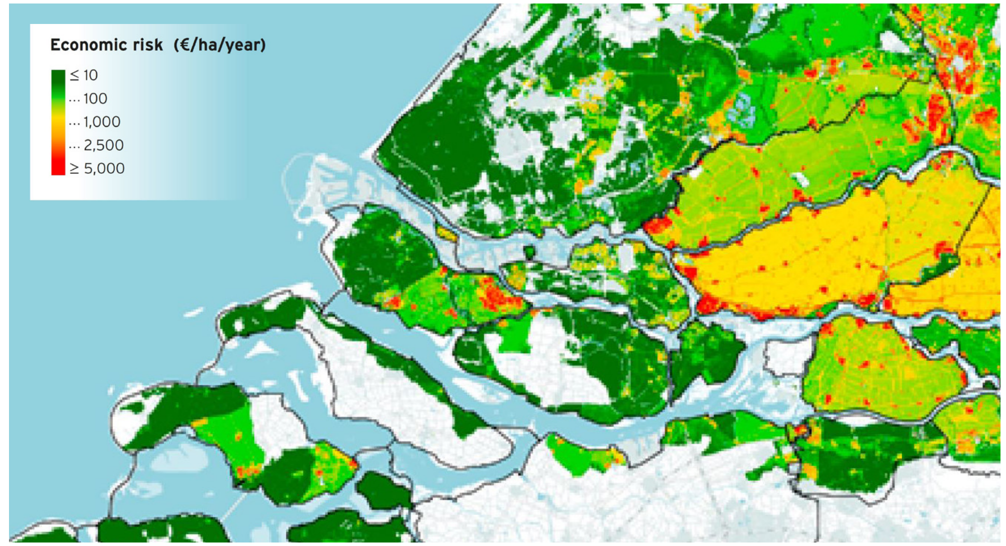
Flood characteristics are input for functions which relate land use (buildings, business, infrastructure, recreation, et cetera) to flood damage, casualties and disruption. Figure 3.5 shows an example of a flood depth and flood fatality map.

An advanced current damage and casualty model is HIS-SSM, which combines stage-damage curves, mortality- and indirect damage functions for a range of land users ((van den Braak et al. 2006; De Bruijn et al. 2015)). Evacuation fractions reduce casualties and vary between 10% for the tidal river area and 15% for Central Holland to 75% for the upper rivers area and 90% for the river Maas (Kolen et. al. 2013). Flood-proof buildings or resilient, robust and adaptive policies also claim to reduce flood consequences (e.g. Allenby & Fink 2005; de Graaf 2009; Zevenbergen et al. 2010). To determine impact on total risk, consequence reductions should be numerically implemented in flood damage models like HIS-SSM; until 2016, this is done in official policy support documents for evacuation fractions, but not for resilience and adaptivity (in De Bruijn et al. 2015 for example, it is only briefly discussed).

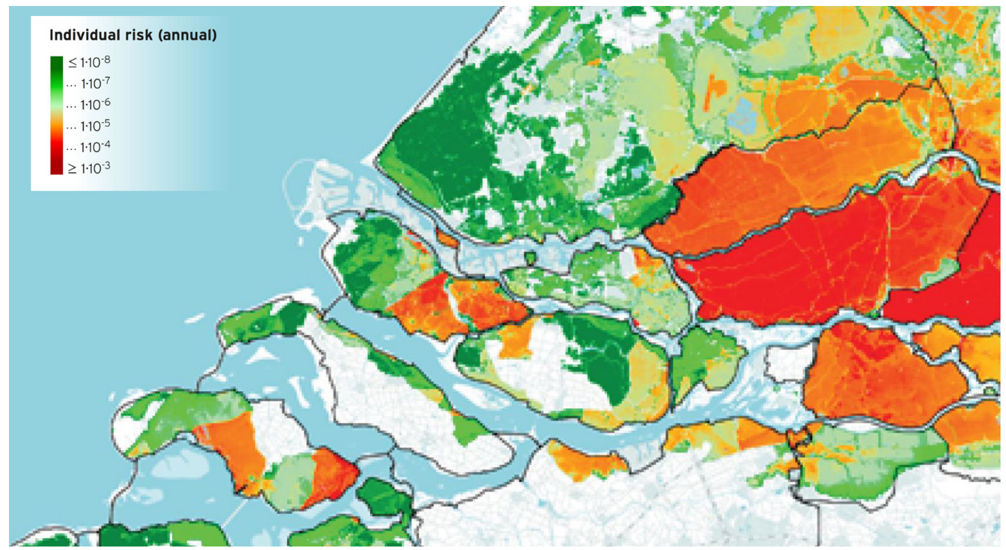
Flood damage, casualties and disruption can be represented in maps and graphs, such as for economic damage (figure 3.6), local risk (the probability for someone to die on location A if he would stay there an entire year), local individual risk (local risk multiplied by the evacuation fraction) and group risk (the probabilities that groups of people would die at once – figure 3.8). Note that often maps are made for a single flood event (like figure 3.5), instead of statistically aggregated events (like figures 3.6 and 3.7), the latter providing more complete information.

How does the flood risk profile of the embanked areas change over time, and can public policy within the dike rings influence potential damages? Risk increases with every baby born and every house built. Risk is generally reduced when levees are upgraded or relocated, floodplains excavated, when operations of control structures change or other modifications to the flood risk infrastructure are made. These are geared towards reducing flood probabilities, but they may also decrease or increase damage levels; deliberately or as a side effect. When embankments are reinforced for example, the probability of a flood decreases, but potential damage can increase, for example because inundation may be deeper when levees are higher.

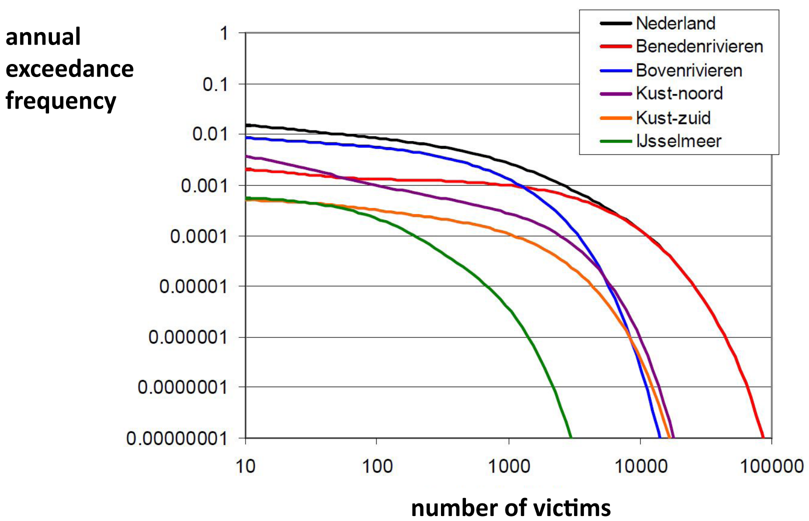
In almost all Dutch dike rings, people live their lives and do their business independent and unaware of the flood risk profile they continuously alter. Since the turn of the century the idea took hold that this should change; we might better conduct spatial projects in a *flood risk-neutral* way, by building neighbourhoods on mounds, floating or otherwise flood-proof buildings, zoning vulnerable activities away from low-lying areas, elevating roads, regional embankments to change flood patterns, et cetera – all such that development does not contribute to a growing total flood risk (e.g. Pols et al. 2007; Roggema 2008; De Graaf 2009; de Wit et al. 2010).



3.6 Yearly expected economic damage (euros) per hectare for three tidal river dike rings, for floods coming from the west and south. For the largest one (South-Holland) alone, total damage estimations have varied between 11 to 288 billion euro (Kok 2006a). VNK estimates an upper limit of 30 billion euro (VNK2 2013).



3.7 Individual risk map for the lower and higher rivers after the measures planned until 2020 are implemented (Beckers & de Bruijn 2011). Most of the light coloured patches have low flood probabilities. The dark patches have higher probabilities, the darkest ones have also high inundation depths and speeds. This often happens in compartments surrounded by historical dikes and elevated freeways.

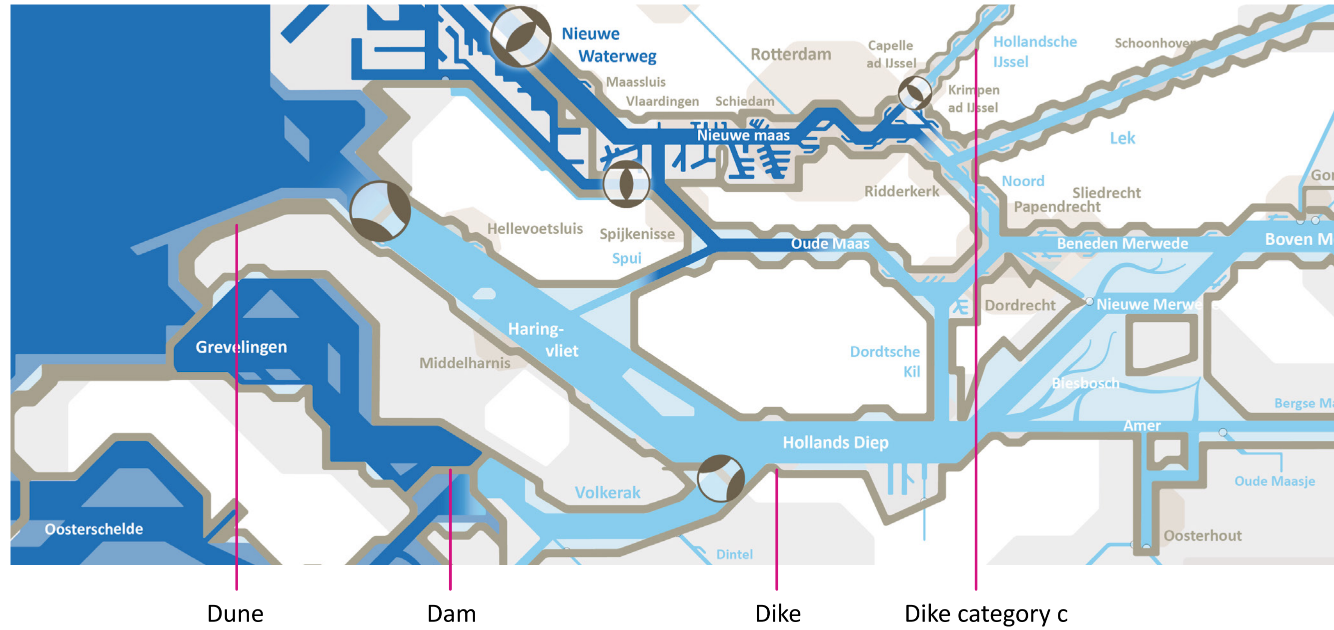


3.8 FN curves representing group risks for the year 2040 (when currently planned measures will be implemented). The black line is the Netherlands as a whole, the red line are the tidal rivers. The majority of events of over 10,000 casualties would happen in the tidal rivers, the upper rivers are good for the majority of the events with 10-1000 casualties. Estimated Dutch flood group risks are higher than other external (industrial) risks (RIVM et al. 2004; Beckers & de Bruijn 2011). Group risks are usually not represented in maps, but this could be done.

The ideas to reduce flood risk consequences in the embanked areas have been advanced since about 2010 under the name *Multi-Layered Safety* (DGW 2009; Deltaprogramma 2013a; I&M & EZ 2014; Rijkswaterstaat 2015) (layer 3 consists of evacuation policies, layer 2 of physical spatial measures located in the embanked areas, layer 1 of flood probability reducing measures). The added value of layer 2 in the Netherlands is disputed for being less effective than layers 1 and 3 (Kolen et al. 2012; T. Rijcken 2012c; ENW 2012; Kolen 2013) – more about this in section 5.2 and chapter 6.

Flood defenses

Flood defenses are dunes, dikes, dams, levees, banks, quays or constructions, combining into line elements which separate an embanked area from outer water, two outer water bodies (dams) or two embanked areas (compartment dikes); see figure 3.9.

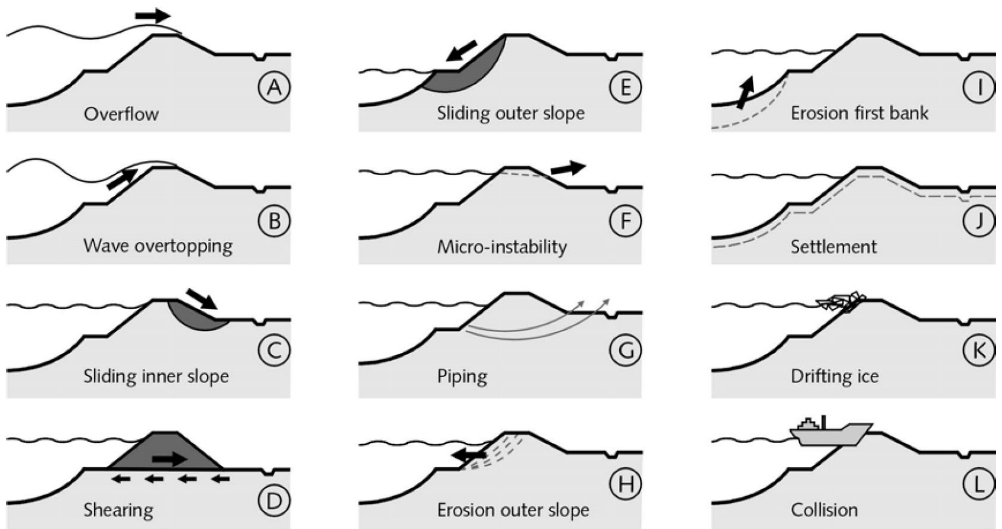


3.9 Flood defenses in Flowz can be classified using line thickness. A recognizable classification for the Netherlands is to distinguish dunes, normal dikes (dikes *category a*) and compartment dikes (dikes *category c*: on land or near highly controlled water). Dams (dikes *category b*) can have the same thickness as normal dikes because a dam is obvious: it has water on two sides instead of one.
Design considerations: the lines are thick enough to remain clearly visible when zoomed out far. On this zoom level, very small rejected dikes are blown up to twice the line thickness so they will not vanish.

In the Netherlands, according to the Flood Defenses Act of 1996 (now Water Act) there are 3.767 km of *primary flood defenses*, of which 723 km are compartment (category c) dikes (Inspectie V&W 2006a and 2011).

Characterising the *state* of the flood defenses requires a measure to relate a previously established requirement (elaborated in section 3.2) to information available on the defenses (strength) and the hydraulic loads: the reliability. There are three different ways to do this: deterministic (level 0), semi-probabilistic (level I) and fully probabilistic (levels II and III) (TAW 1998; van Velzen et al. 2007; CUR Bouw & Infra 2008; Voorendt

2013). Probabilistic calculations are difficult and laborious; before the Deltacommittee of 1961, policy-making could only use the deterministic approach. Since then, with the development of science and the computer, step-by-step the assessments brought more failure mechanisms (see figure 3.10) to the semi-probabilistic level. In the beginning it



3.10 Various failure mechanisms for soil structures (dikes). For dunes and structures additional failure mechanisms apply. Through time, the level of analysis tends to develop from deterministic to probabilistic, taking more and more of these mechanisms into account more and more thoroughly (TAW 1998).

was 'determinism with a drop of probabilism, and now it is opposite' (TAW 1998, p.56).

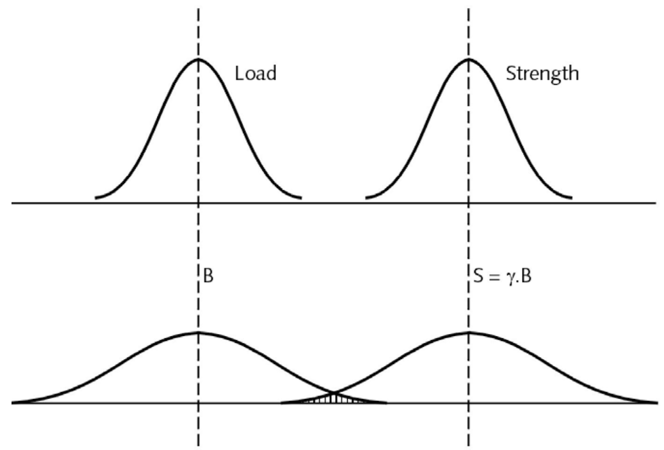
In which units do the three levels express reliability? The deterministic approach uses one set of (design) values for the load and applies one, or a few, rough, intuitive safety factors to account for all uncertainties for strength. A historically frequently used scale is a *height*. The difference between design water levels (load) and crest height (strength; with standardised slope angles, the dike becomes wider with height) is compared to a critical freeboard. This unit indicates not only whether a dike would be rejected or not, but also to what extent.

The semi-probabilistic approach (level I) applies partial safety factors and coefficients for failure mechanisms (see figure 3.10), derived from probabilistic analyses, to account more precisely for different uncertainties. The result of a semi-probabilistic levee assessment is 1 or 0; a levee is rejected if one or more of the failure mechanisms are too likely. Of course a dike can pass the test sharp or easily, but on level I there is no single unit to indicate this extent.

On the probabilistic levels (II and III), the probability density functions of all stochastic variables are mathematically described, combined (taking correlations into account), and used to determine the total probability of load being higher than resistance, usually in a Monte Carlo integration or simulation. The failure probabilities are expressed on a scale between 0 and 1.

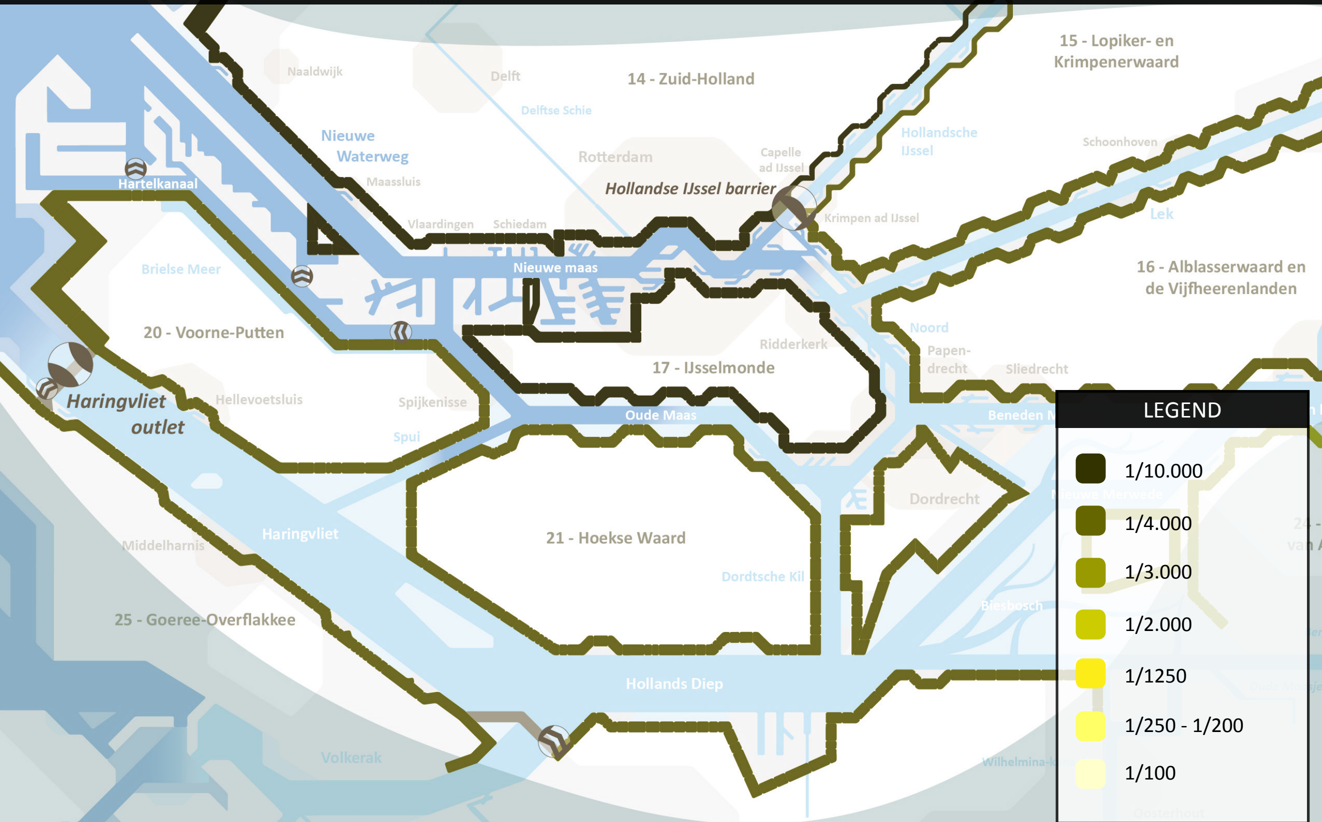
The probability can be compared to a failure probability requirement (standard) set for *single* segments, or for a *cluster* of segments. For the latter, the failure probability of multiple segments combined (like a dike ring) is bounded by the failure probability of the weakest dike section (lower limit) and the sum of the failure probabilities of all independent sections (upper limit). Especially when there are many independent failure mechanisms, the probability of failure increases with the length of the dike; the longer the structure, the higher the chance to encounter either an extreme load or a weak spot (the *length-effect* (Vrijling et al. 2011)).

Different approaches to the exact same dike can lead to different assessments (see figure 3.11). This phenomenon, with the new hydraulic loads of 1985, contributed to the decision for the Europoort barrier. In the cost-benefit analyses for dike strengthening

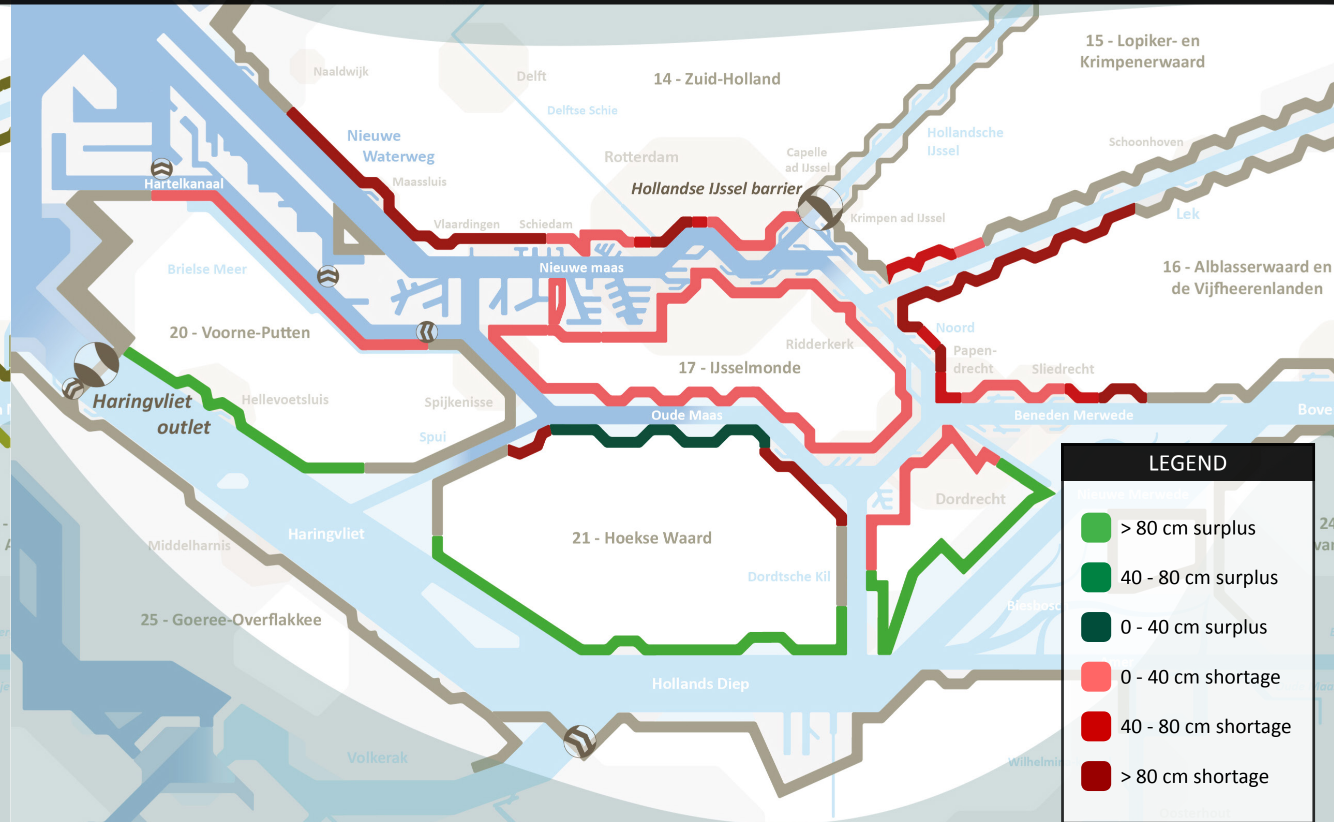


3.11 Two assessments on the same dike, with the same means (the striped line) for load (B) and strength (S), but a different deviation. The failure probability is the shaded surface under both curves; more uncertainty should be covered by a higher safety factor (γ). This is one of the reasons why a new analysis can result in rejection of a dike which was previously approved (TAW 1998).

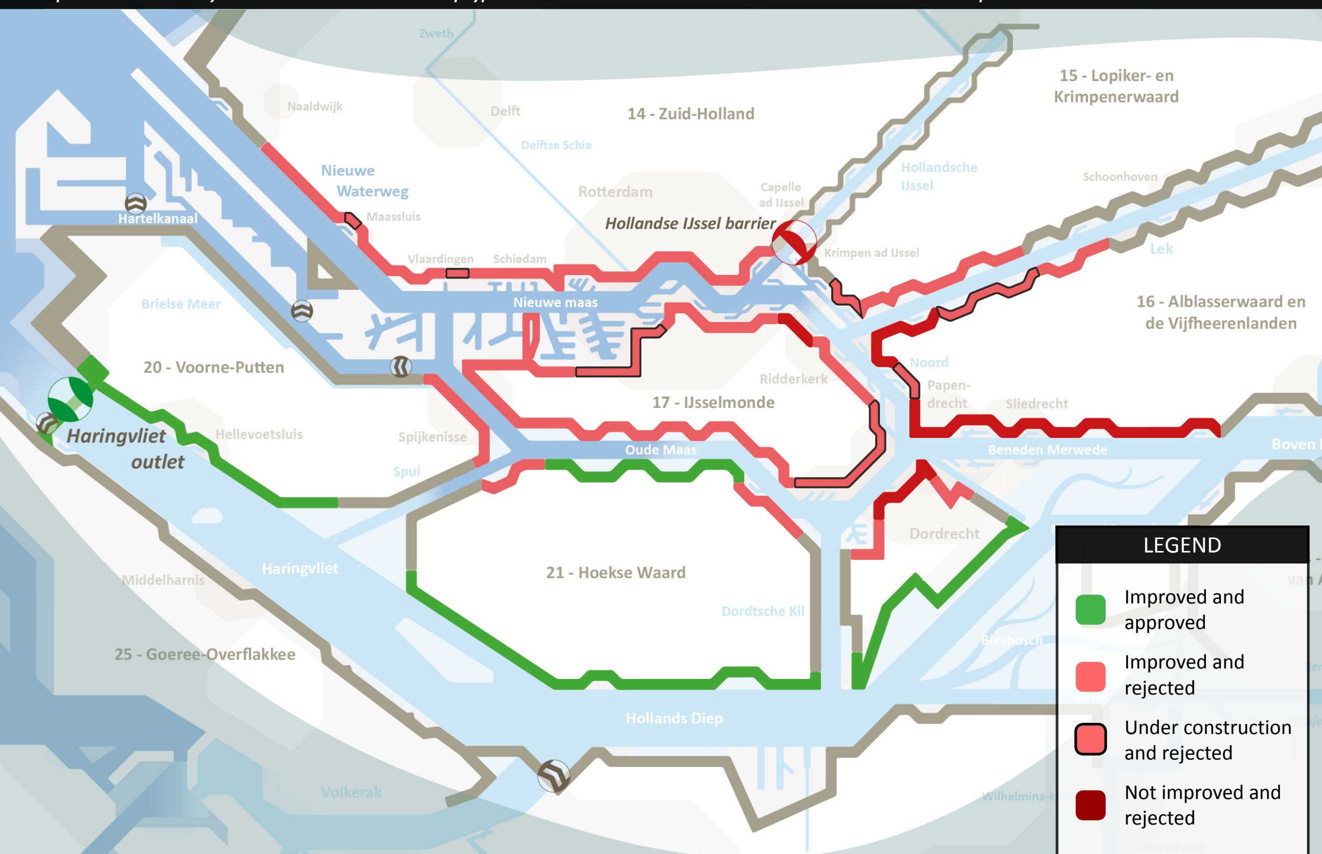
versus various alternatives of the barrier, made between 1987 and 1992, freeboard had to be 50 cm, the planning period was 50 years, sea level rise was estimated 20 cm/century. The semi-probabilistic dike assessments included the failure mechanisms of overtopping and wave overtopping, inner- and outer stability, piping, permeability and erosion resistance (CSW 1987a). See the projected (semi-probabilistic) levee assessments with and without the barrier in Flowz figures 3.12-1 to 4, and the (deterministic) crest height



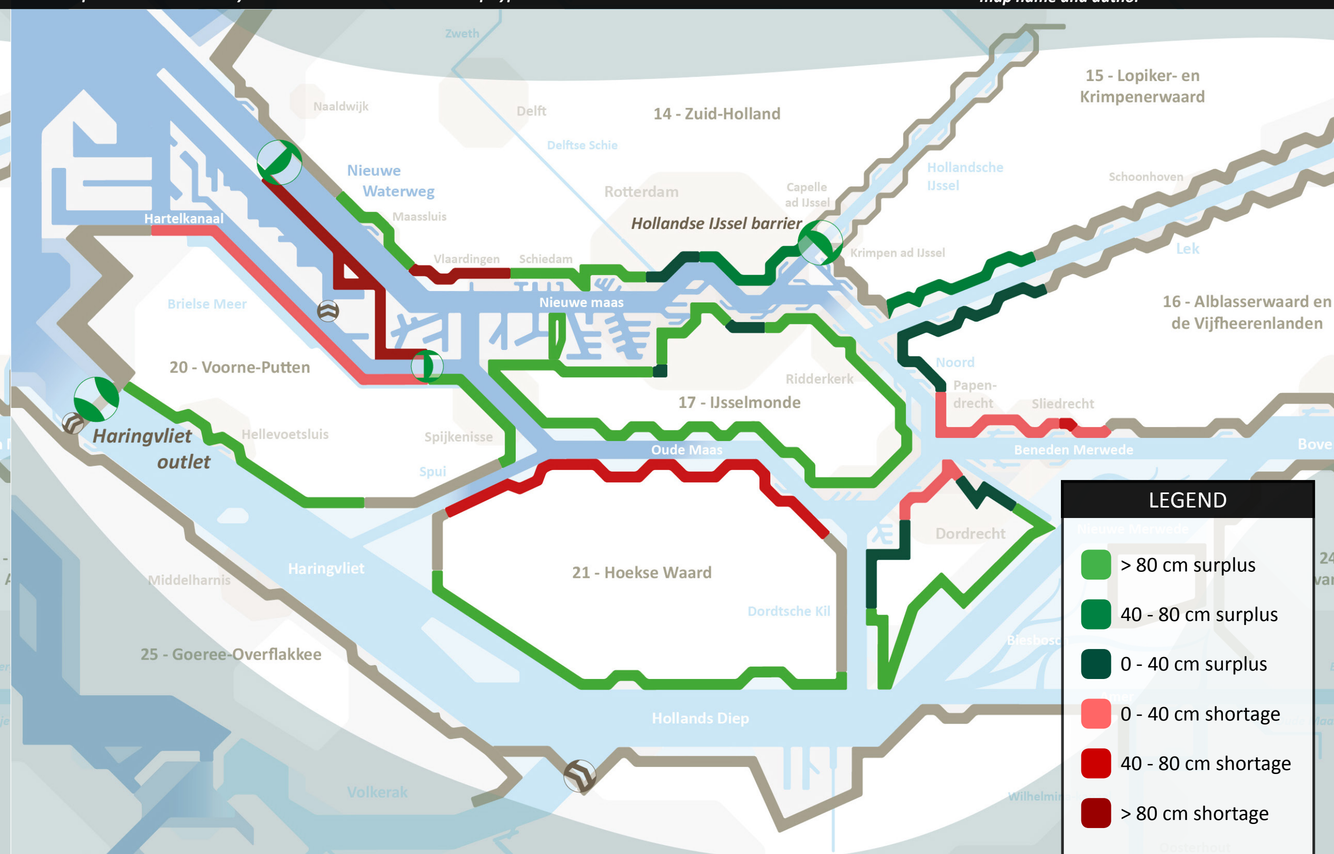
1986 map date | Flood risk system | System requirements map type | n.a. scenario | 1a) Exceedance frequency dike ring standards ... map name and author



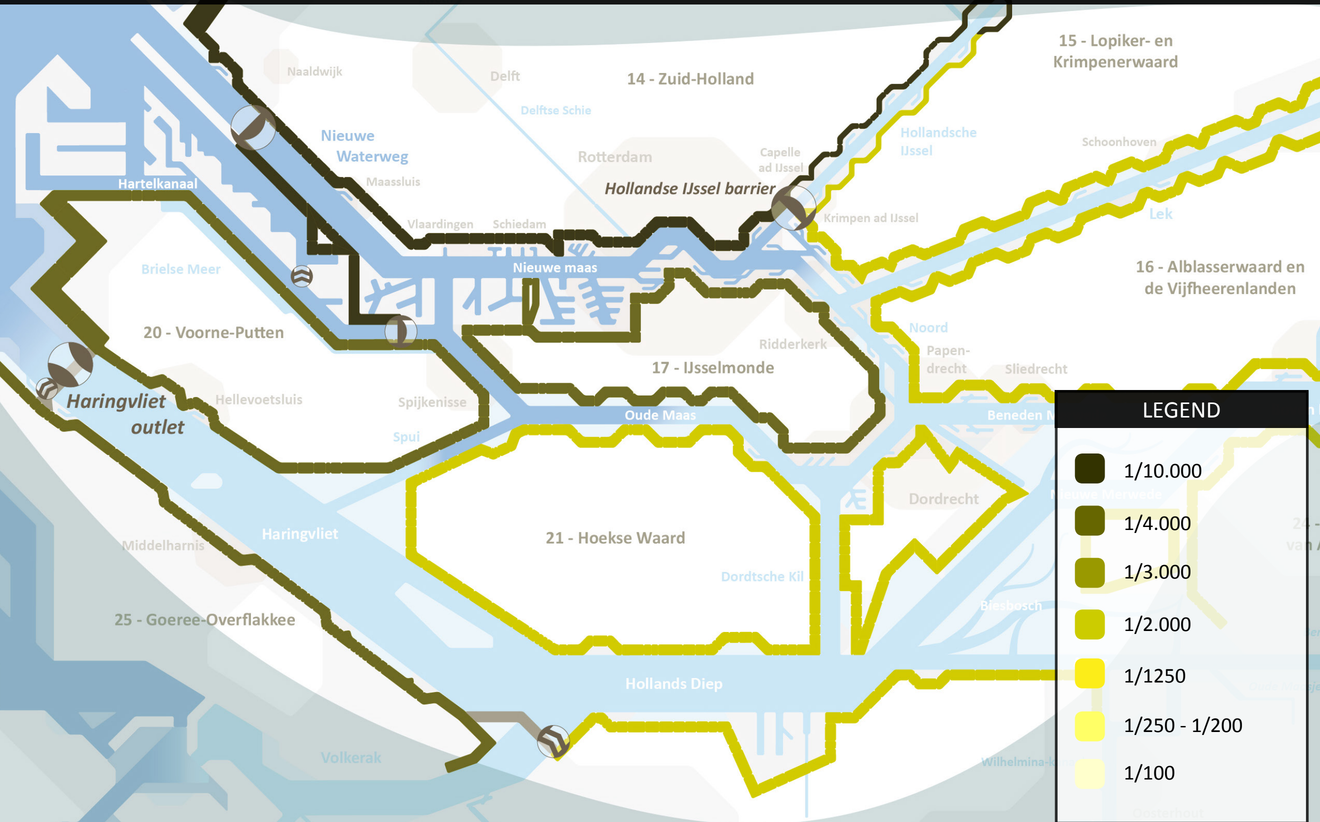
1986 map date | Flood risk system | System assessment map type | n.a. scenario | 1c) Crest heights before the Europoort barrier map name and author



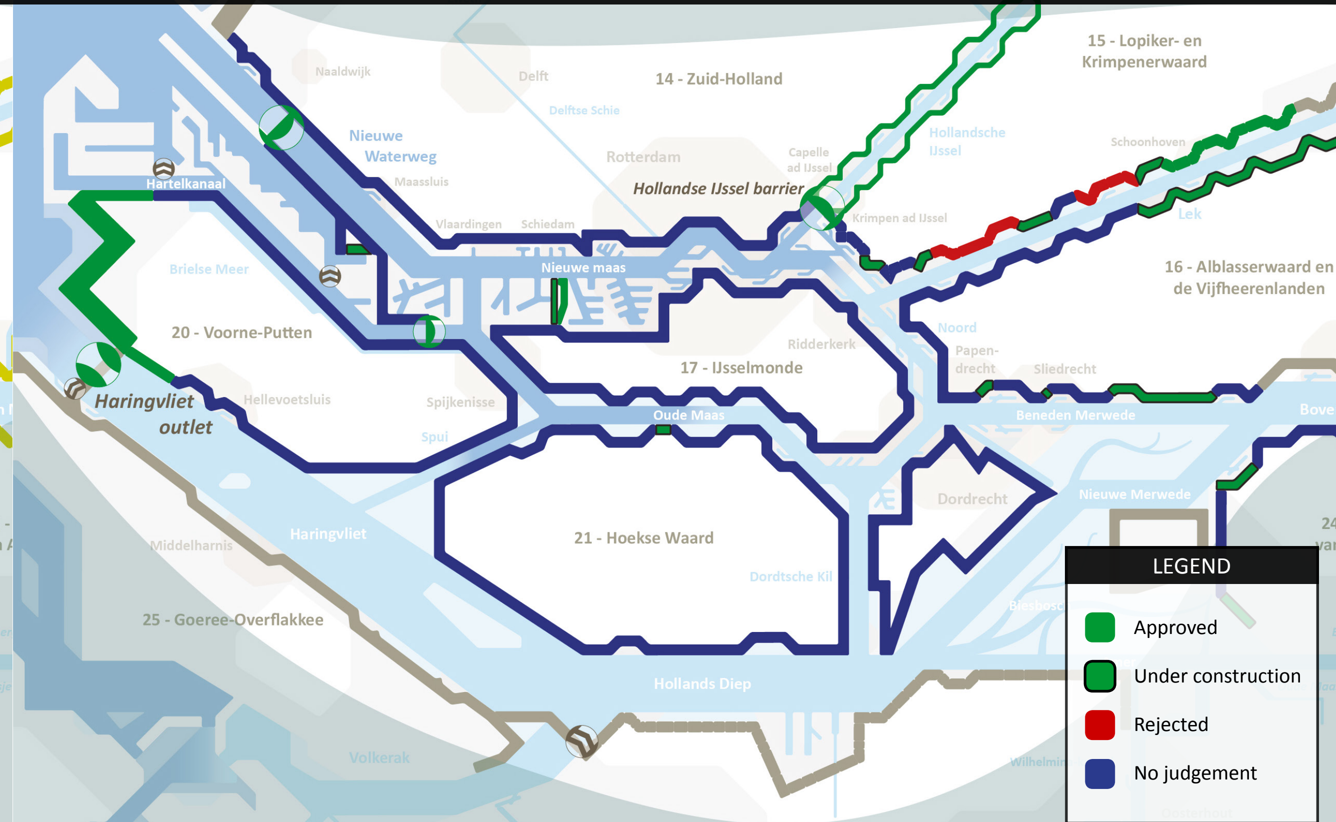
1986 map date | Flood risk system | System assessment map type | n.a. scenario | 1b) Levee assessment before the Europoort bar... map name and author



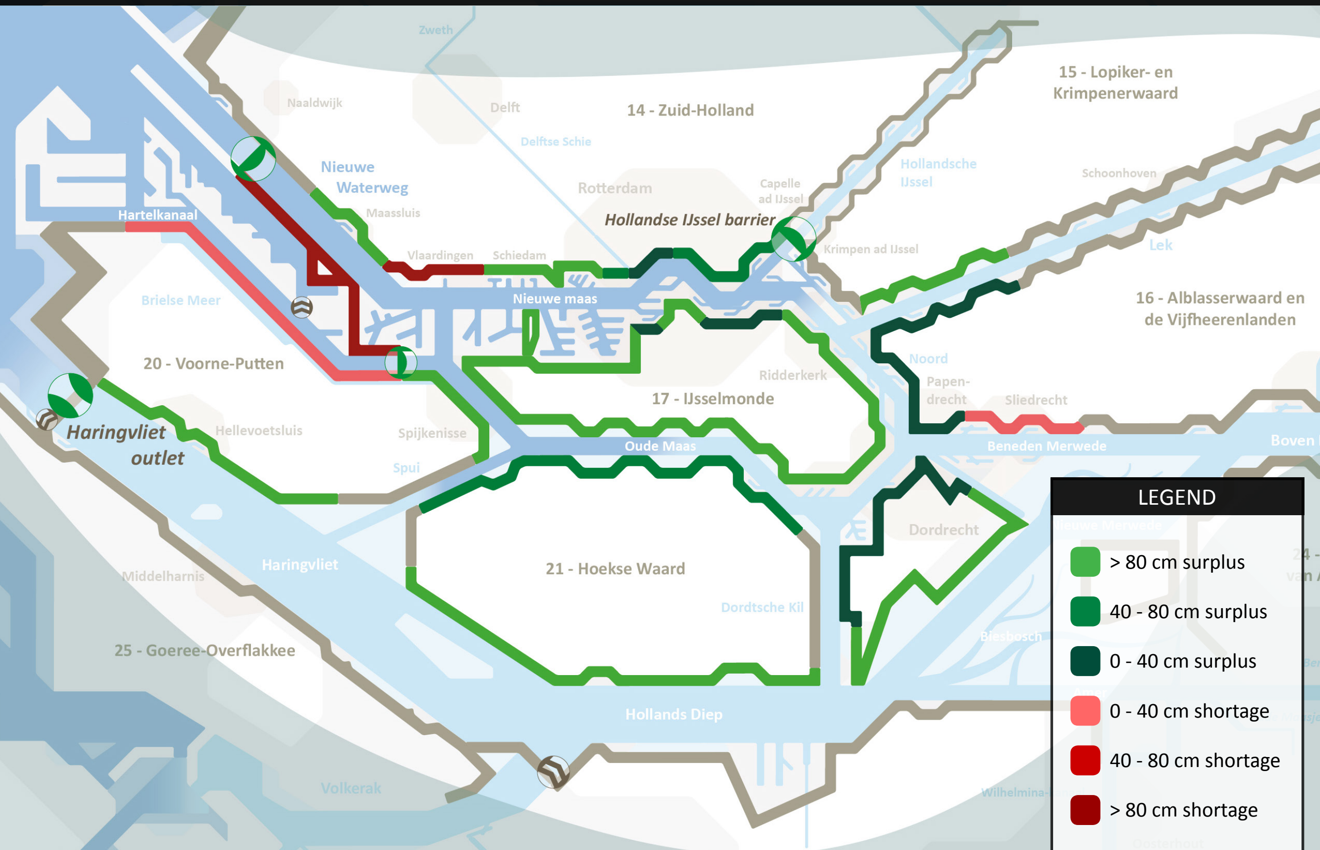
1996 map date | Flood risk system | System assessment map type | RWS1996 scenario | 1d) Crest heights after the Europoort barrier map name and author



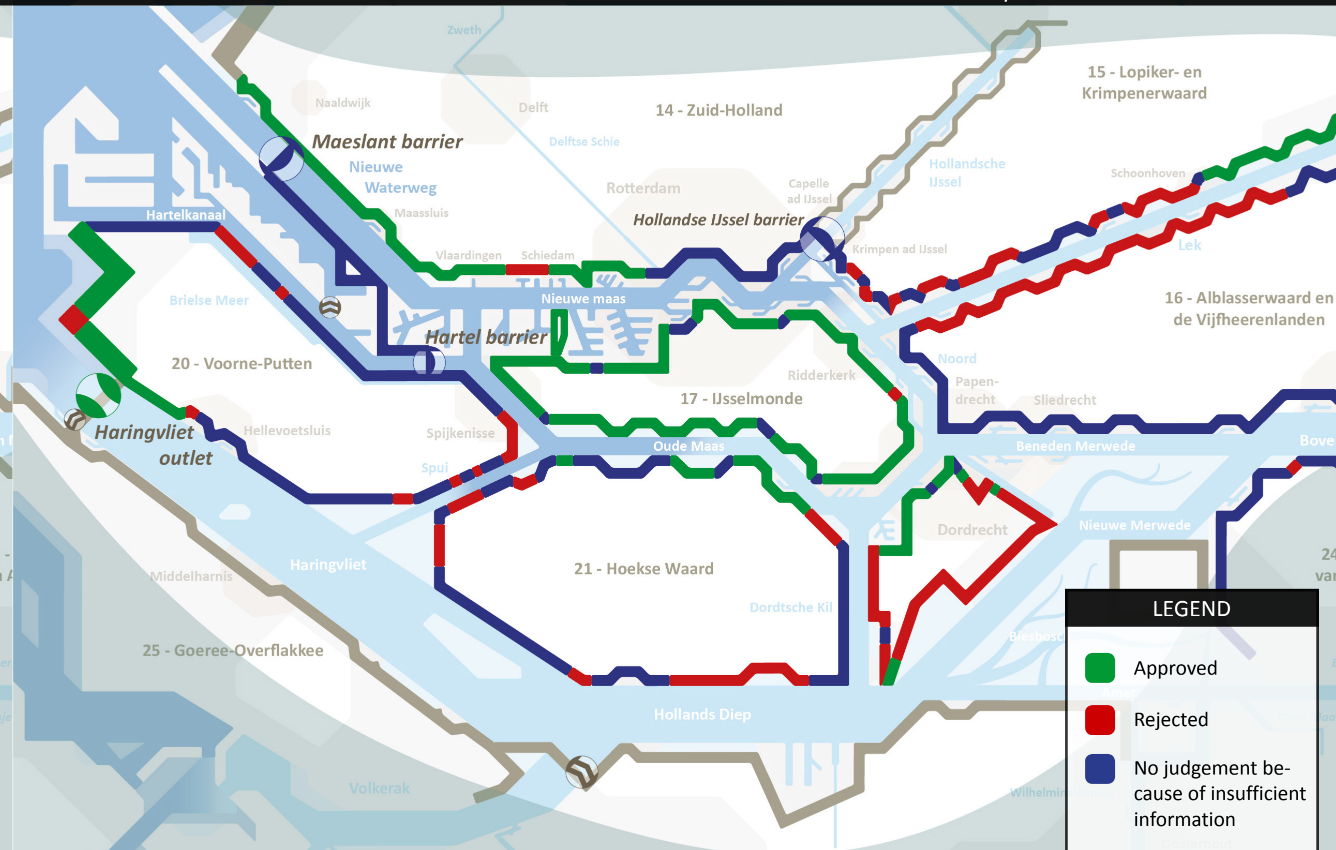
1996 map date | Flood risk system | System requirements map type | RWS1997 scenario | 2a) Proposed new exceedance frequency stan... map name and author



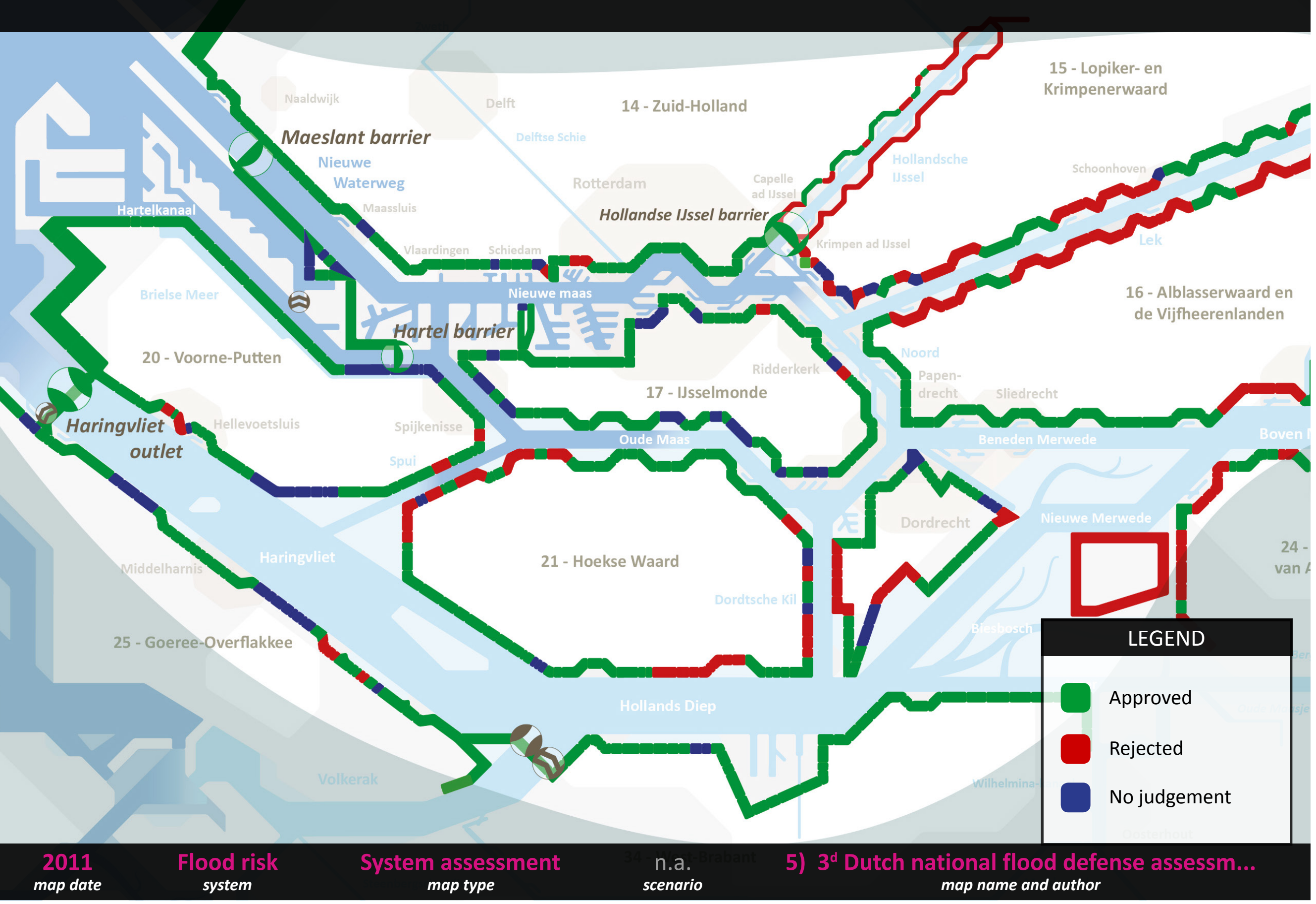
2001 map date | Flood risk system | System assessment map type | n.a. scenario | 3) 1st Dutch national flood defense assessm... map name and author



1996 map date | Flood risk system | System assessment map type | RWS1997 scenario | 2b) Crest heights after new standards and th... map name and author



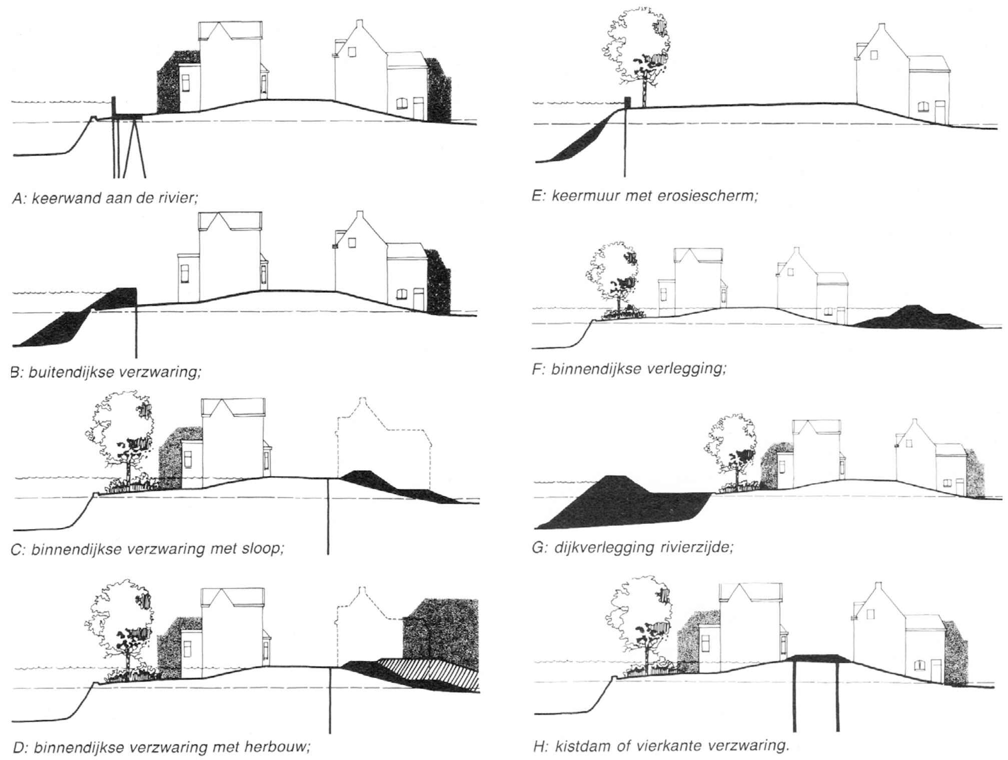
2006 map date | Flood risk system | System assessment map type | n.a. scenario | 4) 2nd Dutch national flood defense assessm... map name and author



3.12 Dikes around Rotterdam assessed through the years - a black outline indicates whether the element has been modified in the period selected.
1a) (Semi-probabilistic) levee assessments before the Europoort barrier (van Schaik 2013)
1b) (Deterministic) crest height approach before the Europoort barrier (van Schaik 2013)
1c) (Deterministic) crest height approach after the Europoort barrier (van Schaik 2013)
1d) (Deterministic) crest height approach after the Europoort barrier and including reduced standards (van Schaik 2013)
2a) New 1996 national standards (Flood Defenses Act 1996)
2b) (Deterministic) crest height approach after the Europoort barrier and the new national standards (van Schaik 2013)
3) Dutch national flood defense(semi-probabilistic) assessment 2001 (V&W 2001)
4) Dutch national flood defense (semi-probabilistic) assessment 2006 (Inspectie V&W 2006b)
5) Dutch national flood defense (semi-probabilistic) assessment 2011 (Inspectie V&W 2011)

approaches in figures 3.12-5 to 7. A TAW (1989) tidal river levee design guidelines report added micro-instability, human failure for control structures, and failure caused by musk rats, ship collision, et cetera; we can assume these were applied in the tidal river levee projects between 1989 and 1997.

In 1996, the *Flood Defenses Act* was adopted (more in section 3.2). Three five-year assessment rounds followed, ending in 2001, 2006 and 2011. In 2001, more than 75% of the tidal river levees could not be assessed (which was more than the national total (50% approved, 15% rejected, 35% not assessed - MinV&W 2001 and 2002). The notorious Sliedrecht dike project (see figure 3.13) was classified as 'intended upgrade', a category



3.13 Dike enforcement principles for the urbanised dikes of Sliedrecht (Rijkswaterstaat 1987).

that disappeared in the subsequent assessment rounds. In 2006, Sliedrecht was not assessed (Inspectie V&W 2006a en 2006b); in 2011, Sliedrecht was finally approved (Inspectie V&W 2011). The levees along the Lek and around Dordrecht remain problematic throughout the years. Dike ring 16, IJsselmonde, appears a fortress with not more than a small weak spot here and there; this is obviously due to the Europoort barrier.

As mentioned before, the semi-probabilistic approach does not show whether a dike is just about assessed reliable, or whether it will remain so for some decades to come. The deterministic dike height-approach does provide more information than either 0 or 1, and this method is still used for future projections and design studies.

A *series* (in time) of semi-probabilistic assessments is likely to provide better information than a deterministic assessment or one single semi-probabilistic assessment, but even better is a fully probabilistic approach. The failure probability can be shown in for example eight shades of red and green. Why do we want to see a wider scope? Because flood defenses should not only be assessed and improved at one particular moment in time, but also with the future in mind. A measure with a wide reach, such as the Europoort barrier, also benefits dikes that might be adequate at the time it is built, but will at some time not be anymore in the future.

The VNK project is a large fully probabilistic levee research project, which started in 2001 and published final reports about the flood probabilities and consequences of 58 Dutch dike rings in 2015 (Vergouwe 2015). The Lek remains assessed problematic, and IJsselmonde is less fortified than we thought. (Note that the VNK results are not yet related to standards or requirements; in Flowz VNK map 3.50-6c, this relation has been made applying the rough 10%-rule to the current exceedance standards, see more in section 3.2).

When the *system state* is determined, a discussion about *system modifications* can start. An inadequate dike section could be dealt with in five ways: 1) ease the requirements, 2) add, upgrade or alter a control structure, 3) implement a river project, such as a floodplain excavation or a bypass, 4) build a dam with or without a control structure, 5) upgrade the dike.

Dike upgrades are triggered by safety assessments and then prioritised based on cost-benefit analyses, available budgets and relations to other objectives. Pros and cons can be permanent or temporary. An upgrade can be minimal ('sober'), or custom and multifunctional, possibly adaptable, designed by for example a civil engineer or architect. Designers have to estimate the planning period. For earth dikes this is normally 50 years, for hydraulic structures and complicated dikes in urban areas this can be 100 years (Kanning 2007). Aspects like climate change, settlement and uncertainties have to be taken into account.

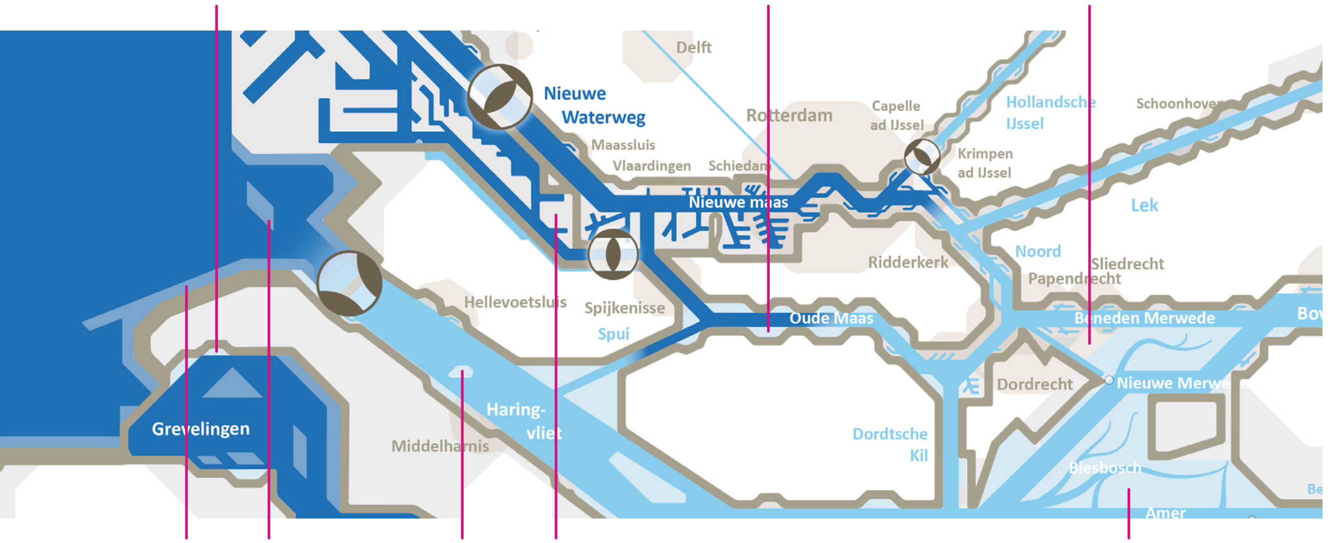
Probably the most legendary tidal river levee is the Voorstraat in Dordrecht. It runs right through the historical town centre, which is why dike reinforcement projects have always been technically complicated and heavily resisted. The Europoort barrier reduced the design conditions in Dordrecht just enough for authorities and habitants to agree on a system of flood stop logs between enforced foundations of the old houses, which could thereby be left intact. In the levee assessment rounds under the Flood Defenses Act however, the Voorstraat was assessed 'no judgement' all three times. Upgrades are

a design challenge: at Delft University of Technology, masters student van 't Verlaat (1998) designed a chain of custom made, partially moveable integrated structures, Hinborch (2010) invented a floating defense hidden in the outer quays in combination with bridges which are at the same time steel gates, and Pol's (2012) solution was to jack up the entire street. Recent flood modeling (Kolen et al. 2011) shows that a failure of the Voorstraat would not flood the entire dike ring, but only a small area. With the VNK results this contributes to the suggestion that the Voorstraat might be fine the way it is if a cost-benefit analysis would be applied (see the next section on objectives).

Unembanked areas

There are two fundamentally different ways to deal with the threat of sea or river flooding: surround an area with embankments, or not. *Embanked* areas may lie below sea level; *unembanked* areas have to be elevated above daily water levels, but could flood (if they can never flood, they are high grounds).

Over the centuries, in the Netherlands the unembanked areas have almost disappeared and are now only found between the outer water and the primary flood defenses, or are islands (see Flowz figure 3.14). Along the upper rivers they are called *floodplains*,



3.14 Unembanked areas in Flowz are tidal flats, beaches or floodplains – these know little flood damage. Some unembanked areas contain vulnerable objects like dwellings, industry, buildings or marinas. Unembanked areas may be islands or are connected to embankments or high grounds. *Design consideration:* when more than half of an unembanked area is vulnerable, it is drawn in the background as *floodable above sea level*, otherwise as floodplain or tidal flat. On an unembanked flood risk *system map*, however, a floodplain with some (even less than 10%) vulnerable land use is drawn as an unembanked vulnerable patch.

sometimes they are referred to as *inundation zones* or *flood prone areas*. A small dike ring with low embankments relative to a neighbouring large heavily embanked area could be called 'relatively unembanked' – this is the case for many unembanked areas in the Netherlands. Some exceptional unembanked areas (like industrial sites near Rotterdam and Amsterdam) are elevated higher than the dikes. In the Netherlands the distinction between embanked and unembanked (and the high grounds) is determined

by the location of the primary flood defenses established in the Flood Defenses Act (now Water Act).

In the Netherlands the flood characteristics of the unembanked areas are fragmented up to the square meter, depending on land use and history. A major distinction is between land use which hardly damages when flooded (grassland, nature, et cetera) and vulnerable functions (housing, industry, et cetera).

Along the upper rivers, Lake IJssel and the lakes of Zeeland the predominant unembanked land use is agriculture and nature, interspersed with holiday home resorts and marinas. The northern tidal rivers are surrounded by heavy industry, port activities and urban development. In the Netherlands as a whole, about 115.000 people live in unembanked areas, estimated to grow with about 60.000 the coming decades (Deltaprogramma 2012b) – comparably, a rough 10 million live behind primary flood defenses in the embanked areas. Wolthuis (2011) counted 952 developments planned in unembanked areas, of which 183 comprise urban dwelling projects.

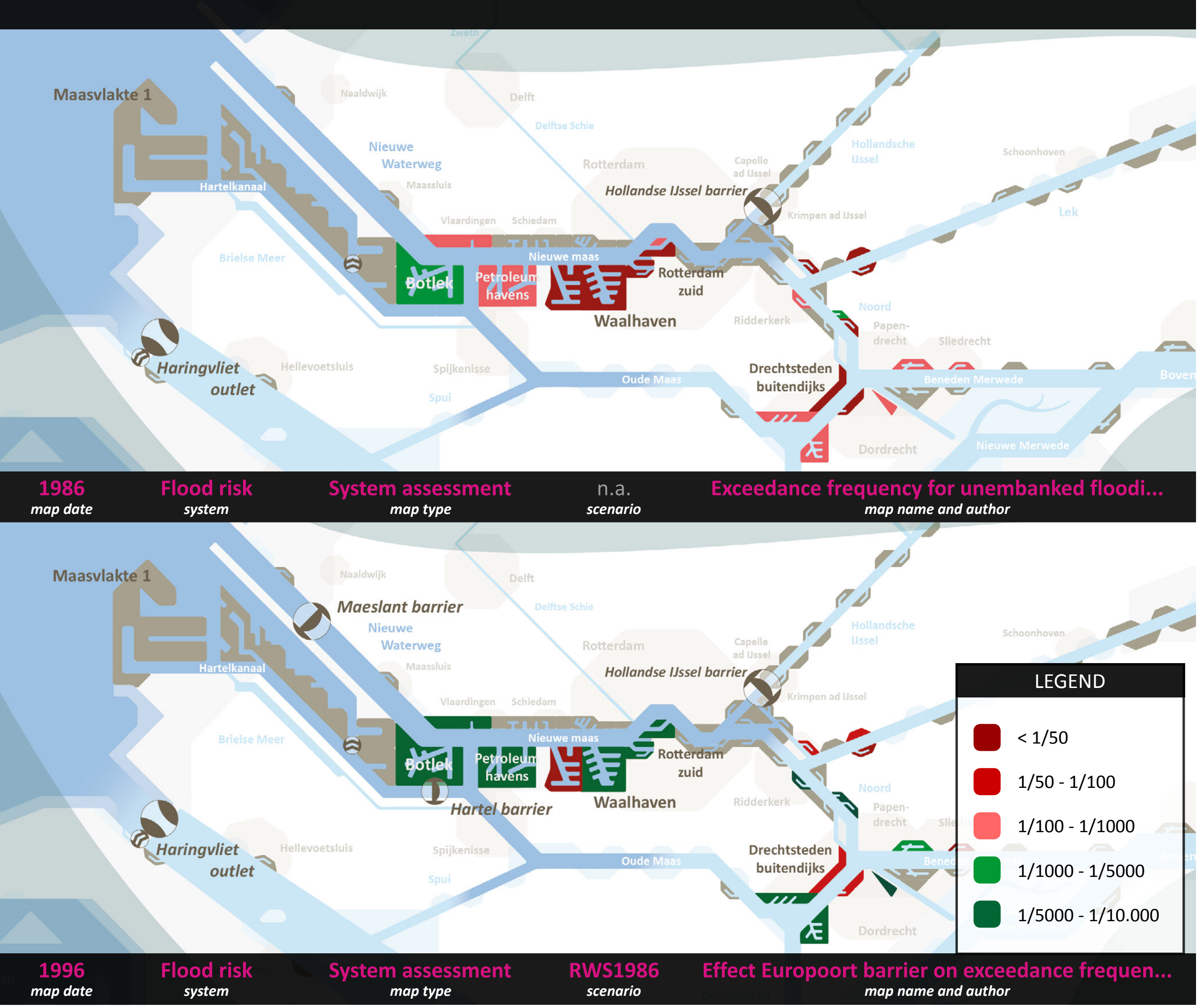
Flowz map 3.15 shows the vulnerable unembanked areas in the western Rijn-Maas estuaries. The vulnerable patches shown are mostly port related industry, but also contain 30.000 homes (de Hoog & Nillesen 2010), which would thus account for more than half of all Dutch unembanked dwellers.

The fundamental parameters to characterise the unembanked areas are the same as for the embanked areas: surface area, land elevation, land use and inhabitants. The unembanked areas however have, in general, an opposite composition: the flood frequencies are high, but the flood depths are low, while embanked areas have a low flood frequency but high flood depths. Because both the embanked and the unembanked areas have developed over centuries towards acceptable low risk levels, the economic risks tend to be about the same. Fatality risks however, are generally low. The unembanked areas are much smaller than the embanked areas and flooding is shallow, so mortality is practically zero, evacuation fractions are high and group risks can be neglected (PZH 2013).

Flood risk analyses for *un*-embanked areas, obviously, do not rely on geotechnical reliability assessments of embankments. Most Dutch unembanked areas are however *semi-unembanked*: many lie behind distant dams and barriers (like Noordereiland), or are protected by small local embankments (like the Botlek).

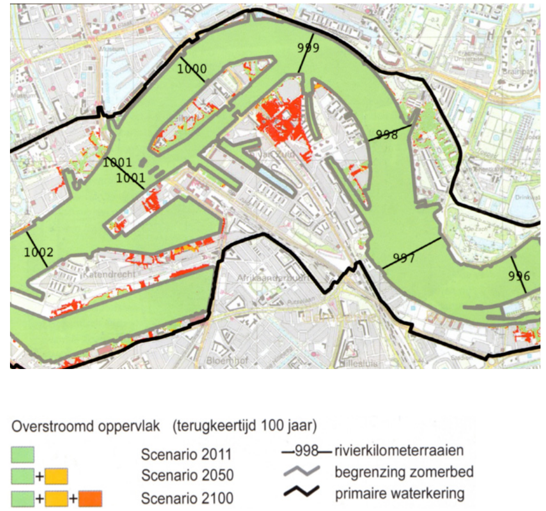
How is the *condition* or *system state* of unembanked areas represented in policy documents? Without hydraulic models, land height is compared to a mean water level or the highest water level observed. When hydraulic models and statistics are available, the state of an unembanked area can be represented in multiple ways. Methods are in essence similar to the embanked areas (flood characteristics + land use + stage-damage curves = flood risk), but the final assessment parameters differ.

The Europoort barrier research (Rijkswaterstaat 1987; van Schaik 2013) compared expected *probabilities for the unembanked areas to flood* (supposedly with more than a centimeter) with and without the barrier – see Flowz figures 3.15. Twenty years later,

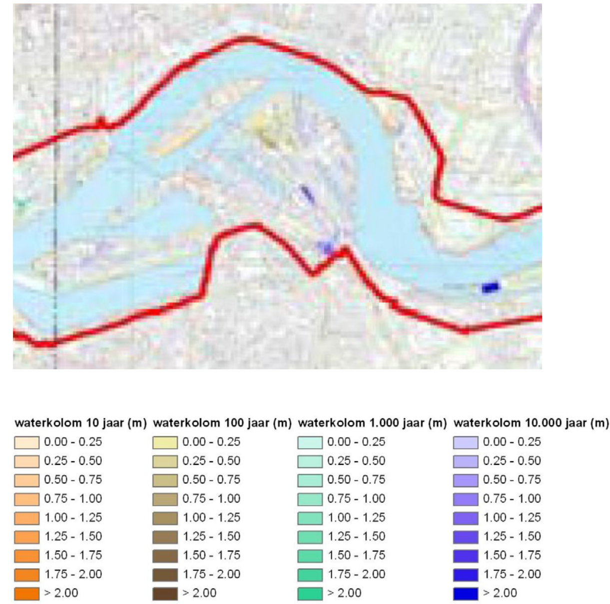


3.15 Exceedance frequency for unembanked floodings in Rotterdam without and with the Europoort barrier (Rijkswaterstaat 1987; van Schaik 2013).

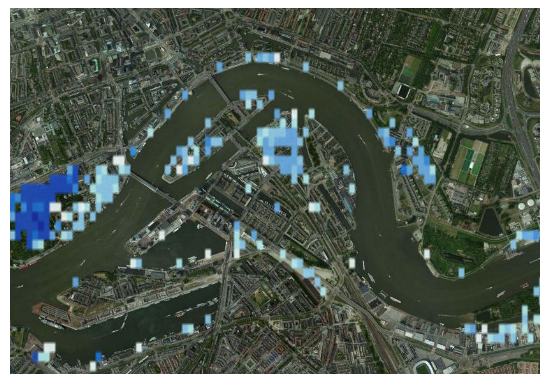
Rijkswaterstaat Zuid-Holland (2007) conducted a systems analysis (triggered by the observation that the failure probability of the Maeslant barrier was estimated ten times more than intended) and published *which parts of the unembanked areas would flood for a given return period* (and future scenarios). For the entire Rijn-Maas estuary this ranged between 51% (return period 10 years) and 64% (return period 10.000 years). For the northern more urbanised (and thus higher elevated) part of the area, Muntinga (2009) calculated these percentages to be 23% (return period 10 years) and 39% (return period 10.000 years). The remaining percentages can be assumed to be vulnerable areas so elevated they do not even get flooded with a frequency of 1:10.000.



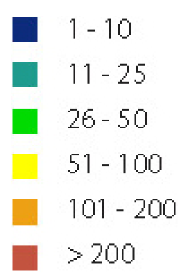
3.16 - Inundated areas in Rotterdam in 2011, 2050 (sea level rise 10 cm) and 2100 (sea level rise 20 cm) for a 100 year return period (Rijkswaterstaat Zuid-Holland 2007).



3.17 - Inundation depths in 2009 for four return periods, by Witteveen+Bos; note the differences with the other maps (Muntinga 2009).



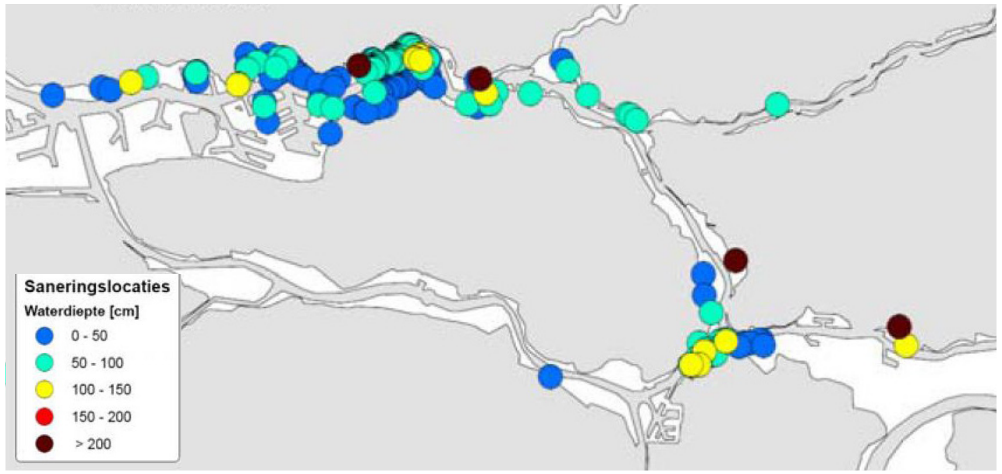
3.18 - Inundation depths in 2010 for a 10.000 year return period, by HKV consultants (Veerbeek, Huizinga, et al. 2010).



3.19 - Inundation depths in 2100 (sea level rise 80 cm) for a 100 year return period (Deltaprogramma 2013a).

Recent studies present maps with *flood depths for given return periods*. They differ from each other; see figures 3.17, 18 and 19. When stage-damage curves per land user are applied to unembanked flood depths for damage and risk calculations (as done for the first time for the river Maas (Delft Hydraulics 1994)), annual expected damage was estimated about € 1 million in 2007 (Muntinga 2009), more than three times less in 2010 (Veerbeek et al. 2010, Zevenbergen et al. 2010), € 90 million in 2012 (Deltaprogramma Rijnmond-Drechtsteden 2012) and € 40 million by de Moel et. al (2013). Differences can be explained by different study area boundaries, but mostly by the many uncertainties and model limitations, acknowledged in all studies.

Other ways to represent the state of the unembanked areas are the number of flooded houses, certain buildings or *hotspots* located in an unembanked area for a certain return period or statistically summed for multiple return periods. Environmental remediation locations are such hotspots – see figure 3.20. The province of South Holland (PZH 2013)

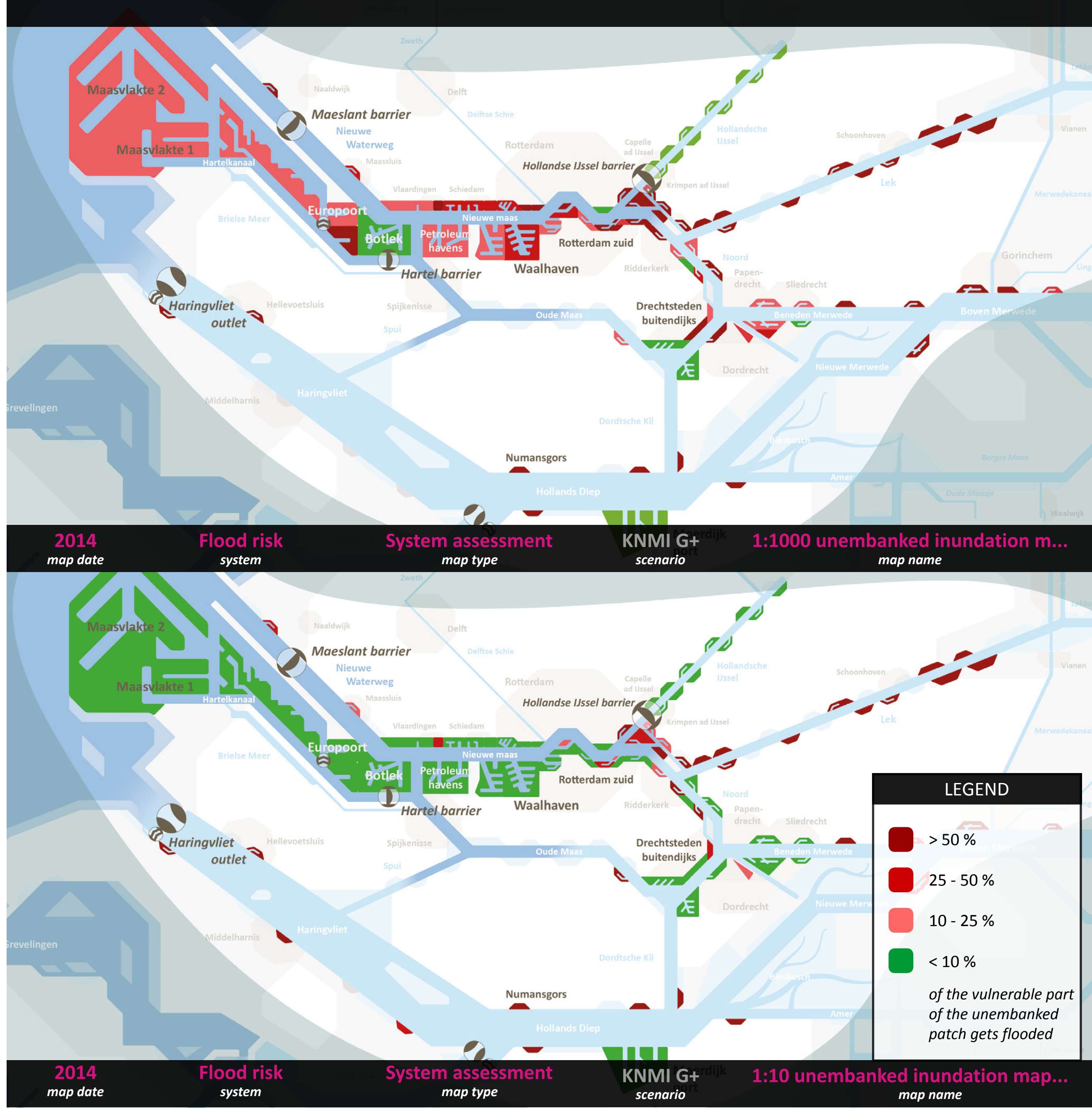


3.20 Inundation depths for environmental remediation locations with 1,5 m sea level rise and an improved Europoort barrier (de Nijs & Claessens 2010; Rijcken et al. 2010).

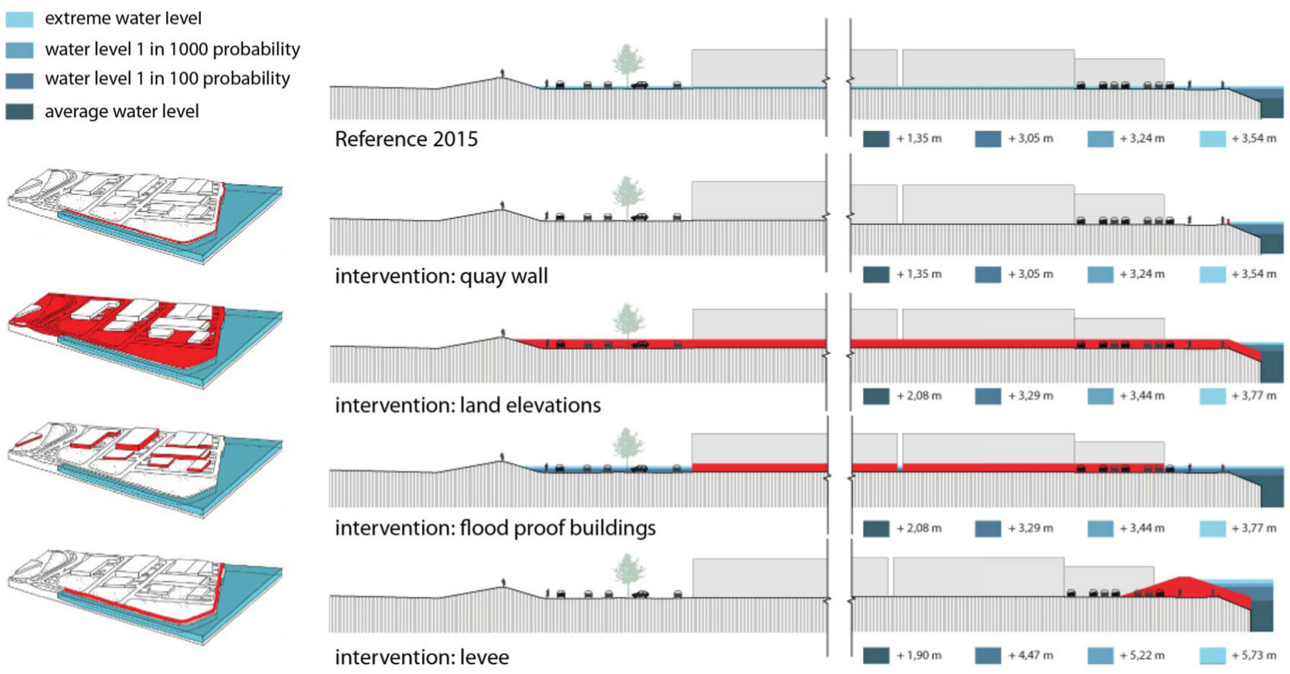
focuses on *local individual risk* (see page 87) and *societal disruption*, defined (with HKV consultants) as the number of physically, socially or emotionally flood-affected people, per hectare per year (conducted for the majority of land users – Huizinga et al. 2011).

Which parameter is preferred depends on the purpose of the assessment. Regional policy-makers will want a general overview of the most pregnant areas. Directly involved residents, urban designers and architects need detailed local information.

Which measures (*system modifications*) can influence the unembanked flood characteristics? Figure 3.22 shows measures on four levels, from flood-proofing of



3.21 Available inundation depth studies like in figures 3.16 to 19 are usually highly detailed and show flood depths for vulnerable and non-vulnerable unembanked areas. This is suitable for local stakeholders, but blurry and unpractical for national policymaking and general overview (the Flowz objectives). In Flowz the vulnerable patches as a whole are coloured, using a number like average inundation depth or total inundation volume for a certain return period, or annual expected inundation depths or volumes relative to a certain desired value – all only counting the vulnerable parts of the unembanked patches.



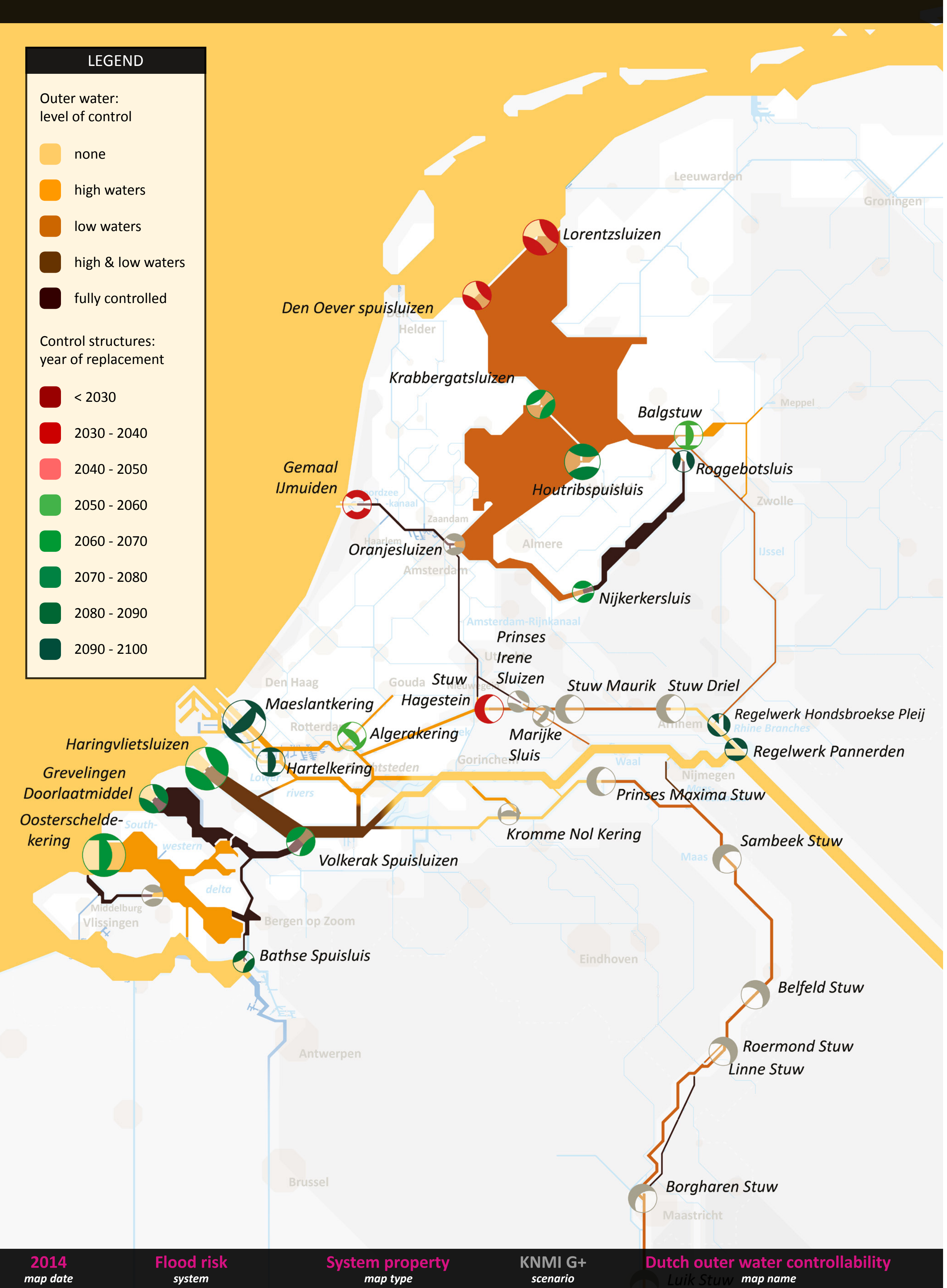
3.22 Typical unembanked urbanized area along the tidal rivers. The embanked land (left in the cross section) is usually lower than the unembanked land (right). The elevation of the land at both sides varies greatly throughout the system. In red, four ways to reduce flood risk: A-raising the quay, B-heightening the entire area, C-flood-proofing buildings and D-relocating the primary flood defense: turning unembanked into embanked land (Nillesen et al. 2011; Nillesen 2013). A fifth option would be a new or modified distant dam and/or control structure.

individual buildings, to relocating the primary flood defense. We can add a fifth: adding or altering a nearby dam or control structure like the Maeslant barrier. According to Wolthuis (2011), the profitability of collective (higher scale, like dikes) measures grows linear with the dwelling density and transcends individual measures at 24 dwellings/ hectare.

When a building or piece of infrastructure is *flood-proofed*, floods do little or easily repairable damage to foundation, facade, interior and utility connections. To achieve this, buildings and infrastructure can be raised or moved, float permanently or occasionally (referred to as *amphibious*), buildings can be *dry proofed* to prevent water from entering the house, or *wet proofed*: when the water enters the house this does no damage (Zevenbergen et al. 2011; van Veelen 2013; de Moel et al. 2013). Flood-proof *neighborhoods* should remain accessible during a flood. A famous example of a flood-

proof neighbourhood containing flood-proof buildings is *Hafencity* in Hamburg, but large parts of Rotterdam are in fact similar.

Costs of flood-proofing are lower for newly built than for existing buildings. De Bruijne (2008) made an inventory of buildings in the floodplains which had to be adapted and/or relocated for the Room for the River project. Costs for relocation or jacking up are often about the same as the value of the building itself. Costs of other flood-proofing measures are generally lower and can introduce typical architectural qualities and a unique waterfront identity (Rijcken et al. 2010; Zevenbergen et al. 2010; Nillesen & Singelenberg 2011; Nillesen 2013).



Outer water

The flood risk system component *outer water* consists of water bodies, connected or separated by a dam or control structure; rivers, lakes, bays, the sea, et cetera. Outer water fills volumes enclosed by primary flood defenses or high grounds, the unembanked areas and the water beds. Within these volumes are objects like groins, bridge pylons and trees, which influence discharge capacity and other parameters.

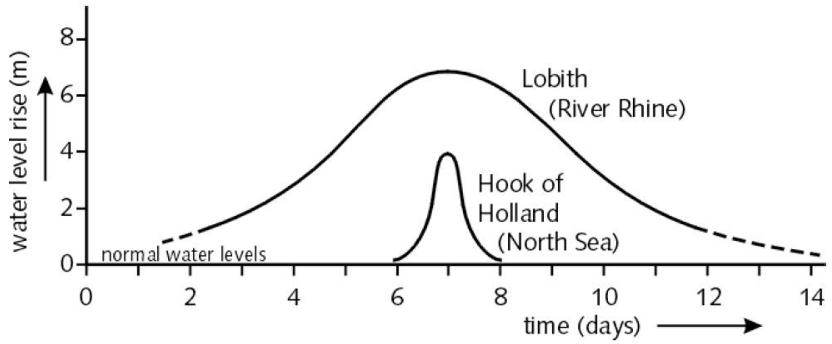
In the Netherlands, the outer water bodies are under primary authority by the national government; the last water bodies which were adopted as outer water under the Flood Defenses Act were lake Marken and the small Flevoland lakes, in 2002, and parts of the Maas, in 2005.

Water levels within the embanked areas are highly controlled (having low variability); outer water is not controlled, little controlled or in some lakes and canals also highly controlled (see Flowz figure 3.23). In other contexts, outer water is only the sea, but in this thesis also the large rivers and the largest canals are considered *outer*, as long as they are located *outside* of the embanked areas as defined in the Flood Defenses Act (now Water Act).

The Dutch outer water constitutes 14% of the Netherlands west of the North sea. Half of this are the wild (uncontrolled) Wadden sea (6%) and Westerschelde (1%). The other half are former seas and estuaries, mainly lake IJssel (including lake Marken 5%), and the large rivers, which take about 0,5% (perhaps 2% if the floodplains would be included). Water and swamps within the embanked areas take 4% of the remaining 86% (the rest of the Netherlands is land: agriculture (56%), built-up areas (13%) and dry nature (11%)) (CBS StatLine 2008).

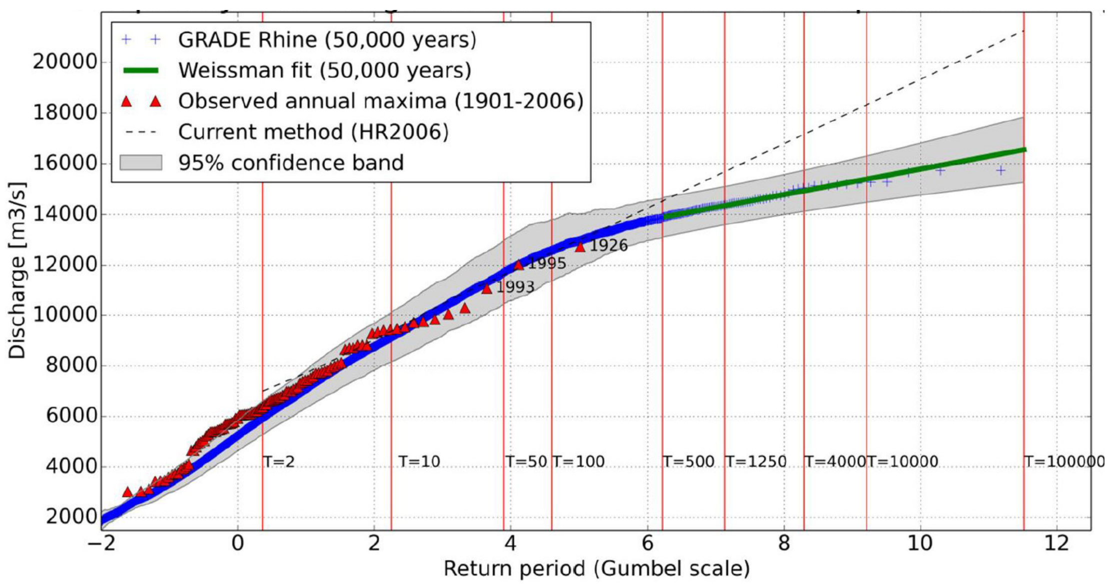
Which parameters describe the outer water condition? All-including would be full statistical distributions on each location, of temperature, chemical compositions such as salinity, and of course the hydraulic conditions: water levels, flow velocities, wave and turbulence characteristics. Frequently used parameters are historical water levels (the *Waterdata* website - Rijkswaterstaat 2013), statistical water levels for certain return periods and the *design water levels* (the *Book of hydraulic conditions* - Ministry of Water Management 2007). Parameters not describing the water at a specific location but large water bodies as a whole are *discharges* and maximum discharge capacity (for the upper rivers) and *storage capacity* (for the dammed estuaries and seas). Water levels are of course time dependent. High river water levels last much longer than storms at sea (see figure 3.24).

◀ 3.23 Dutch outer waters with a level of control made possible by control structures (colours taken from the VONK asset management project (Deltaportaal 2014)). Design considerations: outer water bodies are planes or lines. Large lakes and seas (planes) match their real size or are slightly enlarged. Rivers and canals (lines) are enlarged more than ten times; line thickness is determined by the discharge capacity. For clarity and visual calm, bends are straightened and 45 degree angles are used, except for very distinctive shapes. See page 117 for the meaning of the control structure symbols.



3.24 Course of high (design) river water levels compared to sea levels caused by storms (relative to daily levels). (TAW 1998).

Since 1887 (Van Gelder 2000) water levels have been recorded at Hoek van Holland and other locations, providing valuable statistical series (see figure 3.25 for Rhine river discharge statistics). In the 50s and 60s, physical models were built to estimate levels



3.25 Water levels with a return period higher than the water level record period are usually obtained by statistical extrapolation. The GRADE project includes modeling of rainfall, runoff and upstream flooding for a 50,000 year series. This graph is the frequency-discharge curve with a 95% confidence band, for the Rijn at Lobith, with flooding in Germany (Hegnauer et al. (2014); modified for additional uncertainties like breach types, emergency measures and river roughness in Prinsen et al. (2015) and for breaches in Germany in Hegnauer et al. (2015)).

with a longer return period than the time span of the available series, on locations without historical data, and/or as a result of major interventions such as the Delta Works. Since then, computer models have taken over and nowadays (design) parameters are generated in a combination of statistical extrapolations and modeling, which since the 2000s also aim to incorporate the effects of climate change.

The main outer water system model is the *Hydra model* (used for the majority of the Dutch national levee assessments between 1996 and 2011(DGW et al. 2007; Geerse et al. 2010)), which requires the following *input*.

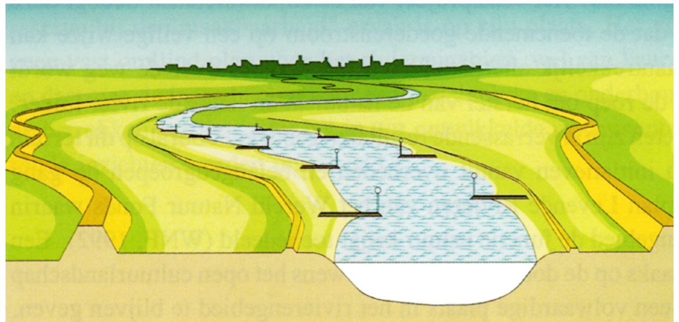
- The geometry of the outer water system of basins and arteries (in the Hydra models, rivers are represented as a network of axes between nodes, defined by cross-sections and roughness factors. Local surge factors are applied to maintain fast 1D-modeling. At complex parts such as bifurcations, 2D-modeling is conducted. For the lakes and coasts, different models apply, like SWAN).
- Hydraulic and meteorological boundary conditions: peak river discharge, sea level, storm duration, wind speed and direction, et cetera (in the Hydra models, for the coast, lakes and tidal rivers these are all distributions, the upper rivers often use a single (design) discharge. The distributions are derived from historical water level and wind speed recordings and/or (current or future) climate models. Some stochastics are correlated; wind direction for example is related to storm surge level, but not to river discharges).
- The operations of control elements within the outer water system: outlets, storm surge barriers, spillways, et cetera (in the Hydra models, these open or close according to various closure criteria, with certain failure probabilities and prediction errors – see the next section on control structures).

The Hydra model *output*, for each location (*kilometraai*), are water levels for certain return periods, required dike crest heights (given a critical return period and an allowed overtopping discharge) and wave conditions (for assessment and design of revetments).

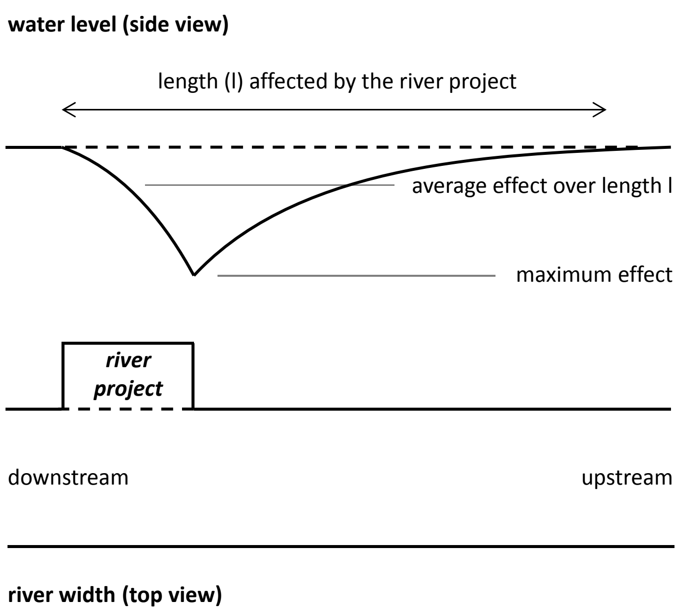
The geographical and statistical water system information and equations of the Hydra models are also used in the models *PC-ring* and the *Delta Model*. Other outer water models are *Waqua* (used for parts of Room for the River) and *3Di* (under development). Over the last decades, models have advanced due to faster computation possibilities, better geodata and general improvement, but it takes time before the model improvements are used for actual policy support.

What kind of measures can change the shape of the outer water such that they significantly alter flood risk, and which measures have been implemented in the tidal rivers over the last 30 years? The effect of the outer water measures (often called *spatial measures*, in Flows *river projects*) are usually evaluated in terms of (design) water level reduction. A significant water level reduction does not, however, necessarily imply a significant flood risk reduction, but it is a practical and imaginative unit to talk about the outer water (more about objectives in the next section). The general effect of a single local river project on water levels is shown in figure 3.27. The effect of a spatial measure is usually expressed as the peak in this graph.

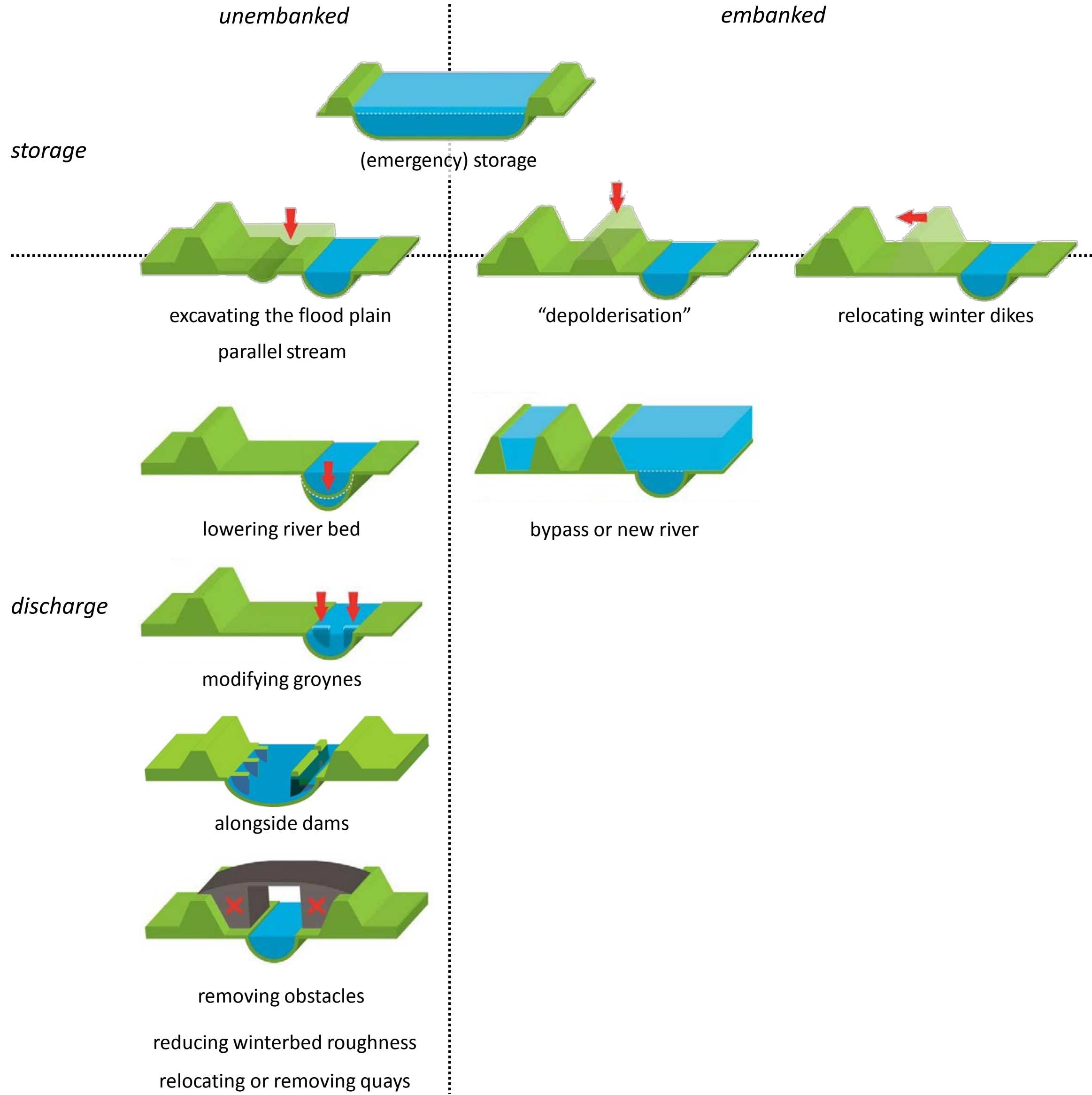
Figure 3.28 shows measures presented on the Room for the River website (PBR 2013), complemented with measures listed by Silva and Kok (1996). For this thesis, the measures are put in a 2x2 matrix; they can provide more *storage*, or improve *discharge capacity*, by measures within the *existing unembanked areas*, or measures which take



3.26 Archetypical *normalized* (scouring the river bed with groins and preventing flooding with dikes) upper river profile in a delta (Silva & Kok 1996b).



3.27 The water level-reducing effect of river widening measures (including floodplain excavations) works in the upstream direction. The effect of a river project is typically presented by the maximum water level reduction, rather than the average reduction.



3.28 Measures to change the outer water geometry and roughness. Depoldering is usually emergency storage, and sometimes storage and a bypass combined (like depoldering Noordwaard) (taken from Silva & Kok 1996b and PBR 2013 and modified).

space from the *embanked areas*. The efficacy of the concepts is different for the upper and tidal rivers.

The upper rivers could benefit from all four types, although the least, in general, from more storage in the existing river profile. Silva and Kok investigated the main upper river water level reducing measures in a comprehensive study using the predecessor of the Hydra-R model - see table 3.29. Measures were each implemented separately, over

	Design water level reduction (m)				
	Integral Exploration configuration Rhine branches study (IVR)			Room for the River	
	entire river		*5 km*	*project*	
	average	*max.*	*max.*	*max.*	
Reducing roughness	0,05	0,15	-	-	
Removing obstacles	0,05	0,25	-	-	
Removing quays	0,05	0,25	0,10	**	
Parallel stream	0,05	0,25	0,05	0,08	Avelingen
Lowering groynes*	0,10	0,15	-	0,12	Waal
Lowering river bed*	0,20	0,60	0,15	0,20***	IJsseldelta
Excavating floodplain*	0,35	0,45	-	**	
Relocating winter dike (1 km inland)	Waal: 1,50 Lek/IJssel: 0,80	1,80	0,50	0,30	Zutphen, Lent, Overdiepse P.
Bypass	-	-	-	0,71	Veessen-Wapenveld

3.29 Measures to lower water levels in the upper rivers. Modeling results of the IVR project (1996), aimed at the effects of particular measures, are compared to the same measures finally implemented in the fifteen main Room for the River projects (Silva & Kok 1996a; Q-team 2012; Rijkswaterstaat 2007).
* Respectively lowering/excavating/lowering with 1 meter.
** In the Room for the River projects, quay removal and excavations are always combined with other types of measures.
*** This number is derived from the *Blokkendoos* (Rijkswaterstaat 2007), the others in this column from the Room for the River Q-team annual report (Q-team 2012).

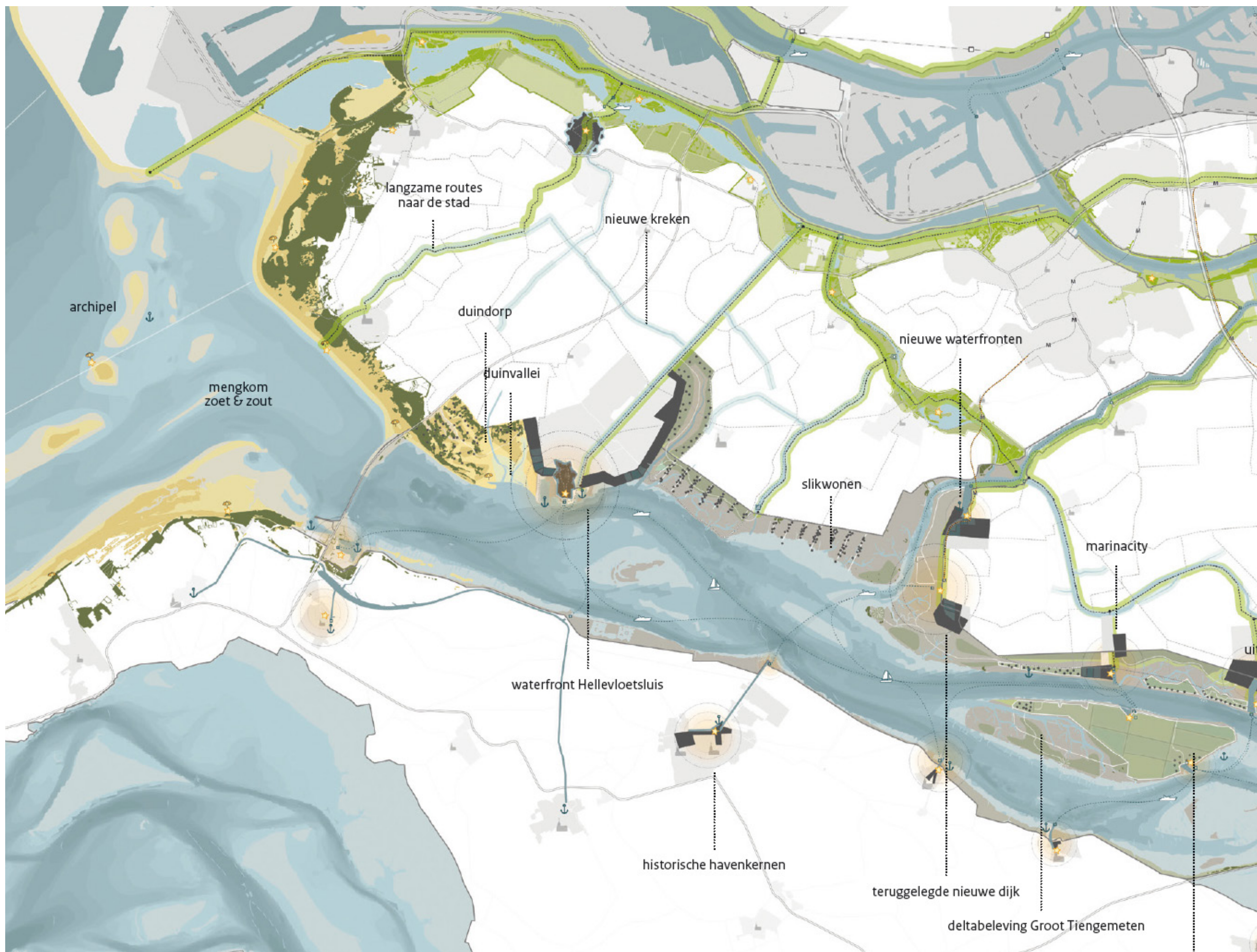
the entire length of the river, and on a trajectory of 5 km only. As the column under *max* under *entire river* compared to the column *max* under *Room for the River* shows, a measure can have multiple times more effect *on a specific location* than applied *in general*.

The € 2.3 billion project *Room for the River* is now (2001-2015) implementing 25 water level reducing projects (of in total 34 projects; the other projects are levee reinforcements). The water level reductions presented by Room for the River are *maximum local reductions* (the lower peak of figure 3.27) which are supposed to be achieved by a project. When these are compared to the modeling results of 1996, a careful conclusion would be that it is hard to achieve *in practice* what could be possible *in principle*.

In the tidal river area, discharge capacity enhancing measures are only effective in the eastern part. In the 19th century, two historical projects dramatically changed the shape of the outer water system of this region. The Nieuwe Merwede was excavated to connect the Waal to the Hollands Diep, and the Bergse Maas diverted the Maas away from the Waal. In modern language, the first project would be called a combination of excavating the floodplains and lowering the river bed, the latter one hell of a bypass.

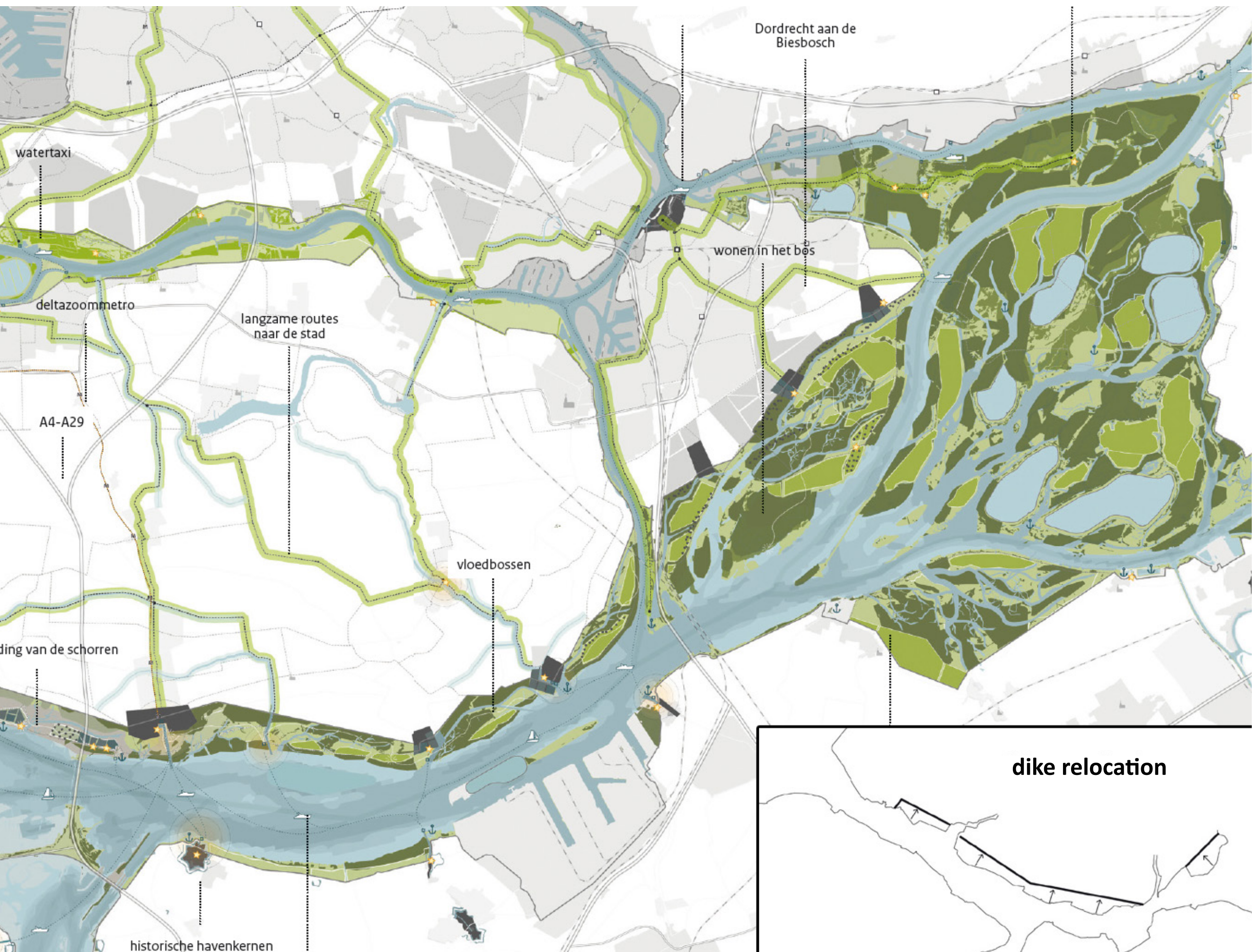
These projects had such a positive impact on the system, that similar large river (outer water) projects were not deemed necessary until about the year 2000. Inspired by the Room for the River ideas, local and regional governments issued a list of 31 possible spatial measures for the tidal river area, large and small (de Jong et al. 2000a). Funny enough, the Room for the River flagship project *depoldering Noordwaard* was not on this list.

The middle and western part of the tidal rivers are different. Further west, the sea has greater influence and most water bodies (like former estuaries and sea ship channels) are wider and deeper than the upper rivers. The closer to the sea, the less advantage increasing discharge capacity would have. What matters here is *storage capacity*: during a storm, the area fills up from two sides until the storm recedes (for this reason, *storm durations* matter a lot in the hydraulic models).



Significantly increasing storage requires substantial measures. The lake Volkerak storage project increases storage capacity of the tidal rivers with about a third (200 added to about 600 million cubic meters). Under certain circumstances, this measure can lower water levels in the region with 0,5 meter, which is a lot, but the lowering of the *design water levels* can not exceed 0,1 meter, due to the statistical interplay with the failure probability of the Europoort barrier. Adding the Grevelingen and/or Oosterschelde and widening the gate opening in the Volkerak dam could increase design water level reduction to 0,6 m, and reduce water levels in specific situations with 1 meter (Slootjes 2009 and 2010). There are not many other feasible possibilities to increase tidal river storage capacity substantially. It has recently been suggested to relocate the Haringvliet dikes away from the Haringvliet (see figure 3.30), but this has little impact on design water levels, as had already been discovered by de Jong et. al. (2000).

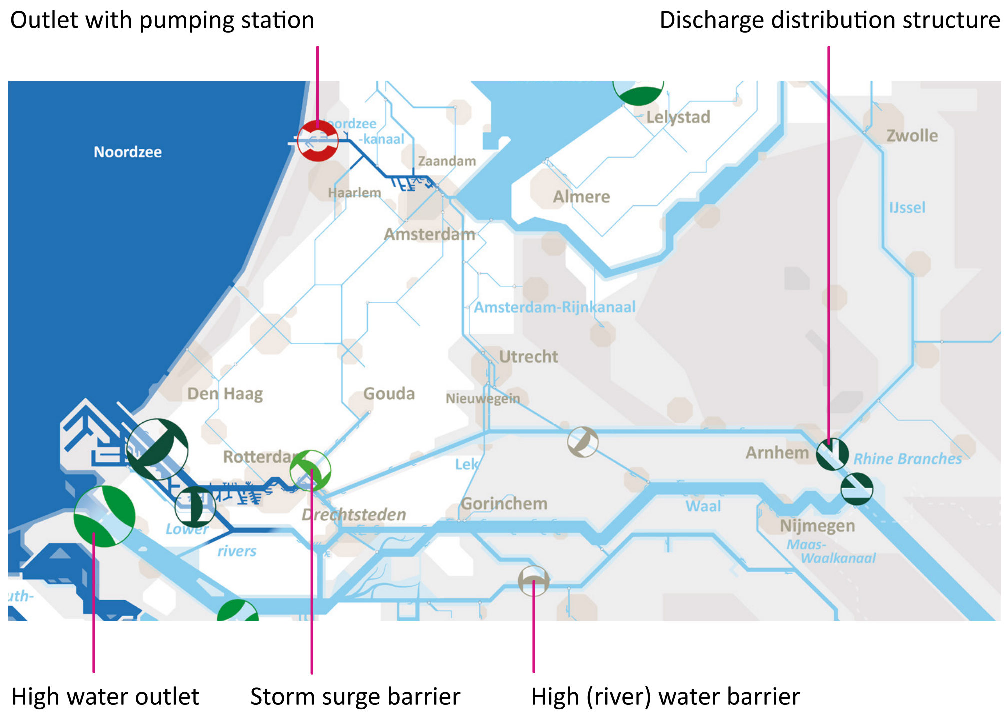
◂ 3.30 ▾ Rendering by Bosch and Slabbers landscape architects for the Delta Programme. The idea is to create 5 to 10% additional storage space in the Haringvliet by moving the flood defenses inland (de Greef 2012).



Control structures

Of the five flood risk system components, two have, in Flowz and in most graphic representations, the shape of *planes*: the embanked and unembanked areas. The outer water elements are surfaces or *lines*. Flood defenses are lines. Finally, there are *point*-shaped elements. In the systems analysis of this thesis, *control structures* are *operable* objects which play, relative to their size, a large role in the system. They are small or enormous civil engineering works to direct flows; either pumping stations or gates, located at the edges of outer water bodies. Control structures can often be operated *instantaneously* by someone pulling a lever or clicking a mouse.

The Dutch national flood risk assessments also distinguish point-shaped objects, called *structures* (kunstwerken). Not all of the 1500 structures inspected in 2011



3.33 In Flowz, a control structure is able to exercise *real-time control*. According to this definition, a dam is not a control structure. The Eastern Scheldt barrier for example, is, in Flowz, a combination of a dam and control structures (62 storm surge barriers and a small ship lock). See figure 3.23 on page 108 for the meaning of the colours.
Design consideration: ideally, the diameter of control structures in Flowz is a function of capacity or gate size (different for each control structure type).

(Inspectie V&W) however, influence flows; tunnels and other *utilitarian crossings* are also structures. The majority are part of the *category a-defenses* (see the Flowz figure 3.9 caption), connecting the outer (wild) water to the (tamed) water in the embanked areas. *Category b* flood defenses connect different parts of the outer water with each other and will in this thesis simply be called *dams* (as from 2017, national law does not distinguish a, b and c defenses anymore). Of the control structures in dams, the Netherlands had 34 in 2013 – see figure 3.23.

The purpose of this type of control structures is to direct flows through the system in directions where they lead to less worsening of hydraulic conditions, where worsening leads to a lesser increase of risk (or other problems), or where it is easier to modify the system.

The same physical control structure can serve different system functions. Outlet gates in a sea dam for example, close to block a storm surge and open to let river water flow through to serve the function of *flood protection*. For *freshwater conveyance*, they close to keep salt water out. They open for *fish passage*, and have no impact on *shipping*: the *dam* obstructs shipping but opening or closing the *outlet* does not affect the shipping system at all.

How can control structures be characterised, and how is determined how they perform? Control structures block, allow or enhance flows in some desired way, prescribed by the object's geometry and its operational scheme. There should be no problem as long as system components in the adjacent *hinterland* meet *their* objectives. When these do not, this could be considered an inadequacy of the control structure, but not necessarily. Control structures are often assessed on whether they do what they are supposed to do when they were designed, regardless of problems in the hinterland. Let's elaborate on this, illustrated by the history and future of four control structure types: outlet sluices, high water (storm surge) barriers, pumping stations and spillways. Table 3.34 shows some characteristics of the main control structures in the tidal rivers.

The Haringvliet dam *outlet sluices* were designed for the maximum capacities of Rhine and Meuse combined, plus additional room for floating ice (which we now hardly have anymore because of the many industrial cooling plants along the Rhine (van de Ven 1996)). With higher sea levels, the discharge through the sluices decreases. Increasing the Haringvliet sluice capacity might someday be a solution to rejected dikes along the Haringvliet (Boorsma 2007; Aerts, Sprong, et al. 2008).

The Volkerak dam *outlet* was not implemented for flood risk related reasons, but to flush lake Volkerak. As a *Room for the River* project, these sluices and possibly the adjacent ship locks will be used to divert river water towards the South-western Delta at times of a North sea storm surge under rare circumstances (claimed 1:1400) (Slootjes 2010; PBR 2013). This measure can reduce Haringvliet water levels with 50 cm under

Control structure	*Characteristics*	*Lower rivers control objects*	*Built /planned*	*Capacity /size*	*Operations*
Outlet	Gate opening (m^2)/ (Maximum) discharge capacity (m^3/s)	Haringvliet	1971	22.000 m^3/s	Opens at 6000 m^3/s at Lobith
		Volkerak	2015*	2000 m^3/s	Opens at N.A.P. + 2.60m
Storm surge barrier	Door surface (m^2)/ Water level difference (m)/ Storage volume created (m^3)	Hollandse IJssel	1958	930 m^2	Closes at N.A.P. + 2,25m
		Maeslant	1997	9240 m^2	Closes at N.A.P. + 2,90/3.00m**
		Hartel	1997	1370 m^2	Closes at N.A.P. + 2,90/3.00m**
River barrier	Door surface (m^2)/ Water level difference (m)	Kromme Nol	2002		Closes at N.A.P. + 3,42m
Spillway	Gate opening (m^2)/ Treshold height/ Control range (m^3/s)	Hondsbroeksche Pleij	2011		
		Pannerden	2013		
		Noordwaard	2015		
Pumping station	(Maximum) pumping capacity	None			

3.34 Four control structure types as used in Flowz, and the major characteristics of the ones located in the tidal rivers and the spillways near the eastern Rijn bifurcations (van de Ven 1996; van Overloop 2009; PBR 2013; Keringhuis 2013).
* The Volkerak dam outlet was built in 1970, but it has not been implemented as part of the flood risk system until *Room for the River*.
** The closure regime is a forecasted water level of 2.90 m in Dordrecht and 3.00 m in Rotterdam.

specific circumstances (as the project website presents), but design water levels with not more than 10 cm (as the project website does not present), because it contributes only to a particular part of the statistical composition of the tidal river design water levels. It has been suggested to add extra outlets in the western part of the dam (Hellegat). A low threshold could reduce design water levels with a couple of decimetres, but would overflow too often. A high threshold does not have enough impact, and moveable parts are too expensive. Perhaps this will at some time be reconsidered.

The next control structure type is a *moveable high water barrier*. The idea behind the Hollandse IJssel-, Maeslant- and Hartel *storm surge* barriers is to create a volume at the (eastern) river side, which can only be filled by the river and not by both the sea and the river. This always works to some extent, but a barrier becomes less feasible when the created storage volume is small. An interesting way to express storm surge barrier *capacity* would be the surge volume it can store. In practice however, the importance of a barrier is expressed by its *size*, like the surface area of the doors and the maximum water level difference between the two sides.

Storm surge barriers are effective but expensive feats of engineering, requiring costly maintenance. The Eastern Scheldt and Europoort barriers had cost 2.9 and 1.2 billion euro (price levels 2010 – Rijcken et al. 2010). In 2011, average yearly maintenance costs were 26 and 19 million euro, respectively (Rijkswaterstaat & Harmsen 2012).

After the Deltacommittee (2008) studies have been done for storm surge barriers behind the existing ones. This might become feasible after about 50 cm sea level rise (Rijcken et al. 2010; de Hoog & Nillesen 2010; Botterhuis et al. 2012; Deltaprogramma Rijnmond-Drechtsteden 2012).

Just east of the tidal rivers we find the Kromme Nol *river barrier*. This structure was built as a response to the high river discharges of 1993 and 1995. It prevents the (semi-) unembanked area to the north from filling up.

In the current Dutch flood risk system, there are no river barriers which direct through-flows. The Deltacommittee (2008) suggested to build four of these in the tidal rivers, to direct river inflow southbound (see figure 3.35). The idea was studied between

3.35 Four optional river barriers in the tidal rivers and a new river, according to the concept Rhine estuary closable but open (Deltacommittee 2008; Rijcken et al. 2010).

2009 and 2011 (Rijcken et al. 2010; Stijnen & Slootjes 2010; de Hoog & Nillesen 2010; Slootjes et al. 2011), but was discarded in the Delta Programme in 2012. The positive effect in the north was judged not worth the negative effect to the east (Deltaprogramma Rijnmond-Drechtsteden 2012).

Of *pumping stations* located in dams, none are found in the tidal river region. Currently these are only found in IJmuiden, between the North Sea and the Noordzee canal

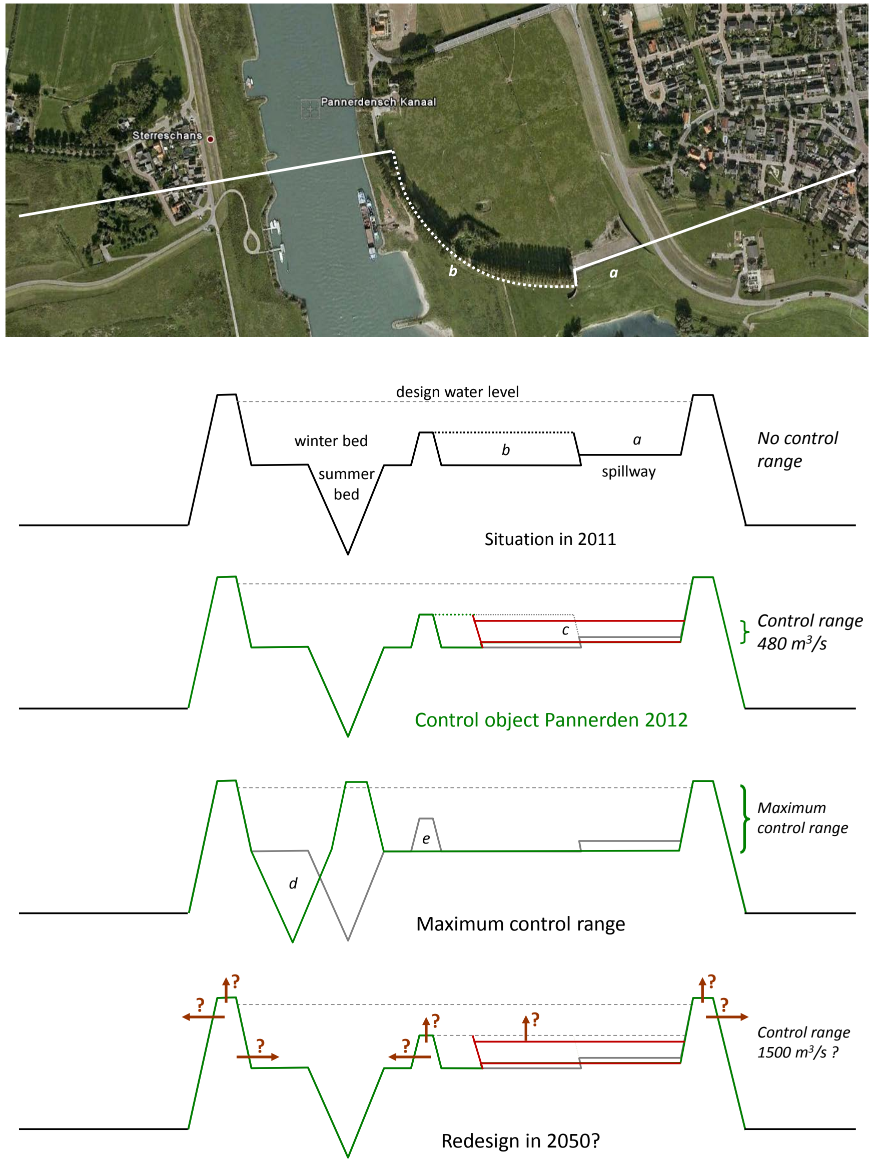
(see Flowz figure 3.23). Strictly speaking these do not discharge high river flows to prevent a river flood; they drain rain falling in the adjacent catchment (about 15% of the Netherlands in size), particularly at times of high outer water levels, when gravity-induced outflow at low tide is not sufficient. Pumping capacity is 260 m^3/s; annual electricity consumption was about 700.000 € in 2005 (van Overloop et al.).

The Delta Programme (2013a) recommends to implement pumping stations in the Afsluitdijk at some time in the 21st century, to control Lake IJssel levels (fed by the IJssel river and some smaller rivers and canals). In the tidal rivers, pumps could be implemented near the Maeslant barrier or the optional barriers in the Nieuwe Maas. This has never been studied so far, but might be a cost-effective alternative to dike upgrades in case of sea level rise. Pumping away 1000 m^3/s would require an investment in pumps of about 150 million euro at current pump prices, the equivalent of about 15 km of dikes to be raised 0.5 meter. The electricity bill is negligible, since the pumps would only very rarely be used.

In this thesis and in Flowz, *spillways* are control structures combined with a flood channel (an *outer water* element) parallel to a river branch just near a river bifurcation, with the purpose to direct part of the river in one or the other branch of the bifurcation. See Flowz figure 3.23 for the two spillways in the eastern Dutch river branches, which are relevant for the tidal rivers, as they influence the discharge distribution between the rivers Waal, Lek and IJssel. The *Pannerden spillway* was created in the 60s to divert water towards the IJssel; the *Hondsbroeksche Pleij spillway*, built in 2011, is foremost a *Room for the River* dike relocation to lower design water levels. To compensate for disruptions to the original discharge distributions by Room for the River projects nearby the bifurcations, adjustable openings were added to both spillways. There are arguments for a different (more optimal) distribution in the future (Volleberg 2012; ten Brinke 2013). See figure 3.36 for possible future modifications to the Pannerden spillway. The control structures are adjusted each summer using the latest model input, and can not be adjusted on-the-spot.

In the tidal rivers, the *depoldering Noordwaard* project could be considered a spillway because it it diverts water away from the Beneden Merwede towards the Nieuwe Merwede. (This was, however, not the main goal of the Noordwaard, which was lowering water levels in the Boven Merwede.) The threshold is not adjustable (and is therefore, strictly speaking, not a control structure according to the systems analysis of this thesis). At a height of N.A.P. + 2,0 m (PBR 2013), it starts overflowing about once a year, without hindering other functions, such as shipping (PBR 2013). This frequency will increase with climate change.

The effect of a spillway depends on the gradient, length, volume and roughness of the flood channel (van Steijn 2012; T. Rijcken 2012a). The size of the adjustable gate opening determines the control range.



3.36 The control range provided by a spillway depends on its length, gradient, bed roughness, gate size and the geometry of the cross-section relative to the main river. This scheme is a schematized cross section of the Pannerden spillway (see Flowz figure 3.23). Before the new control structure of 2012, there was no controllability. *b* is a dike and *a* is the spillway entrance (enforced with concrete against erosion). *c* is the spillway redesign of 2012: a lowering and widening of the entrance threshold and positioning of operationable gates with a total control range of almost 500 m^3/second. In theory, for any river bifurcation the *maximum control range* without measures in the winter bed (the shipping channel) would be obtained by minimizing the cross-section of the winter bed (relocating the winter bed *d*), removing dike *e* and maximizing the control range all the way up to the design water level (Rijcken 2012).

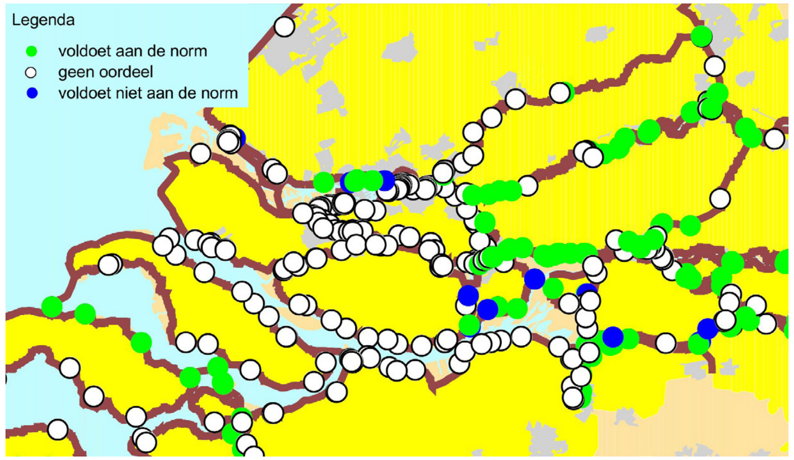
How is the state of a control structure represented? Similar to dikes, a control structure has to be sufficiently *reliable*. Control structures are of course different because of the moveable parts. According to the *TAW Guidelines Hydraulic Structures* (TAW 2003), the probability of too much water flowing over or leaking through the moveable parts has to be lower than the (exceedance frequency) standard. Furthermore, design and assessment have to account for other functions, like ship passage. Water level prediction errors can play a part; when predictions are more accurate, less redundancy is required to compensate for the possibility of too late or too soon gate closure or opening. The planning period for structures is usually 100 years (for dikes it is 50 years).

Similar to the dikes, in the three Dutch national assessments the *semi-probabilistic* approach to reliability was used; the VNK research project uses a *fully probabilistic* method. In the subsequent assessment rounds, 43% of 808 (2001), 29% of 942 (2006) and 52% of 1458 (2011) Dutch *category a*-structures were approved, the rest was not considered, under construction, rejected or postponed (MinV&W 2001; Inspectie V&W 2006a and 2011), but this could have many reasons; also reasons which might not directly threat flood risks. In the VNK studies, the contribution of failing structures to flood risks is generally very low (VNK2 2013), so the impression arises that the national assessments were conservative, and/or assessed more than only flood risk objectives. See table 3.37 and figures 3.38 and 39 for the 2006 and 2011 *category b*-(dams) assessment results in the tidal rivers.

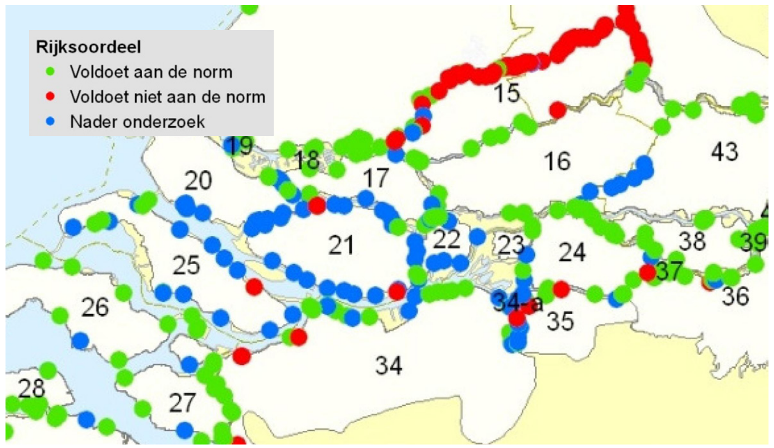
In 2008, the Ministry of Infrastructure and Environment launched a programme on replacement of major Dutch water infrastructure structures (including non-flood risk objects like bridges) - RINK and VONK. VONK revolves around the *remaining lifetime*

Lower rivers control objects	*Assessment 2001*	*Assessment 2006*	*Assessment 2011*	*Probability of non-closing/ opening (2010)*	*Replacement year (VONK)*
Haringvliet dam	No judgement	No judgement	Approved	Very low	2060-'70
Volkerak dam	No judgement	Not existing	Not existing	n.a.	2070-'80
Hollandse IJssel	No judgement	n.a.	Rejected	1:30	2050-'60
Maeslant	Rejected	No judgement	Approved	1:100	2090-2100
Hartel	No judgement	No judgement	Approved	1:100	2090-2100
Kromme Nol	n.a.	No judgement	Rejected	n.a.	2050-'60
Hondsbroek-sche Pleij	n.a.	Not existing	Approved	Not existing	n.a.
Pannerden	n.a.	No judgement	Not considered	Not existing	n.a.
Noordwaard	n.a.	Not existing	Not existing	Not existing	n.a.

3.37 Assessments and VONK remaining lifetime for the control structures in the dams and outer water of the tidal rivers and near the eastern Rijn bifurcations (V&W 2002; Inspectie V&W 2006a; V&W 2007; Inspectie V&W 2011; Welsink 2013).



3.38 Results of the 2006 flood defense structures (category a and b) assessment.



3.39 Results of the 2011 flood defense structures (category a and b) assessment.

until replacement is required. The relationship between VONK and flood risk is not straightforward, because the criteria for replacement do not directly and solely aim at acceptable flood risk. The line between maintenance, upgrades and replacement is blurry. See figure 3.23 for all VONK structures with a relationship to flood risk and their estimated remaining lifetime.

An assessed short lifetime or rejection has different consequences for control structures of *category a* (in dikes) or *b* (in dams or in an outer water axis, like a storm surge barrier). A shortcoming in a category a-structure means unacceptable flood risk and has to be tackled under the Flood Defenses Act (now Water Act). Initially apparent

inadequacies in dams (category b-defenses) however, could appear acceptable when the adjacent *hinterland* category a-defenses are in good shape. The other way around, a rejection in a category a-element (dike or artefact) could be covered by an improvement of a control structure in a related dam.

The Maeslant barrier case illustrates this issue. In an early stage, the failure probability for the barrier was opted a difficult 1:1,000,000 (Raad van de Waterstaat 1987, p.43). According to the TAW guidelines a probability like this is allowed to be higher, when a *hinterland study* shows that failure not necessarily leads to a major flooding (DGW et al. 2007). For the storm surge barrier design competition the design requirement was set to 1:1,000. The sector gate barrier finally built was, unfortunately, during the early 2000s, estimated to have a probability of non-closure of 1:100 (Bijl 2006). The 2006 assessment was a careful *no judgement*. Hinterland studies were conducted (Bijl 2006; Rijkswaterstaat Zuid-Holland 2007) and for the next assessment a failure probability of 1:100 was used to calculate the design water levels for the tidal rivers (V&W 2007; Horvat & Partners 2007). In 2011, logically, the Maeslant barrier was *approved*, and slightly more dikes were rejected than in 2006 (this might, however, also be because of other reasons than higher design water levels) – see also figures 3.13-4, 5 and 6.

To benefit more from the Maeslant barrier, the Delta Programme and others have been studying on structural upgrades, improving operations and refining hydraulic modeling. Structural modifications can reduce the failure (to close) probability towards 1:200. Adding the possibility of *partial failure* (only one arm closing, or the floaters not fully sinking) in the hydraulic models, can reduce design water levels in the hinterland with a little over 0,10 m. Improving prediction can also give a decimetre advantage (Botterhuis et al. 2012; Zhong et al. 2013; Zhong 2014).

This example illustrates that control structures in dams have to be treated in an iterative manner in relation to the adjacent category a-defenses, and are subject to system requirements quite different from the regular dike rings. For most Dutch control structures in dams, requirements and assessments are not crystal clear.

3.2 Flood risk – system objectives

The general flood risk objective

The previous section described five physical components of a flood risk system. With enough information about these components, a model can give hydraulic conditions throughout the system, possibilities or probabilities of flooding of embanked and unembanked floodable areas, and finally total flood risk. The next question is how to relate this to flood risk *objectives*, such that it can justify *modifications* to system components and to operations of control structures.

A way to deal with an undesirable phenomenon with a low probability of occurrence is to make effort to bring the probability to an *acceptable* level, a level where more effort is no longer considered worthwhile. For flooding, undesirable effects are loss of material goods, casualties, environmental damage and societal disruption. The probabilities of these effects may be unacceptable for financial reasons, comparisons to the past or to neighbours, national solidarity, political promises, legal constraints, related emotions or stories (see figures 3.40 a and b), risk averse or risk seeking attitudes, et cetera. The total flood risk consists of all these effects times their respective probabilities. When different acceptable probability levels yield different measures, usually the strictest objective, the one requiring the strongest measures, dominates (Vrijling et al. 2011; Mostert & Doorn 2012).

A flood risk objective can aim *directly* at an acceptable flood risk level, or at a factor which *contributes* to flood risk. For example, along the Dutch coast, the Base Coast Line policy applies (Rijkswaterstaat 2011). This minimum beach line has to be maintained (mostly by sand nourishment), for several reasons, such as providing space for holiday homes, sunbathers and seals, but also to contribute to hinterland flood protection. Maintaining the coast line however does not suffice as the primary flood risk objective because the width of the sandy coast is not the only factor that matters for flood probability and flood risk. Similarly, since 1995, along the rivers, the unofficial flood risk objective has been to lower design water levels, in order to, among other reasons, spare the landscape from further dike heightening (which is not the same as to lower flood risk). Lastly, the current Dutch dike designs also do not *directly* aim at an acceptable flood probability, but at withstanding hydraulic conditions with a certain probability of occurrence.

Acceptable flood risk can be seen as an objective which is singular, or *pure*, while derivatives are often intermingled with other objectives, both *content* and *process* objectives. Computing risks is more laborious than computing flood probability, and computing flood probability is more laborious than computing water levels. Political

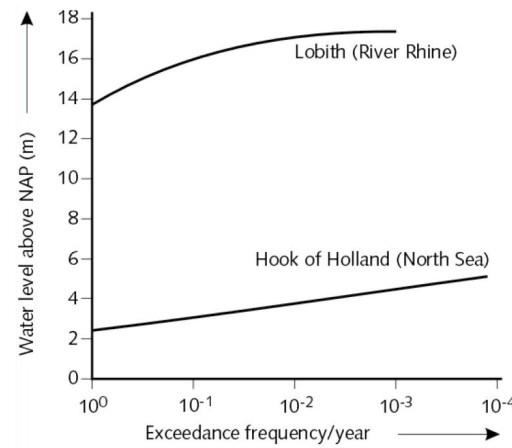
3.40 Emotional traumas and societal disruption also play a part in determining which risk levels are acceptable. In the Dutch motion picture *De Storm* (page 126), the chaos of the 1953 evacuation enables a woman to steal another woman's baby. The book *Zeitoun* describes how an innocent man in New Orleans is put in prison for weeks on end because administrative and legal institutions are disfunctioning after the Katrina flood.

debates about which flood risks are acceptable, have to take place on a high, national level, and therefore have a low frequency, while debates about derivatives can be held on regional levels and with a higher frequency. Focusing on a derivative can create a practical separation of responsibilities between determining which risk is acceptable, and making sure this objective is met, be it indirectly (Lund 2008; Eijgenraam 2008; Rijcken et al. 2010).

This section describes how the flood risk objective at the times of the Delta Works and Delta Act (1953 to 1986) was phrased and operationalised, how this developed towards the national standards in the national Flood Defenses Act of 1996 and how national law changes again in 2017. Two changes are at hand: there are arguments for higher flood safety levels, and to change which flood risk component is standardised. The final subsection deals with unembanked flood risk objectives, which do not revolve around national standards.

Historical flood risk objectives

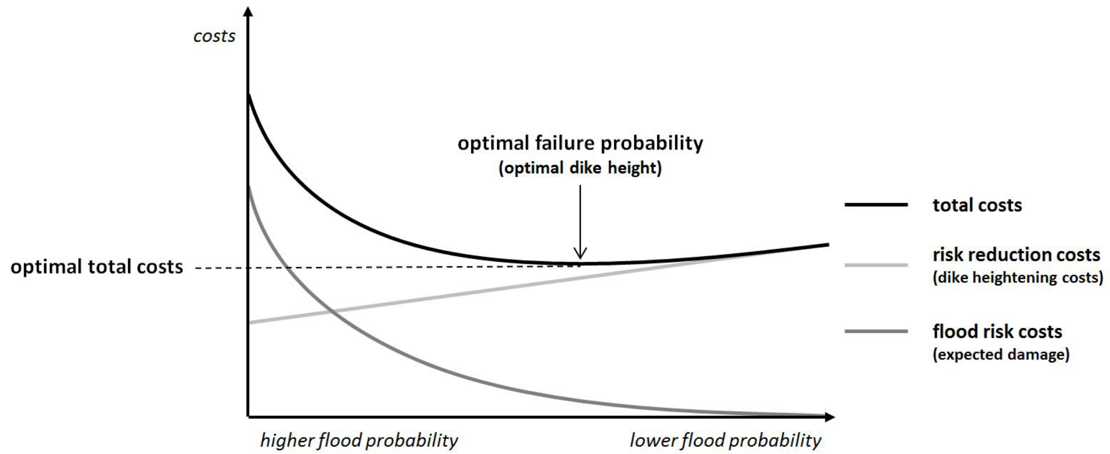
Until about half way the 20th century, the main flood risk objective was to build dikes up to a certain height above the highest adjacent water levels hitherto observed (TAW 1998; Hoekstra & Kok 2008). Records of water levels and levee heights are hard to find and map, so we will never know to what extent this objective has been met during the decades. After the delta floods of 1953, the Dutch constructed the Delta Works, a series of coastal reinforcements and dams, addressing the unofficial but widely acclaimed objective 'this never again'. Wemelsfelder (1939) and a 1940 Storm-Flood Committee had however long before concluded from statistical analysis that no upper limit to high water levels existed and 'never' would not be possible (van Danzig 1956) – see figure 3.41.



3.41 Average frequency of a water level exceeding the level indicated, for the Dutch coast and river. Sea level statistics are different from the river; the river appears to level off, for the see it appears there will always remain a probability of exceeding a certain level (TAW 1998).

The national Deltacommittee of 1953 knew this and had, in accordance to the historical method, chosen a base design water level for the coastal reinforcements of the Holland provinces of about one meter above the 1953 storm level (4,0 + 1,0 meter at Hoek van Holland). This level had, according to Wemelsfelder (1939 and 1960), an exceedance probability of 1:10,000, which was acceptable as to be a chance of 1% in a lifetime.

The committee also assigned flood risk optimization research within the then emerging scientific field of *decision theory*. At the Amsterdam Mathematical Centre, van Dantzig derived a formula for the optimal heightening of a dike ring: $1/\alpha \ln C$, where α is a parameter describing the shape of the exponential water level distribution (a higher α means lower probability for higher water levels) and C holds constants such as the exceedance probability of the current dike height, dike reinforcement costs, the



3.42 The theoretical optimal flood probability (or height/heightening of a dike ring) is reached when the total costs (risk reduction costs added to risk) are minimal. Initial building costs do not contribute to the optimum, but they do determine investment decisions – see figure 3.46. See figure 3.45 for the time dimension. This concept can be applied to single dike sections as well as to determine a standard for an entire dike ring.

discount rate, sea level rise and land subsidence, and the planning period – see figure 3.42. He computed an optimal probability of flooding for Holland of 1:125,000. This corresponded to a design water level of 6,0 meters, one meter above the already legally anchored Deltacommittee level of 5,0 (van Danzig 1960). The solution to the discrepancy was found by stating that the optimal *disaster level* was 1:100,000 (6.0 meters) and the levees would have to be able to withstand an optimal *design water level* of 1:10,000 (5.0 meters) with a probability of 9:10 (at this time the *length effect*, which increases the total flood probability when a dike ring is longer, was not taken into consideration) (van Danzig 1960; Kok 2006a). See table 3.43.

			Probability
Delta Committee 1954	'Base level'	5.0 meter	1:10,000
Van Dantzig 1960	Optimal 'disaster level'	6.0 meter	1:125,000
	Optimal 'levee design level'*	5.1 meter	1:10,000

3.43 The Base Level decision of 1954 was connected to van Dantzig's optimal flood probability by stating that there ought to be roughly a probability of 9:10 that the levee can withstand the storm at the base level, so that the optimal flood probability is 1:100,000, almost 8:125,000 (van Danzig 1960; Kok 2006a).

The 9:10 probability became unofficial policy, the 1:10,000 exceedance probability became the starting point for the official flood protection standards in the Delta Act and its successors, the Flood Defenses Act and the Water Act. The large North- and South Holland dike rings and some smaller urbanized coastal dike rings were given this 1:10,000 standard. The other coastal dike rings in the North and Southwest, and the Flevoland land reclamations got a standard of 1:4000. The upper river dike rings were given a standard of 1:3000 (proposed by the director of Delft Hydraulics in the face of some journalists on an airplane stairway, so the story goes – Hoogland 2013). See the dike rings of the Rijn-Maas estuary in 1986 in figure 3.13-1.

Did the first Deltacommittee determine the flood risk objective in the Netherlands until now? Not entirely. First, quite some dike ring standards have been modified. Following the Becht state commission recommendations, the upper river dike standards were brought down to 1:1,250 in the 80s. The construction of the Europoort barrier reduced the prevalence of the sea over the rivers, which was argued to reduce potential flood damage (TAW/TNO 1989). In the 90s therefore the standards of five eastern tidal river dike rings were altered, from 1:4,000 to 1:2,000 (Maij-Weggen 1990).

Furthermore, for dike design, the requirement not to fail under the hydraulic design conditions (with an unofficial 9:10 probability), needs an interpretation. This comes down to tacit expertise and to technical design manuals for different kinds of dikes and hydraulic loads. Expertise and manuals were subject to advancing geotechnical, hydraulic and probabilistic insights and incorporated more failure mechanisms and added more robustness: higher safety factors, additional partial safety factors and lower critical overflow discharges (TAW 1985; TAW 1989; DGW et al. 2007; Vrijling et al. 2007).

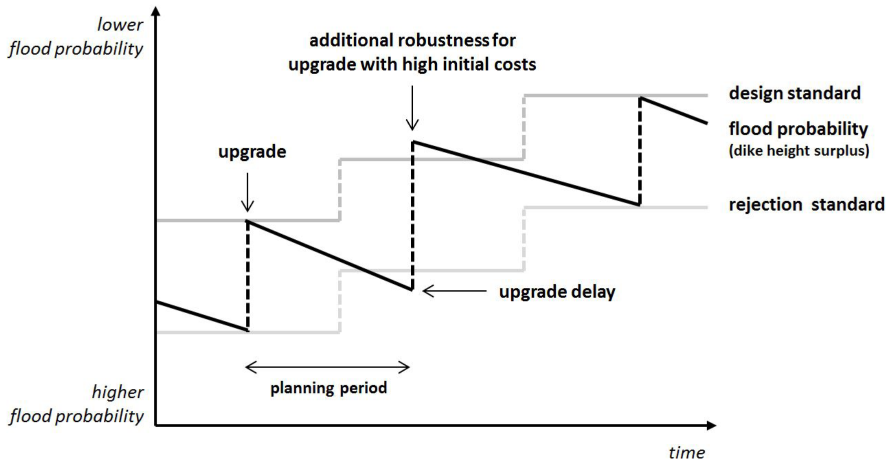
In 1996 the *Flood Defenses Act* standardised the approach to all dike rings (WodW 1996; TAW 1998). The new law prescribed national levee assessments, which were conducted in 2001, 2006 and 2011. For each assessment not only the design guidelines, also the hydraulic and statistical background of the design water levels was updated. After 1996, standards of the then existing dike rings have not changed anymore (but they could have, under article 3.5).

In the assessments, the three essential elements of the system requirements (standards, hydraulic design conditions and design guidelines), projected on the physical state of the system, result in three types of judgements (the system state): *approved* (green), *rejected* (red) or *undecided* (blue) (in 2001, there was a fourth category: *under construction*). Of course some rejected dikes are in worse shape than others. Since 2001, the information gathered during the assessment is passed on to and elaborated upon in the High Water Protection Programme (HWBP), which establishes a dike reinforcement *priority list*.

Future flood risk objectives (1)

From 2010 to 2016, the Delta Programme has been preparing major changes to the national flood risk legislation. Modifications were forecasted in the Flood Defenses Act of 1996; the theoretical foundations originate further back.

One of the first critiques to the method of the Flood Defenses Act was given by Vrijling and van Beurden (1990), who showed that van Dantzig's optimal flood probability changes when sea level rises faster or slower than was forecasted in 1956. They suggested a step-by step increase (or decrease) of required dike height or flood probability (see figure 3.45), keeping pace with changes of not only sea level rise but



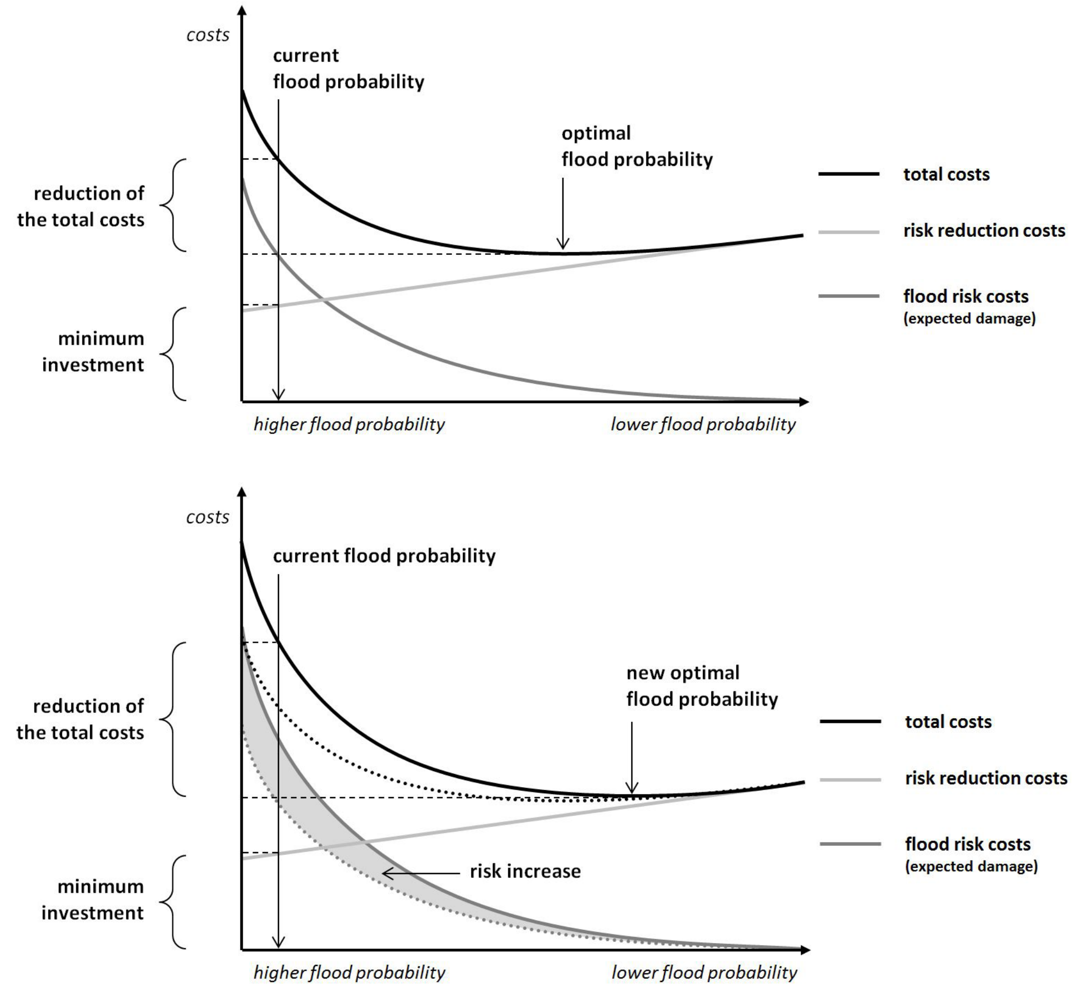
3.45 Periodic system upgrades like dike heightening or river widening (the vertical dashed lines) follow from settling of the embankments, climate change, new insight in failure mechanisms (the diagonal black lines) and more stringent rejection- and design levels (the horizontal grey lines). In practice, when initial costs of a project are high, the official rejection level is often surpassed, and when the project is finally built, often more safety is obtained in order to lengthen the lifespan (the planning period) – this was for example the case with the Europoort barrier (after Vrijling 2008).

also settlement of the embankments, river bed roughness, the discharge distribution at the river bifurcations and other uncertain geotechnical, hydraulic, statistical and economic factors, unfolding in time (Vrijling et al. 2007). High initial upgrade costs (costs independent of the upgrade level) suggest fewer steps and thus a larger step size (planning period).

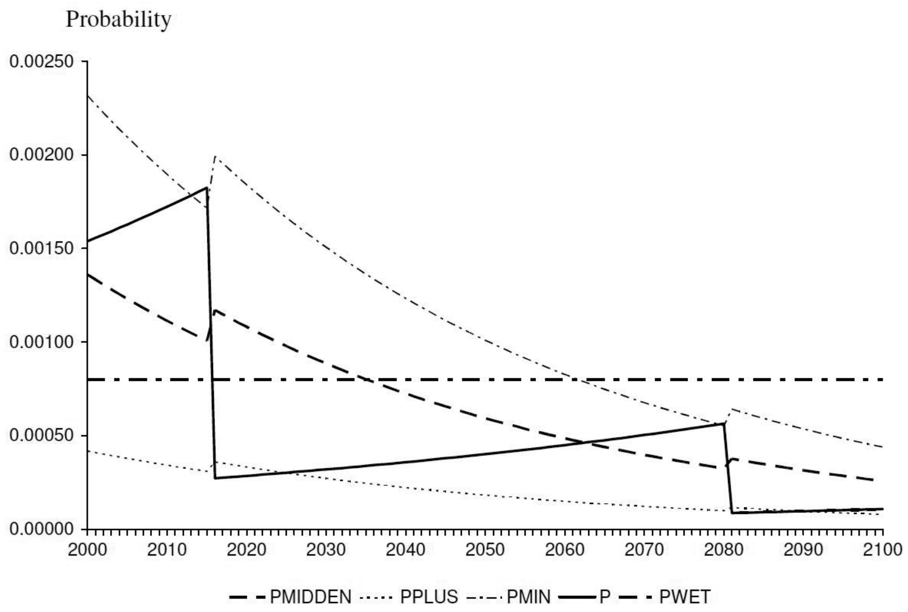
Eijgenraam (2006, 2009, et cetera) elaborated on the economic objections to van Dantzig's infinite planning horizon. He also advocated a step-by-step approach, to adapt to increase of investment costs, different developments of relative prices, new insights in how flood damage depends on dike height and inundation depths, and most of all on

increasing vulnerability by economic growth behind the dikes.

Piecemeal changes of the flood risk profile require a *rejection level* and a *design level*. If optimizing investment costs and material risk were all that mattered, upgrades were conducted each time when the initial investment costs are lower than the actual decline in flood risk (rejection level), up to a level where the sum of the total investment costs and the resulting risk (including future developments like sea level rise, economic growth and levee settlement) is minimal (design level) – see figure 3.46. The rejection



3.46 If there were no initial (or fixed) costs, investments would be effective every time risk increases. Because of the initial costs, investments may not be made even though the current flood probability is below the optimum (above). (Below:) when risk increases, system upgrades become worthwhile when the total costs reduction exceeds the risk reduction investment costs (after Vrijling et al. 2007).



3.47 Flood probability of the Betuwe dike ring 43, between Waal and Lek. The actual physical flood probability (P) zig-zags between the rejection (PMIN) and the design (PPLUS) levels (PWET is the Flood Defenses Act exceedance frequency standard). The discontinuity around 2015 in the P-line is created by the project Room for the River. The discontinuities in the other lines emerge when it is assumed in the model that the same flood probability reduction becomes more expensive in time (Eijgenraam 2007, p.6)

level can be made stricter (pulled forward in time) when severe project delays are expected; the design level can be made stricter (pushed further in time) for projects with high expected initial costs for future upgrades.

Using rejection and design levels, the actual flood risk oscillates around the optimum risk with an amplitude related to the initial costs: for some time the actual risk remains lower than the optimum, but at some moment the actual risk will exceed the optimum. Since the initial costs of a measure are not included in the optimum, no new measure will be implemented until the initial costs remain more than the risk reduction of the measure. When this finally occurs, the next measure is taken and the cycle starts again. The approach can be applied to dike sections, to clusters of sections (like dike rings) or the entire system.

This procedure relies on benefit-cost analyses alone and standards are not required. In practice, more matters than money and we deal not only with *optimal* economic risks but with *acceptable* risks and related acceptable flood probabilities. As mentioned earlier, a legal standard is a practical way to aggregate all arguments into a derivative of a collection of acceptable risks. When standards are used and updated every few decades, the design and rejection lines become saw tooth lines – see figures 3.45 and 3.47.

Still, how to operationalize the design and rejection levels, is not straightforward. “This approach may be too complicated for practical application since both the determination of the design level and the determination of the assessment level needs elaborate probabilistic analysis for each location.” (Vrijling et al. 2007, p.9)

The bandwidth between assessment and design levels under the 1996 Flood Defenses Act, is small. The standards in the act are the rejection levels. The design levels are in the design manuals. For coastal reinforcements, these subscribe to incorporate the expected rising sea level; river dikes have a robustness addition and an addition for expected settlement. These additional factors are however generally incomplete and have no strong theoretical basis. Most of all, the current procedures do not anticipate on economic changes and do not prescribe the moment *when* to upgrade once a dike stretch has been rejected (Kok 2008). In practice, design targets are often determined *ad hoc* (“we won’t regret a couple of decimetres more”) and synergy with other objectives is sought.

The small bandwidth resonates the spirit of the Flood Defenses Act, which was to consolidate the flood probabilities obtained by the Delta Works in the coastal zone and the tidal rivers, and to reduce flood probabilities along the upper rivers and Lake IJssel up to a level that would then only have to be maintained. Later upgrades were foreseen in articles 3.5 (economic growth), 4 (changes in hydraulic conditions) and 5 (changes in technology).

In the mid 2000s, the comprehensive research project Water Safety 21st Century (WV21) was launched to determine, for the period until 2050, optimal dike reinforcements and optimal moments to invest, and translate these into new assessment standards (Kind 2011 and 2013). All negative effects, including casualties, environmental damage, societal disruption and risk aversion, were monetarised; separate reports were issued on individual and group risk (Beckers & de Bruijn 2011). The WV21 level is not an optimal rejection or design level, but the ‘mediate probability’, a level in between the assessment level and the design level, a concept developed by Eijgenraam (2009) to reject before the optimum flood risk level is reached, because upgrades tend to be postponed and take long to build.

Neither the rejection standards in the Flood Defenses Act nor the WV21 rejection mediate standards use the initial cost rejection criterion; it can thus be expected that problematic (urbanised) rejected flood defenses may stay rejected for some time.

The outcomes for the dike rings in the Rijn-Maas system and others are presented in table 3.48. Dike ring south-Holland has an optimal “WV21” flood probability of 1:10,000, more than ten times higher than van Dantzig’s initial optimal flood probability of 1:125,000 (table 3.43). This can be explained by van Dantzig’s assumption of complete loss of all goods; more thorough flood modeling reveals that less than half of Holland would really flood under a particular breach scenario.

Type	Exceedance probability			Flood probability					
	Legal standards			Estimated	Supposed	Future standards			
Approach	Delta Committee '56			VNK2	WV21[1]	WV21[1]	Kok 2.0	DP15	
	1970	1985	1996	2015	2011	2011	2013	2017	
Zuid Holland	10,000	10,000	10,000	16,000	10,000	10,000	100,000	100,000	14-1
					10,000	2000	100,000	10,000	14-2
					10,000	10,000	10,000	10,000	14-3
Lopiker- en Krimpenerwaard	4000	1250	n.a.	170	n.a.	n.a.	n.a.	30,000	15-1
		4000	2000		1000	10,000	10,000	10,000	15-2
Alblasserwaard /Vijfheerenlanden	4000	4000	2000	>100	1000	4000	10,000	100,000	16-1
								30,000	16 2-4
IJsselmonde	10,000	10,000	4000	990	2000	4000	10,000	3,000	17 1-2
								100,000	17-3
Rozenburg	10,000	10,000	10,000	7000	5000	500	n.a.	100,000	19
Dordrecht	4000	4000	2000	710	1000	2000	10,000	3,000	22-1
								10,000	22-2
Noordwaard	4000	3000	2000	n.a.	n.a.	n.a.	n.a.	3,000	23
Land van Maas en Waal	3000	1250	1250	370	500	4000	10,000	30,000	41-1
					500		1,000	10,000	41-2
Gelderse Vallei	3000	1250	1250	180	1250	80,000	10,000	100,000	45-1
					500	500	500	300	45-2

3.48 Historical, current and suggested future standards for a number of Dutch dike rings, as well as the estimated flooding probabilities in the VNK project (Vergouwe 2015). The numbers are the return periods, the reciprocates of the probabilities.
Ad 1: second reference.

Future flood risk objectives (2)

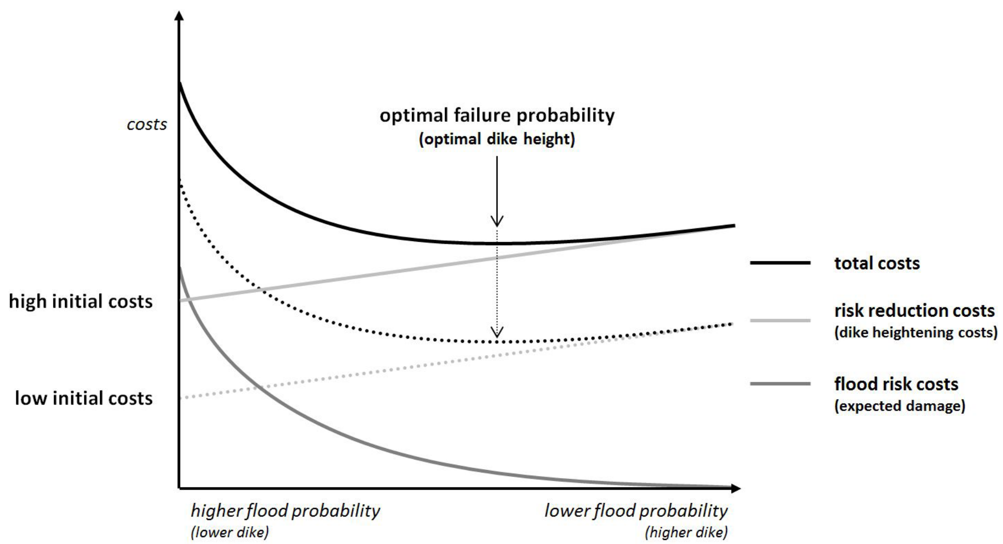
A second objection to the flood risk objective prevailing until 2017 (the Flood Defenses Act/Water Act) was not about the height of the standards and the planning periods but about the which component of the flood risk objective is standardised.

Ideally, as introduced in the beginning of this section, the ultimate fundamental objectives themselves would be standardised: acceptable flood damage, casualty and disruption risks. In civil engineering it is however common, for practical reasons, to standardise a shared *probability component* of these risks instead of the risks themselves. The Flood Defenses Act standardises a component of this component: the exceedance frequency of the hydraulic loads. Practical it may be, for decision-makers and citizens, the meaning of the current exceedance probability standards is hard to grasp: what does it mean that, for example, 5 of 38 dike ring sections do not meet particular design requirements under conditions with an exceedance frequency of 1:4,000? More concrete to a minister, mayor or journalist would be the total *flood probability* of a dike ring or the probability of a breach in a dike defense line, like a coast or river stretch.

The advantages of flood- over exceedance frequency probability standards have been expressed since the mid 80s (Vrijling 1990, TAW 1998). The transition was anticipated on in the Flood Defenses Act itself (article 3.2) and announced in the 4th Water Management Plan of 1998 (V&W 1998, p.68). In theory, this can be compared to replacing the guilder by the euro, but it is not that simple. A first question is whether new flood probability standards should 1) match the *current* state of the system at a certain moment, 2) the state it is *supposed* to be in, according to the Flood Defenses Act or 3) new (optimal) standards (Maaskant et al. 2007). The goal is a smooth transition between the two approaches; no unexpected high investments and no public outrage over the consequences of the new standards.

Two decades ago, the knowledge about the current state was 'a patchwork with holes' (DWW 1999). Between 2001 and 2015, the VNK project has mapped the failure probabilities of the current Dutch dike sections and dike rings with the latest probabilistic methods (Vergouwe 2015) – see some selected results in table 3.48. In what state is the system supposed to be in according to the current standards, but measured in terms of flood probabilities? This question appears a hard one. The Deltacommittee and van Dantzig's original intention was that dikes designed for 1:10.000 conditions would result in a *lower* flood probability of 1:125,000. Kok (2006b) accordingly estimated factors of 1-10 *lower* flood- than exceedance probabilities if dikes would be upgraded according to the flood defenses act. In 2009, after new insights in the *length effect* (see page 91), Kok and Vrouwenvelder gave factors of 3 times *lower* to 9,1 *higher* flood- than exceedance probabilities (Kok & Vrouwenvelder 2009). They suggested the project Water Safety 21st Century to use a range from 1-5 *higher*, depending on the dike ring – see table 3.48 for some examples. When the Expert Network Flood Safety (ENW) was asked to translate the Water Safety 21st Century's optimal flood probabilities back to exceedance frequencies, factors 6-10 *lower* exceedance- than flood probabilities were estimated (ENW 2011) (and not 1-5). The converting factors vary because the analyses use different lengths of dike trajectories, different failure mechanisms (the way *piping* is included matters a lot), different wave overtopping values, et cetera.

When the reference situations are expressed in the same unit as possible new standards, new standards can be estimated in a cost-benefit analysis. In the WV21 economical optimization it appeared that different reference situations require different investments, but result in the same optimal flood probabilities – see figure 3.49.



3.49 For the economically optimal flood standards matter the damage function and the slope of the flood probability reduction (dike upgrade) costs function, which both do not depend on the initial situation (Kind 2011, p.29).

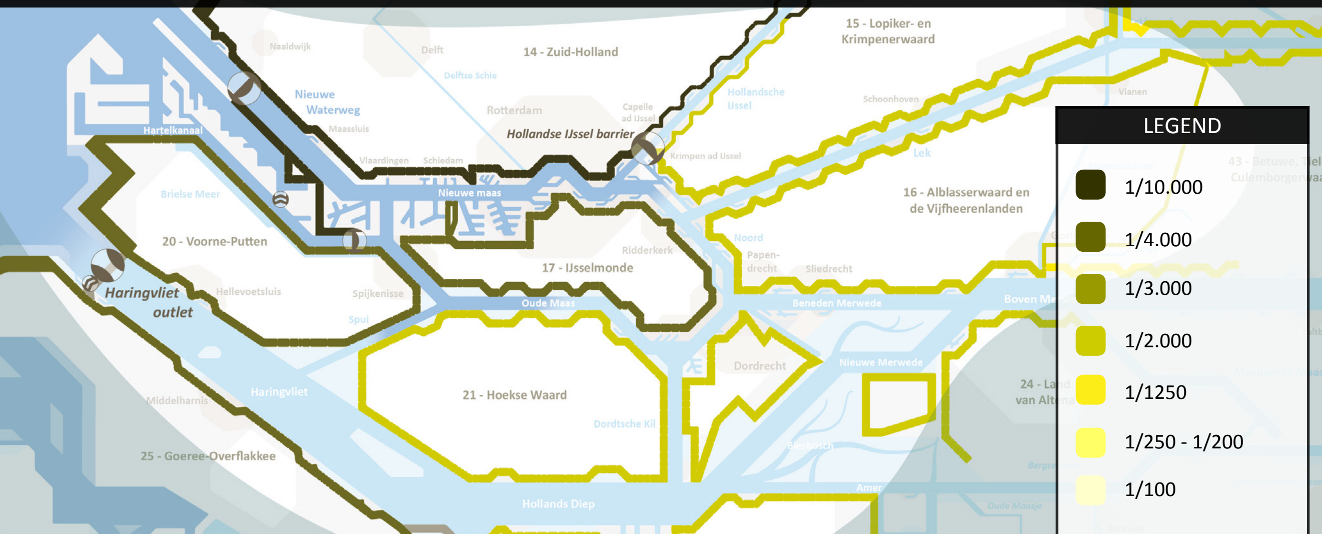
The reference- and future probabilities and other numbers collected in optimization analyses, like costs, fatality risks and uncertainty, have been input for a political debate about objectives and investments (and may remain input for new debates, when knowledge becomes more detailed). These debates also treat additional factors, such as initial investments, risk aversion, group risk, national solidarity, historical risks, other water system objectives, other measures than dike reinforcements, et cetera. Kok's *Flood Protection 2.0* for example, was a suggestion for alternative standards to Water Safety 21st Century (Biesboer 2013). A couple of years later, the Delta Programme offically launched the new Dutch flood risk standards, which originated in the WV21 research and had been debated over in regional committees, for example on additional group risk factors (Deltaprogramma Veiligheid 2014) – see some of these standards in table 3.48.

Part of the new Delta Programme standards are *acceptable casualty risks*. The concept 'base (minimal) flood safety' relates flood casualty risks to other *external risks* (Deltaprogramma 2013b). For industrial disasters, the Dutch External Safety Decree of 2004 prescribes an annual probability of 1:1,000,000 (10^{-6}) that an unprotected, permanently present individual dies due to an accident at a hazardous site: *(Local) Individual Risk* (Jongejan 2008). This objective is easy to understand and to put in a broader context, but for flood protection, the particular level of 10^{-6} would require tremendous effort. The Delta Programme suggested a level of 10^{-5} instead, which is currently reached in more than 90% of the Netherlands (Beckers & de Bruijn 2011). The parts of the Netherlands which do not meet this base safety standard require adjacent dike upgrades such that a flood probability is reached which corresponds to the base flood risk, and this level may dominate the flood probability standard resulting from the economic risk analysis.

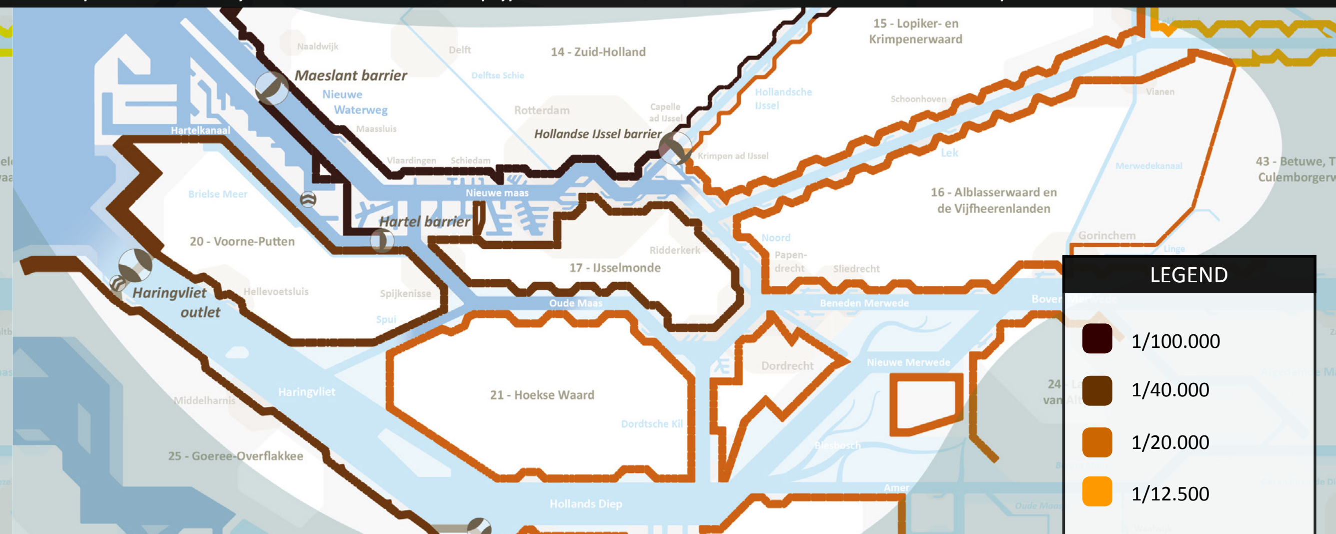
3.50 Flowz shows how system objectives and system requirements change through time. Before 1953, the objective was to build the dikes a meter higher than the water level hitherto observed. Between 1953 and 2017, it was withstand the design water levels. As of 2017, requirements are failure probabilities for dike segments.
The maps on the next pages continue the historical systems analysis on pages 92-96):
5a) National Dutch exceedance frequency standards of 1996-2016 (Inspectie V&W 2011).
5b) Dutch national flood defense (semi-probabilistic) assessment 2011 (Inspectie V&W 2011).
6a) VNK levee (probabilistic) failure probabilities (VNK 2015).
6b) National Dutch exceedance frequency standards divided by 10 to obtain an acceptable failure probability per dike stretch (map modified for this thesis).
6c) VNK results compared to the acceptable failure probabilities of map 6b (map modified for this thesis).
7a) New 2015 Delta Programme flood probability standards (Deltaprogramma 2015).
7b) VNK results against the new Delta Programme flood probability standards (map modified for this thesis).
8) Dike height shortage in 2050 due to settling soil, climate change and new standards (Dekker 2014, p.71).
Design considerations: the color range for the system requirements maps should be different from red and green of the system assessment maps. When a fundamentally different standard is used, a different color range is applied. Different shades represent different standards; a user can retrieve the exact standard by a mouseover.

In the Dutch transition between the two different standards, two key maps were generated in 2015: the VNK failure probabilities of dike stretches (6a) and the Delta Programme map with the new standards for dike segments (map 7a). A map showing the resulting dikes to be modified is expected in 2017. This map will not reveal the reason behind the required modification: the new probabilistic assessment method, or the new standards. The maps on these pages can do this. The VNK failure probabilities per dike stretch (map 6a) are first compared to the current exceedance frequency standards divided by 10 (maps 6b and 6c). Second, map 6c is compared to the VNK results against the new flood probability standards (map 7b) by dividing by 2, 5 or 10 to translate flood probability standards for dike segments towards dike stretches (Kuijper et. al. 2010). Unexpectedly, it appears that overall the old standards would have resulted in *more* upgrades than the new standards. The local differences are the results of the different methods. Map 8 shows that in the future, settling of soil and climate change are expected to lead to additional problems.

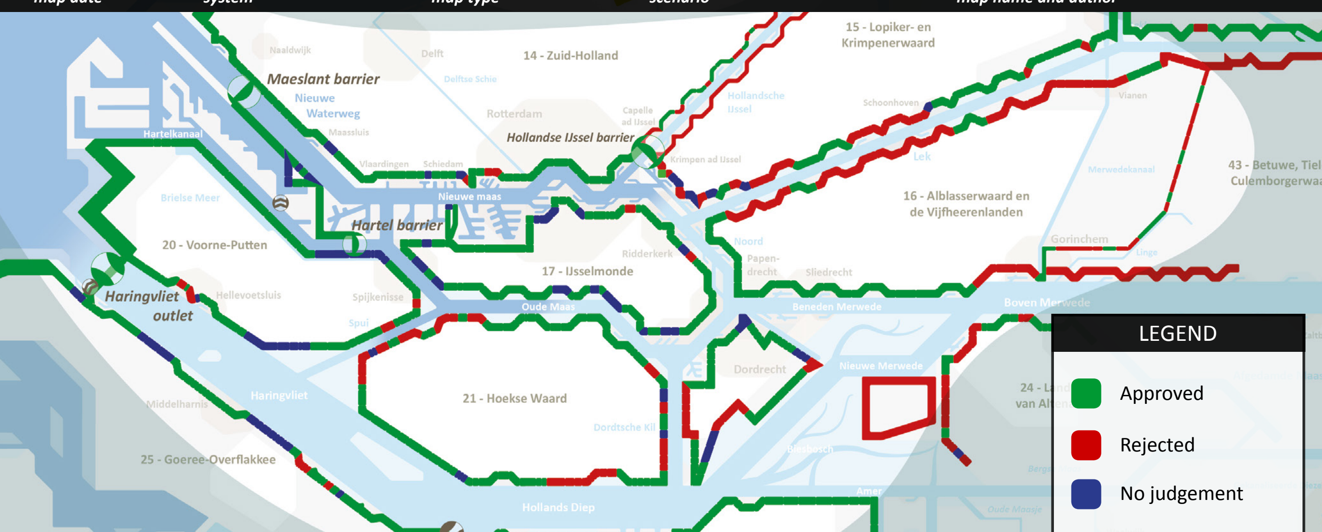
2015 *map date* | Flood risk *system* | System property *map type* | n.a. *scenario* | 6a) Levee failure probabilities (VNK 2015) *map name and author*



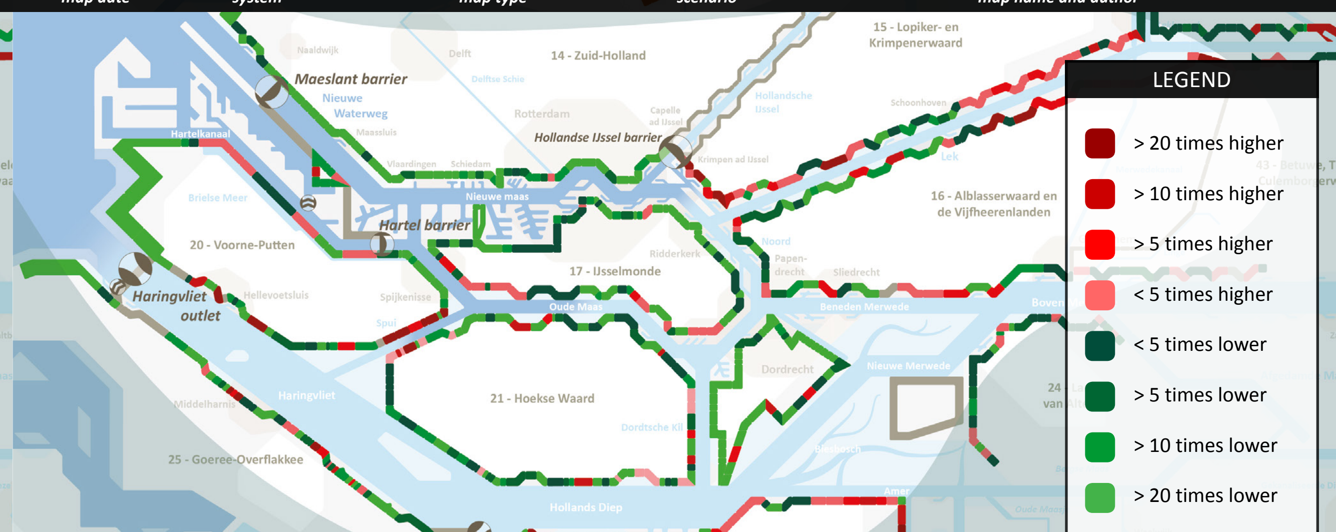
1996 *map date* | Flood risk *system* | System requirements *map type* | n.a. *scenario* | 5a) Dutch national exceedance frequency stan... *map name and author*



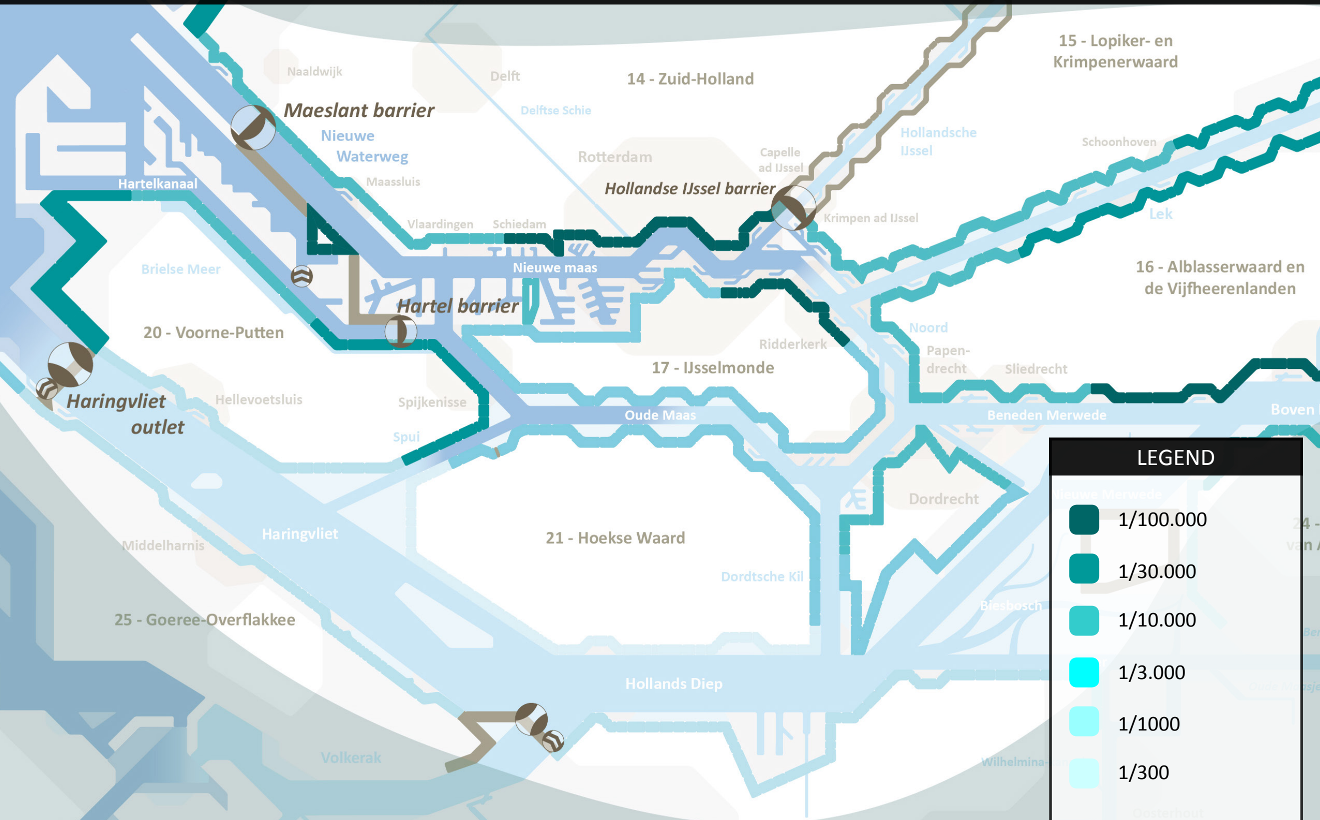
2015 *map date* | Flood risk *system* | System requirements *map type* | n.a. *scenario* | 6b) National Dutch standards *divided by 10* *map name and author*



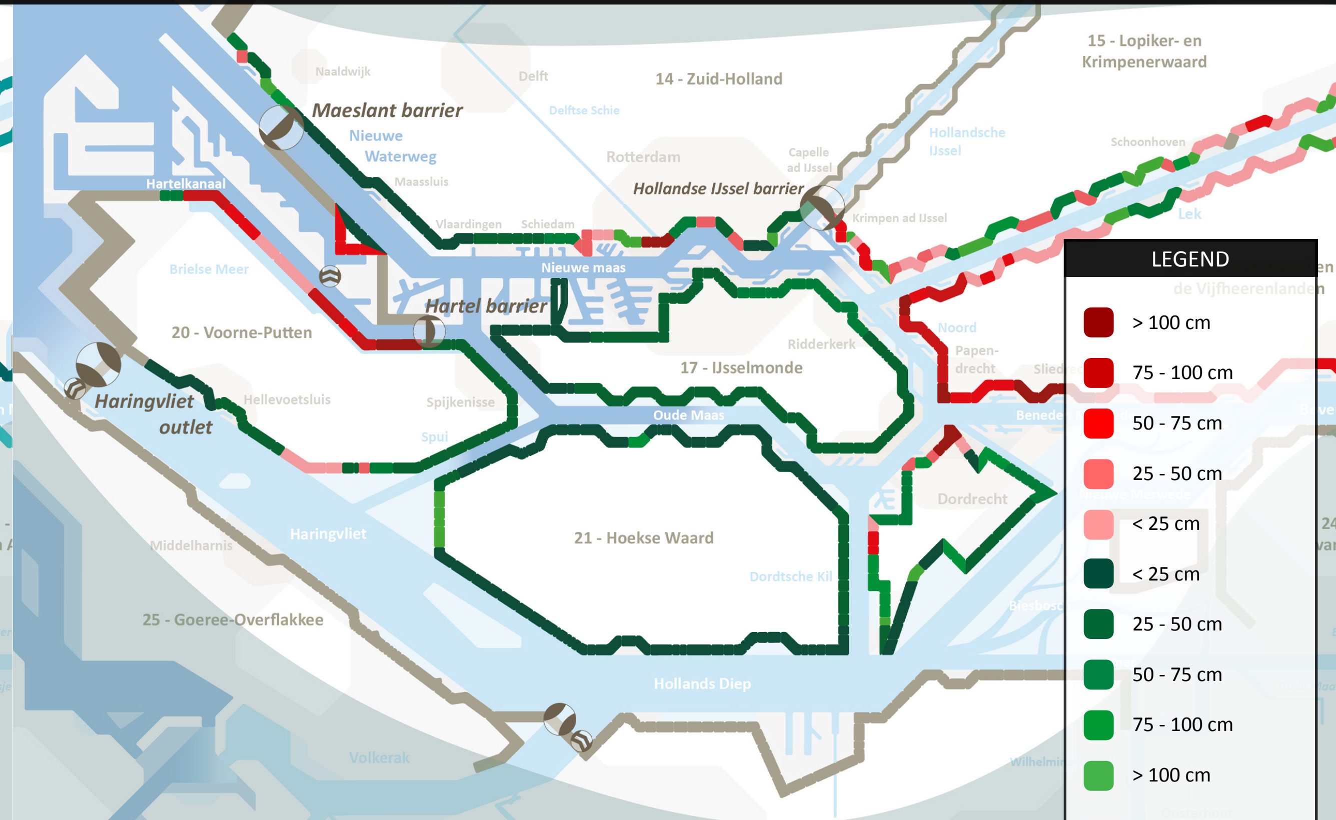
2011 *map date* | Flood risk *system* | System assessment *map type* | n.a. *scenario* | 5b) 3d Dutch national flood defense assessme... *map name and author*



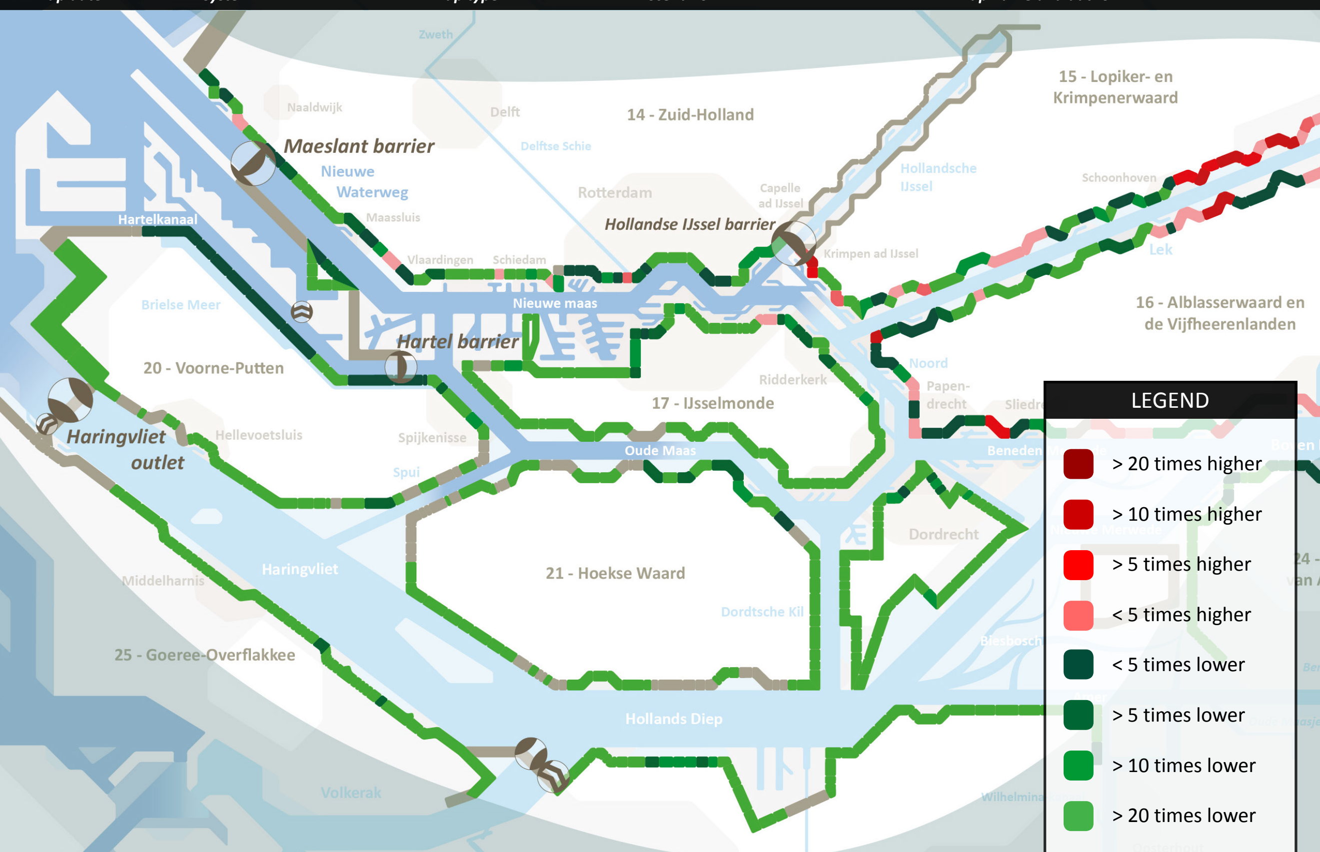
2015 *map date* | Flood risk *system* | System assessment *map type* | n.a. *scenario* | 6c) VNK 2015 failure probabilities against m... *map name and author*



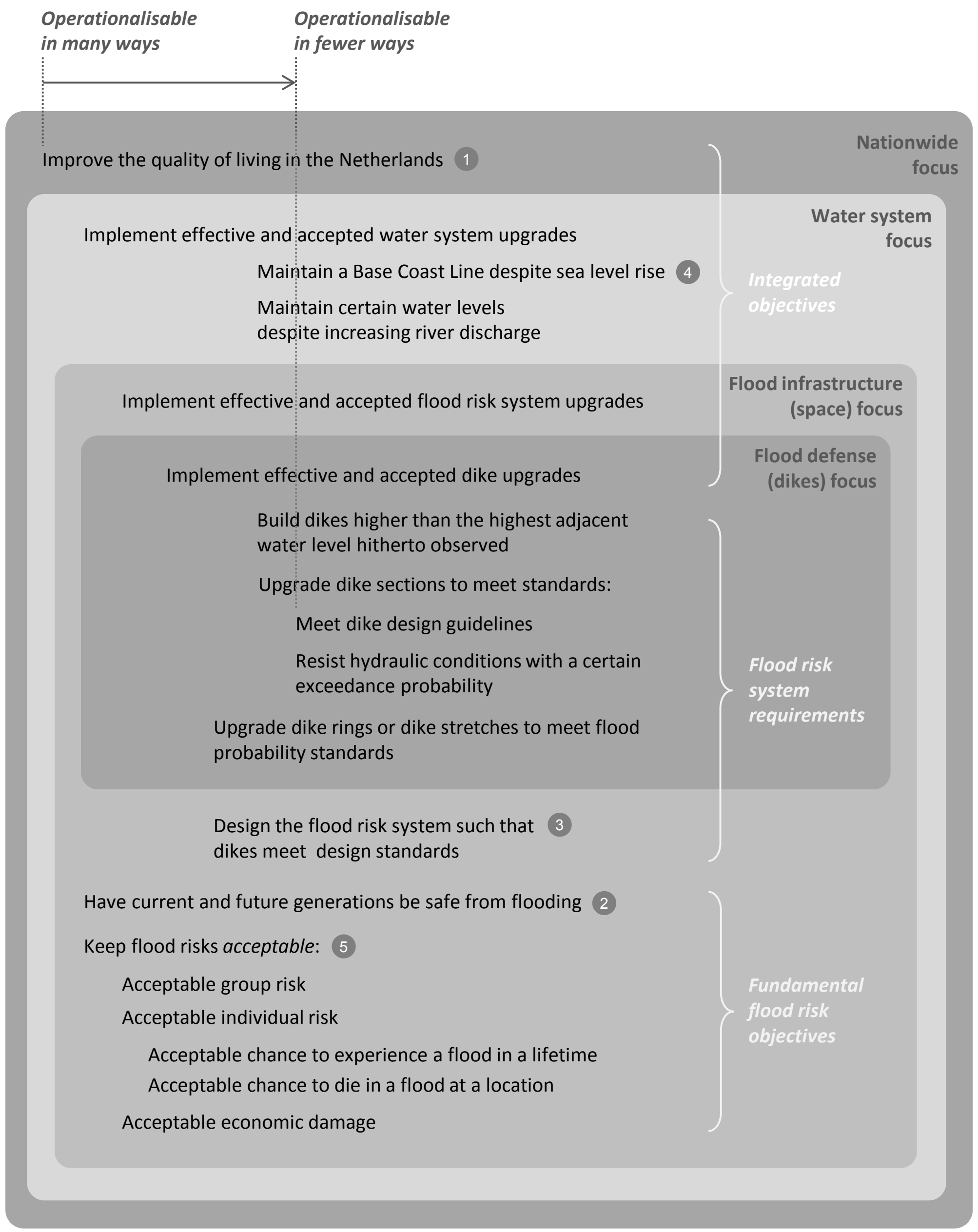
2017 *map date* | Flood risk *system* | System requirements *map type* | n.a. *scenario* | 7a) New Delta Programme flood probability sta... *map name and author*



2050 *map date* | Flood risk *system* | System assessment *map type* | KNMI G+ *scenario* | 8) Dike height shortage/surplus after climate c... *map name and author*



2017 *map date* | Flood risk *system* | System assessment *map type* | n.a. *scenario* | 7b) VNK results against the new standards ... *map name and author*



Nesting flood risk objectives

Figure 3.51 organises all flood risk system objectives as they have been expressed over the last decades in important documents by *nesting* them (after Keeney 1996) in three directions: the *types of measures* (from dike upgrades only to any public policy measure), the *scope of the objectives* (from reducing flood risk only to enhancing the liveability of the Netherlands) and the *operationability* (from clear instructions for getting to work, to requiring many additional steps before knowing what to do).

To illustrate how much objectives diverge, the Deltacommittee report of 2008 opened with "the fundamental question (…) 'How can we ensure that future generations will continue to find our country an attractive place in which to live and work, to invest and take their leisure?'" (Deltacommittee 2008) (bullet 1 in figure 3.51). The Delta Programme's objective for 2012 was to "make sure current and future generations in the Netherlands, are safe from flooding (bullet 2), and secured for fresh water supply" (Deltaprogramma 2011b). The Flood Defenses Act gives "general rules to ensure protection by flood defenses from flooding by high outer water levels" (WodW 1996) (bullet 3).

Proper nesting avoids misunderstanding and frustration caused by legitimizing measures by objectives on a different level. For example, the *Sand Engine* is not a measure to safeguard the Netherlands from flooding (bullet 2), but to maintain the Base Coast Line (bullet 4) on the long run, which, among other objectives, on some locations, helps to achieve acceptable flood risk (bullet 5). Instead of striving for *natural flood defenses* as an objective in itself (Deltaprogramma 2013a), we might better formulate certain nature or landscape quality objectives, and meet them with and/or without synergy with flood risk reduction. This is not possible in the current Delta Fund: measures are *only* funded when they reduce flood risk or improve water quality. It is correct to state that nature is necessary and flood protection is necessary, but incorrect that new nature is necessary to provide flood protection – see also the next chapter, on flood risk-related objectives.

◀ 3.51 Flood risk- and flood risk-related objectives as found in influential policy documents, collected throughout this thesis. The objectives are grouped according to: 1) their focus (from the entire nation to dikes only), 2) whether they are integrated objectives (also addressing flood risk-related objectives), fundamental flood risk objectives, or flood risk system requirements and 3) to how clear they are to operationalise.
See the body text above for the explanation of the bullets 1-5.

Unembanked flood risk objectives

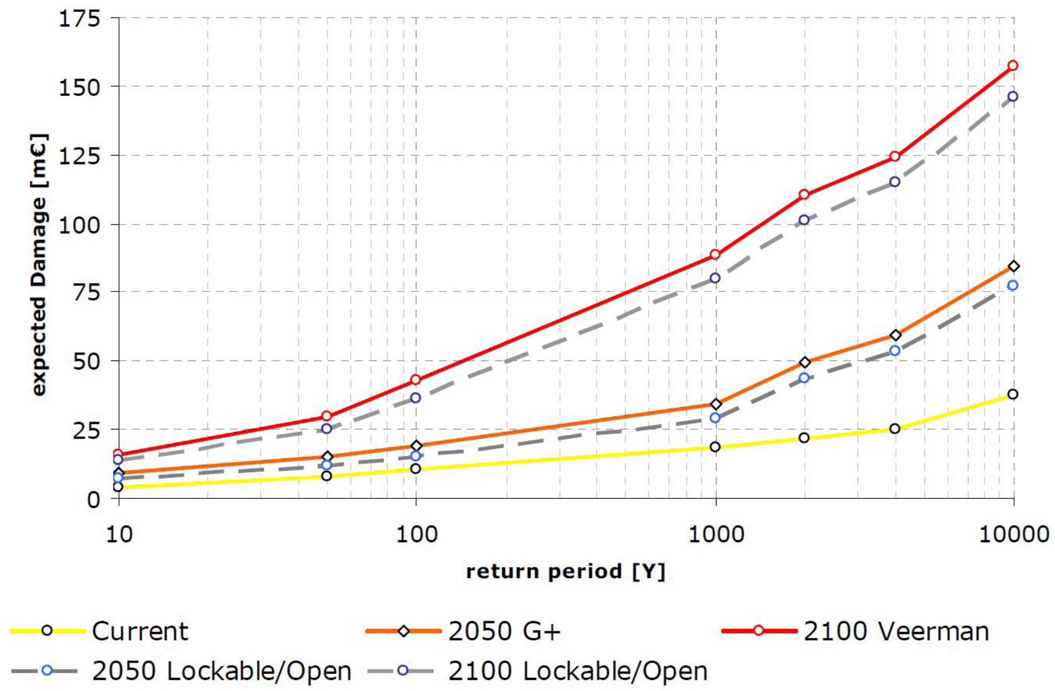
Similar to the system of embankments, unembanked risk management has long been conducted by intuition and trial-and-error. In a typical upper river floodplain we find the road a meter above the cattle field, the courtyard two meters higher than the road, but one or two meters below the crest of the primary winter dike. A group of houses is soon surrounded by a small summer dike with a height in between the winter dike and the courtyards. Along the tidal rivers, where we no longer speak of floodplains, the elevation of unembanked areas is high for industry and housing, low for farmland and nature. For the upper and lower rivers, most unembanked elevations reflect risk assessments by local land users, based on past flood levels and the nearby primary dike.

With the systematic systems analyses which started under the Delta Works, more information about the unembanked areas became available and governments started to be concerned about unembanked development. Along the tidal rivers, industry and other land users were recommended to build above certain levels, which have increased throughout the decades. At the end of the 20th century, the building level for the center of Rotterdam was set to 3,60 m above sea level, since 2013 it is 3,90 m (a recommendation for developers and does not apply to already developed sites – van Veelen & Richter 2010). The design water level for the flood defenses in Rotterdam is 3,60 m, which means more or less that, without sea level rise, according to the hydraulic models, the newly developed plots can only be flooded by waves.

The result of this historical development is a range of land elevation heights between 2 meters (parts of historical Dordrecht and Noordereiland in Rotterdam), and 5 meters (the Maasvlakte ports in the west). These reflect different hydraulic circumstances, changes in hydraulic modeling, and/or changing objectives and higher flood consequences.

Until 2016 there have not been any national legal standards established for unembanked development. Yet, on a national systems level, relating the data behind unembanked flood maps (such as figure 3.19 on page 103) to a reference or requirement helps to locate strong and weak parts of the system, which is interesting for the interactions between unembanked flood risk and other water system objectives.

Similar to the embanked areas, levels for acceptable material damage, fatality risks and societal disruption can be compared to actual risks. Acceptable *local individual risk* can be expected to be equal to the level of 10^{-5} (Deltaprogramma 2013a) in the embanked areas (for high value land use). In the Netherlands however, unembanked individual risk levels are low because of the small inundation depths and high evacuation fractions, as mentioned in section 3.2. For this same reason, *group risks* in the unembanked areas are near zero. Methods to determine *societal disruption*, like flooded schools, roads and subway stations, are currently under development. Huizinga et. al. (2011; 2013) define

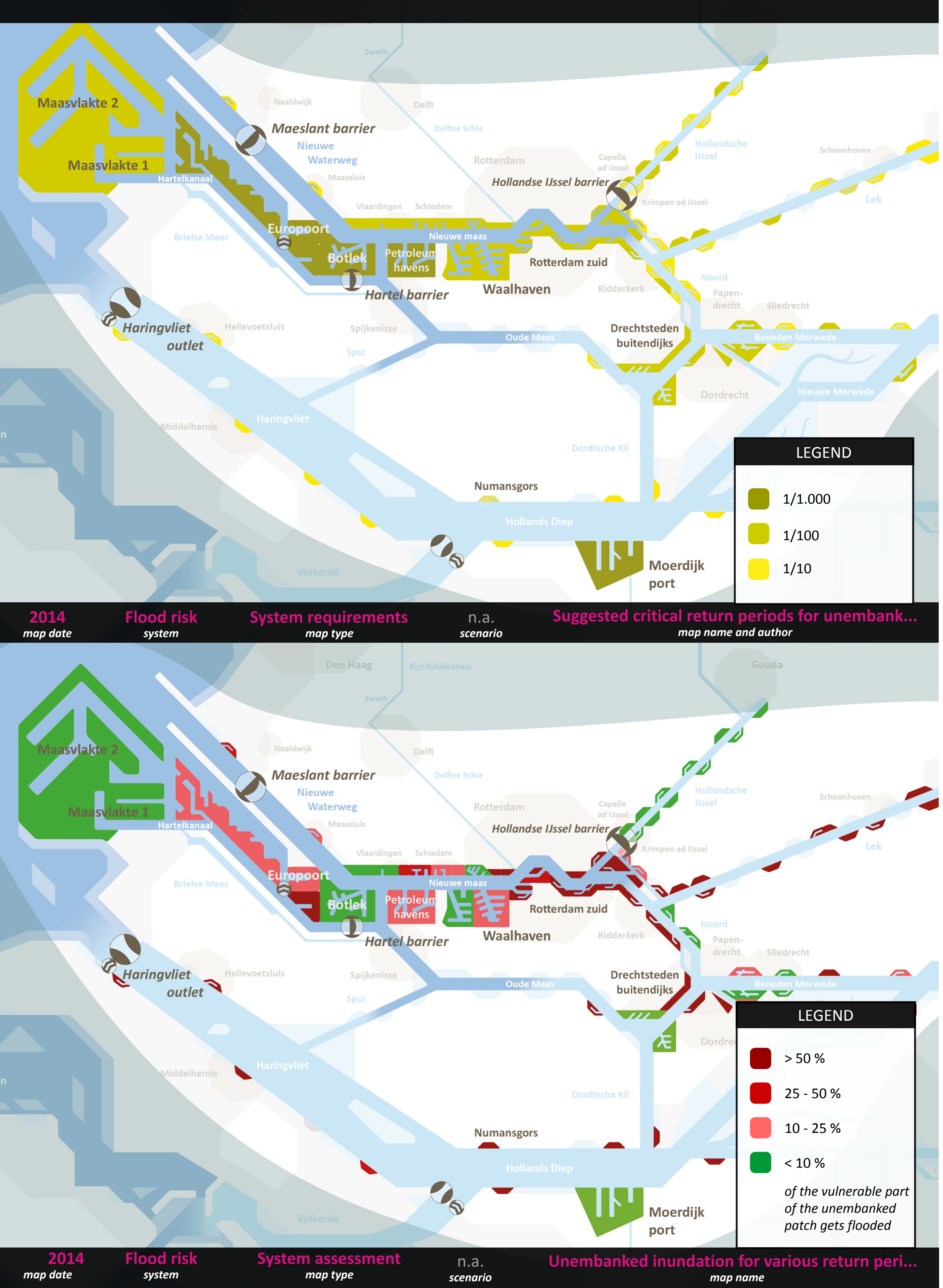


3.52 Expected aggregate unembanked economic direct damages in the tidal rivers, for a range of return periods and scenarios (Veerbeek et al. 2010).

this as the expected number of physically, socially or emotionally flood-affected people, per hectare per year. Reference (acceptable) levels ('orientation values') are based on a comparison to similar calamities.

Of the unembanked economical flood risks (like in graph 3.52), the bulk of the total risk is in the lower return periods; the probability of subsequent higher flood levels declines faster than the according damage grows. There is an optimum to the extent to which to implement measures to reduce the risk (flood-proofing, quays, et cetera – see figure 3.22), but this analysis has never been made for the tidal rivers as a whole or a couple of sub-regions. On the local level however, municipalities and developers are making such cost-benefit considerations out of their responsibility for new development, supported by provincial (most of the urbanised parts of the tidal rivers are located in the province of South Holland) zoning policies and interactive tools (PZH 2013). This can then be applied parallel with the individual risk and societal disruption analyses to see which approach requires the strongest measures. The resolution and legal status of these outcomes is related to what's at stake, the model uncertainties, the administrative costs of enforcing the reference and to who bears the costs and the benefits.

Note that the chosen system status reference (requirement, standard, orientation value, et cetera) depends on the objective of the analysis. The province of South Holland's main objective is to provide detailed information and clear legal boundary conditions for local development. Flowz provides insight in the national system as a whole, looking for policy frameworks and large-scale measures (like in figure 3.35) related to multiple objectives, of which unembanked flood risk is one.



◀ 3.53 Return periods for unembanked areas can be used as *system requirements*; they vary throughout the region depending on general expected damages and costs of modifications, here 1:10 for small ports and industry, 1:100 for dwellings and offices and 1:1.000 for industrial areas susceptible to fierce pollution when inundated. These return periods give a *system assessment* map with different degrees of inundation (data based on de Nijs & Claessens 2010 and RWS 2016) - see also the maps on page 105).

3.3 Conclusion

Discussion

The previous sections did not treat all imaginable flood risk system modifications, nor all conceivable phenomena affecting the system. The most important omissions are treated in this subsection.

The system modification *emergency storage* has not been treated here but has been debated in the '90s and 2000s. In 2002, the Dutch Luteijn state commission (Commissie Noodoverloopgebieden) recommended to implement this measure to achieve 20 to 70 cm lowering of high water levels (Luteijn 2002), but the advice was discarded. For a river like the Rhine, emergency storage areas have to be vast and even then, scientific studies show that uncertainty in operations limits the effect of emergency storage on design water levels (TAW 2002; Stijnen 2007). TAW (2002) estimated a negative cost-benefit ratio for the measures proposed by the commission and local resistance was intense, as described by Roth et al. (2006). In this thesis' systems analysis, an area designated for emergency storage, would be a separate embanked or unembanked area (depending on the probability of flooding), possibly combined with a control structure.

Measures in the *third and second layer* of *Multi-Level Safety* have only briefly been addressed in the embanked areas subsection. Evacuation planning and disaster management (layer 3), are a rather separate field of expertise, studied by Kolen (2013) and others. The largest project was the Task Force Flood Management of 2007 (190 million euro - (V&W 2009)); the *evacuation fractions* provide the link to the flood risk system as described in this thesis. Effects and feasibility of flood-proof zoning (layer 2) are studied by spatial planners and public management analysts (like Aerts et al. 2008; Pieterse et al. 2009). 'Water-resistant' building techniques (also layer 2) resemble measures described in the *un*embanked areas subsections, but in many Dutch *em*banked areas these would have to resist much deeper inundation levels. Layer 2-measures can reduce individual risk, group risk and damage; their relation to the entire system and to alternative measures depends on whether risks are directly standardized, evaluated in custom cost-benefit analyses, or are part of a system revolving around requirements (standards) for the flood defense system. In the latter case, local (2nd and 3d layer) measures only affect the other system components' performance when they work so well that a lower flood defense standard becomes possible. According to a cigar-box calculation this will only very rarely be the case: risk reduction by prevention rather than consequence reduction is, for the dike rings of the Netherlands, 10,000 to 20 times more effective, mostly for reasons of geometry (Ties Rijcken 2012).

A large and relevant scientific domain not addressed in this thesis is *morphology* (sedimentation and erosion). Morphological phenomena influence outer water conditions and the stability of flood defenses and control structures, but very slowly (occurring over decades). In this thesis's systems analysis framework it is assumed that morphology is incorporated in the hydraulic models described on page 111.

Modeling the system components and their relationships involves different kinds of uncertainty. Van Gelder (2000) and Schweckendiek (2014) distinguish inherent uncertainty (in space and time), model uncertainty and statistical uncertainty. The research project FloodSite (Samuels & Gouldby 2009) adds to uncertainty in science and technology (knowledge uncertainty, natural variability, decision uncertainty, accuracy, precision, errors) uncertainty in the *social sciences*: ignorance, indeterminacy, institutional uncertainty, legal uncertainty, proprietary uncertainty, scientific uncertainty and situational uncertainty. Walker (2011) considers four uncertainty levels, from 'we know it all', 'we know the probabilities', 'from probabilities to plausibilities' to 'the future is unknowable'. Thissen and Kwakkel distinguish recognized uncertainty, shallow uncertainty, medium uncertainty, deep uncertainty and recognized ignorance (Kwakkel et al. 2011). Some argue that uncertainty is rather an *organization al* than a *scientific* problem (Mathijssen et al. 2006; De Vries 2010).

Most scientific and technical policy documents on flood risk aspects recognize and specify uncertainty, like Klijn et al. (2011), (Kind 2011), (Mens et al. 2011), Moel & Aerts (2010; 2012), VNK (2013) and so on. The essence of the role of the many kinds of uncertainties in the flood risk system is that they need to be addressed only in as far as they are expected to have an impact on the particular decision problem at hand. According tot Kok (2014), the main quantitative uncertainties for the Dutch flood defense assessments surround the river discharge, the discharge distribution, tolerated dike overtopping flows and the duration of North Sea storms.

Finally, a note on the term most basic to this thesis and this chapter: flooding. In this thesis, a *flood* means that an attempt to avoid flooding (on a macro- or micro level) has failed and this causes harm. Yet, in many current foreign and Dutch contexts, a flood is not necessarily considered harmful. The European Floods Directive for example defines floods as "the temporary covering by water of land not normally covered by water" (EU 2007). The reputable British FloodSite team considered floods harmful by definition, but changed this after 2007, following the European Directive. Many Dutch and foreign policy documents since the turn of the century, like the publications *Language of Risk* (Samuels & Gouldby 2009), and *Floods, from Defense to Management* (van Alphen et al. 2005), emphasise the distinction between *flood probabilities* and *flood consequences* and support the idea that floods can be managed in such a way that little or no harm is done

– an idea for which floods should indeed be defined as possibly *un*harmful. In other words: whether floods do harm or not, is up to good management. Inspiring for sure, but in the Netherlands unrealistic and impossible as a general idea.

Defining floods as *unharmful* and the emphasis on flood *consequences* support at least two shifts.

First, the policy domain of flood risk reduction becomes entangled with management of wetlands, floodplains and coasts (where harmless floods occur daily). These are obviously important domains, but often hardly related to floods which *do* cause damage. Entangling the two broadens the scope, but also introduces confusion. Flood management budgets for example are often allocated out of public concern for safety, but the European Directive definition supports spending it on risk reduction ánd wetland restoration, since these are both considered flood management.

Second, from emphasising the *fundamental distinction* between flood probabilities and flood consequences, it often follows that it is also *fundamentally logical* to implement measures to address both. This logic safeguards flood consequence-reducing measures (like disaster management) from a fair comparison in efficiency with flood probability-reducing measures (like dike reinforcements).

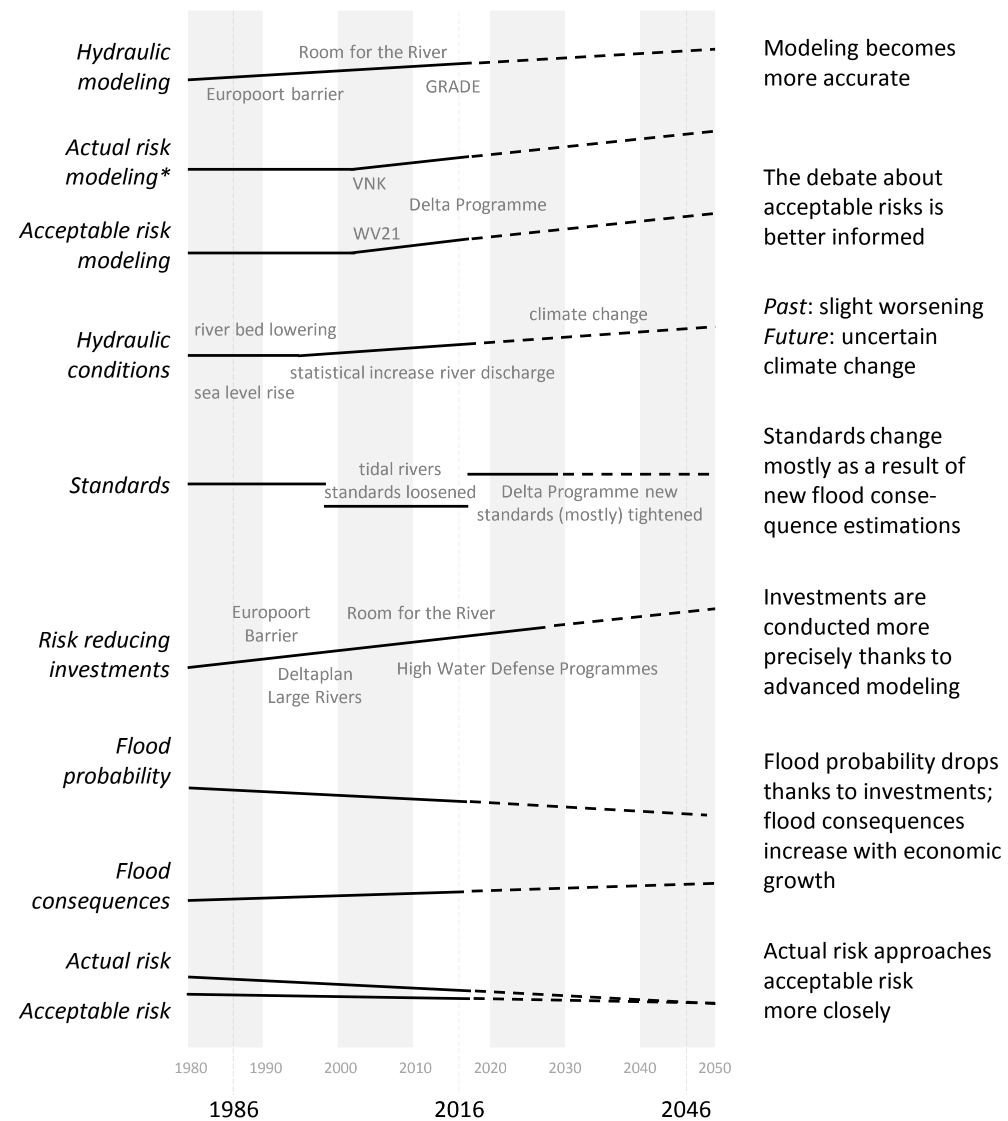
This thesis avoids the new perspective on floods and uses the general common definition: floods are harmful. Flood-risk related water system objectives like wetland management are systematically separated from flood risk objectives, to provide a clear view on what is wanted and how this can be achieved.

The above discussion explains choices in terminology made in this chapter, and contributes to the historical trends in thinking about flood risk which will be elaborated in chapters 4, 5 and 6.

Main trend 1: continuous investments in flood protection, strongly motivated by improved risk and acceptable risk analyses

Which common theme runs through this chapter? The main trends to be identified in this thesis (see page 18) have to do with content (what and why), not process (by whom and how). A trend should be a continuous shift taking a couple of decades, and has to be manifested physically (projects), in modeling (system descriptions, equations), in publications (reasonings, evaluations, values), and possibly in legislation.

A reasoning towards an answer to this question is represented in figure 3.54. The first



3.54 The development of essential flood risk system aspects since 1986 and projected onto 2046. On the vertical axis the aspect improves or increases in the upward direction. *Actual risk modeling includes geotechnical failure probability and flood consequence modeling.

three lines represent general improvements of the models of the relevant parameters. Along with the Europoort Barrier, the Flood Defenses Act and Room for the River, *hydraulic models* of the outer water system, including the role of control structures located in the outer water system, have advanced. *Modeling actual risk and acceptable risk* had been basic before the end of the 90s, when the VNK project and related scientific endeavours started to improve dike failure probability and flood consequence modeling (see pages 84-88). The WV21 (pages 137-139) project and its successor under the Delta Programme used the same new techniques to model how investments and flood consequences interact, in order to calculate *optimal economic risks* and inform the political debate on *acceptable individual and acceptable group risks*.

Improved hydraulic modeling does not influence *hydraulic conditions*, of course, but sheds more light on them. In the river area, hydraulic loads have slowly reduced as a result of the eroding of the river bed after the river normalisation of the 19th and 20th centuries (between 1 and 2 meters since 1900). Along the coast and in the tidal rivers however, sea level rise (22 cm since 1900) increased loads. The high river water levels of the 90s are sometimes interpreted as a result of climate change and further sea level rise keeps being predicted.

The way *flood protection standards* have changed is unambiguous: apart from for the small dike rings in Limburg and around the controlled lakes near Flevoland, standards for Dutch dike rings have not changed since 1986, except for nine major dike rings in the southwestern sea-river transition area. For about 1 million inhabitants, flood protection standards were loosened with a factor of 1,5 to 2,5. This was justified by a flood consequence reduction by the Europoort (Maeslant) barrier: this project reduced the relative sea influence over the river influence in the sea-river transition area, which is attractive as long as damage to agriculture (for which salt sea water flooding is more damaging than fresh river water flooding) dominates damage to urban areas (for which deep river water flooding is more damaging than shallower sea water flooding). In 2017, the standards are no longer expressed as exceedance frequencies but as flood probabilities. They will also be modified according to the latest risk modeling and acceptable risk insights, like the new base safety level for individual risk; overall resulting in increasing safety levels. Interestingly, many of the dike rings in the sea-river transition area, where standards were loosened in the 90s, now again face tightening. This stems in the shift of the focal point in flood consequence thinking from predominant damage to agriculture to predominant damage to urban areas, which has been made explicit by the improved flood consequence models.

Improved hydraulic and risk modeling, changing hydraulic conditions and changing standards lead to *risk reducing investments* (building projects). Table 3.55 lists the main

				Main driving forces	
Project	*From*	*To*	*Size (G€)*	*Policy framework*	*Additional force*
Closure dam	1927	1932			Floods 1916
Delta Works North		1969		Delta Works	Floods 1953
Delta Works South	1954	1986		Delta Works	Floods 1953
Remaining dike upgrades Delta Works	1986	2005	0,4	Delta Works	Floods 1953
Europoort barrier	1991	1997	1,4	Delta Works	Unembanked risk
Delta Plan large rivers	1995	2000	2,3	River Normalization/ Flood Defenses Act	Near-floods 1993-'95
Maas works	1995	2015	0,6	Flood Defenses Act/ Space for Water	Floods 1993-'95
Ramspol barrier	1995	2002	0,2	Flood Defenses Act	Near-floods 1993-'95
Sand nourishments sandy coast	1995	2015	0,8	Dynamic Coastal Maintenance	Available technology
River projects before Room for the River	1998	2006	1,0	Space for Water	Environmentalism
Kromme Nol barrier	1996	2001	0,1	Flood Defenses Act	Near-floods 1993-'95
Weak Links coast	2003	2015	0,9	Flood Defenses Act	Sea storms 1998-2003
Revetments Scheldts	2004	2007	1,1	Flood Defenses Act	Delta Works
Room for the River – spatial projects	2007	2015	1,7	Flood Defenses Act/ Space for Water	Near-floods 1993-'95
Room for the River – dike enforcements	2007	2015	0,6	Flood Defenses Act	Near-floods 1993-'95
Task Force Management Floodings	2007	2009	0,2	Multi-Level Safety	Hurricane Katrina
1st & 2nd High Water Defense Programmes	2007	2020	2,6	Flood Defenses Act	Hurricane Katrina?
Closure dam upgrades	2012	2016	0,8	Flood Defenses Act	
Sand engine	2012	2013	0,1	Dynamic Coastal Maintenance	Building with Nature
3d High Water Defense Programme	2014	2028	3,7	Flood Defenses Act	
Delta Programme – flood protection	2014	2028	2,4	Flood Defenses Act/ Dynamic Coastal Maint.	Climate change
Delta Programme – not yet allocated	2014	2028	0,9	Multi-Level Safety?	
Total	1986	2028	21,8		

3.55 Large national flood risk investments (prices converted to 2014 at 3%). Each project is connected to one or two of six essential 'policy frameworks': ways of thinking which have dominated policy-making and projects (see also chapter 6, page 328). Sources: (DGR 1995; V&W 1998; DG Water 2007; HWBP 2011; Keringhuis 2013; Deltaprogramma 2014; MIRT 2014) investments since 1986, most of which are described throughout this thesis. Two-third of all projects can be covered by the four project names depicted in table 3.55: Europoort barrier, Deltaplan Large Rivers, Room for the River and the High Water Defence Programmes. In general, it can be concluded that with the exception of the years between 1987 and 1992, major investments have continuously been made and will keep being made in the decades to come.

According to the approximation in table 3.56, investments have, roughly, reduced

	Coasts (500 km)	*Upper rivers (1300 km)*	*Tidal rivers (800 km)*	*Large lakes (500 km)*	***Total[1] (3100 km)***
Contribution to total risk increase[2]	10%	60%	25%	5%	**100%**
Probability increase (hydraulic conditions)[3]	1,4	4,0	1,9	1,0	**3,1**
Probability decrease (investments)[4]	2,4	18	15	3,2	**15**
Consequence increase[5]	1,6	1,4	1,5	1,3	**1,4**
Flood risk decrease	**1,3**	**3,6**	**6,3**	**1,7**	**3,3**

3.56 Estimates of flood probability, consequences and risk changes between 1986 and 2017.
1: Not included are flood defenses around the Amsterdam-Rijnkanaal, some of the compartment dikes and the dike rings in southern Limburg.
2: The percentages are based on flood consequences and estimated changes of the four regions. The percentages serve to add the regional risk values up to the total values.
3: The values are derived using water level increase and average water level decimation heights (from Kind 2011) for each region.
4: The values are derived using protection level increase expressed in dike height and average dike height decimation heights (from Kind 2011) for each region.
5: Consequences based on regionally varying economic and population growth.

overall *flood probability* in the Netherlands with a factor of 15. Flood probability *increased* about a factor of 3,1 due to increasing hydraulic conditions, resulting in a total factor of 4,8 in flood probability reduction.

Flood consequences have increased as a result of a growing population (from 14.5 million in 1986 to almost 17 million in 2016) and economy (from € 400 billion in 1986 to € 677 billion in 2015 – per year on average 2,8% before 2008 and -0,2% after) (CBS StatLine 2016). There has been a net migration to the flood prone areas, but economic and population growth only partially lead to growing flood consequences. Therefore, the growth of flood consequences is roughly a factor of 1,4.

The *actual risk* decrease since 1986, the result of increasing consequences and decreasing probability, is thus a factor of 3,3.

Acceptable risks have decreased as a result of general growing risk averseness in society. Van Dantzig established an acceptable chance of 1:125.000 for a total destruction of central Holland in the 60s; since 2017, for the main parts of central Holland, we accept dike failure probabilities of (an almost same) 1:100.000 (see figure 3.50-7a on page 142), but with less severe consequences (see for example figure 3.5) than total destruction.

When actual risk at some point drops below acceptable risk, not only on average but also geographically dispersed, the ultimate flood risk objective will have been achieved. Most probably, however, future system modeling, hydraulic conditions, willingness to invest and damage profiles will remain dynamic, as they have been until today.

From this chapter is concluded that the main trend regarding policy-making from a strict flood risk perspective since 1986 has been that *investments in flood protection have been continuously made and were strongly motivated by more refined risk and acceptable risk analyses, such that actual risk has, overall, approached acceptable risk more closely.*

In water infrastructure development, scientific advances strongly contribute to policy decisions and projects. The other way around, projects contribute to scientific advances. Political decisions, however, depend on more than modeling. Non-content (process) objectives play an important role, as do other content objectives, the subject of the next chapter: the flood risk-related water system functions *freshwater conveyance, shipping, nature/ecotopes* and *landscape quality*.

Chapter 4 in brief

Chapter 3 described Dutch flood risk policy-making using a framework of mappable *system components* in a *system state* or *condition*, relative to *system requirements*, derived from *fundamental system objectives* and changeable by *system modifications* or *upgrades*. The same is done in this chapter for national water system functions *related* to flood risk, focussing on interactions with flood risk.

The goal of the chapter is to formulate the second main historical trend of this thesis (see page 36), describing the role the flood risk-related objectives have played in Dutch flood risk policymaking in the past and next decades. According to this thesis's design objective (see page 36), each section starts and ends with a Flowz Map and adds design considerations in the captions.

The *freshwater conveyance system* consists of service areas, freshwater inlets, freshwater connections, storage areas, weirs, distribution structures, pumping stations and fresh-salt barriers. Investments in the Dutch freshwater conveyance system have been little since the 70s and relationships to flood risk were minimal.

Shipping uses ports and hinterlands, waterways, locks, moveable high water barriers and flow distribution structures. Major investments have continued to be made in ports, waterway expansions and lock upgrades. Interaction with flood risk has been important, mostly in the tidal rivers, which are mainly kept open to facilitate shipping.

The *'nature/ecotope system'* can be seen as an interplay between 'eco-service areas', aquatic and amphibious ecotopes, eco-gates, pumping stations, fish passages and distribution structures. The nature objective in itself and in interaction with flood risk has been on the rise since 1986.

Landscape quality is always treated as a secondary objective under other water system objectives, but could also be divided in system components and assessed in itself. Landscape quality played a part in almost all flood risk projects over the last decades, even on a strategic systems level.

The role flood risk-related systems have played in flood risk policy-making can be interpreted using Abraham Maslow's hierarchy of human needs (1943). Recent Dutch water infrastructure development can be explained as moving in an *upward direction in 'Maslow's hierarchy of water infrastructure development'*, similarly to how human beings try to fulfil higher needs during their lifetime. This is identified as the thesis's second main trend. It seems, however, that policymakers are struggling with this, as will be described in chapter 5.

Chapter 4

Flood risk-related functions: freshwater conveyance, shipping, aquatic nature and landscape quality

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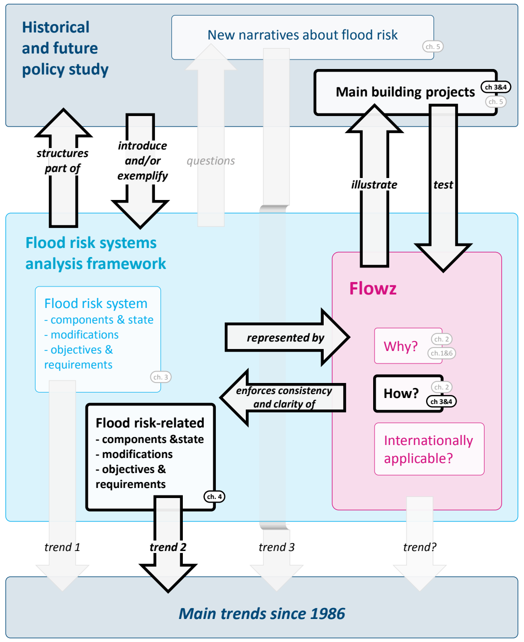
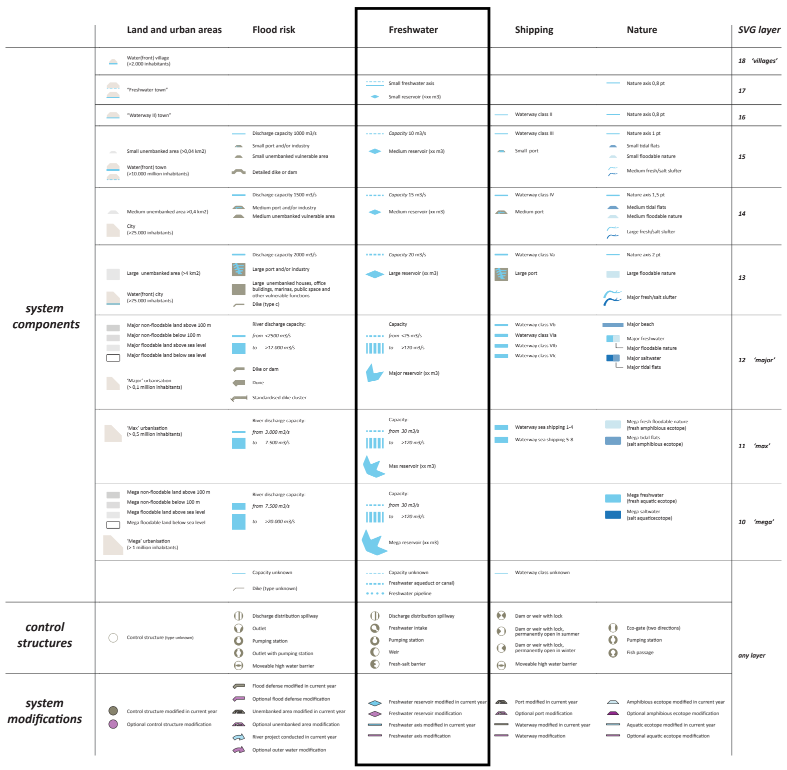
Ir. A. L. Nillesen (Delft University of Technology / Defacto Architecture and Urbanism) *Landscape quality*



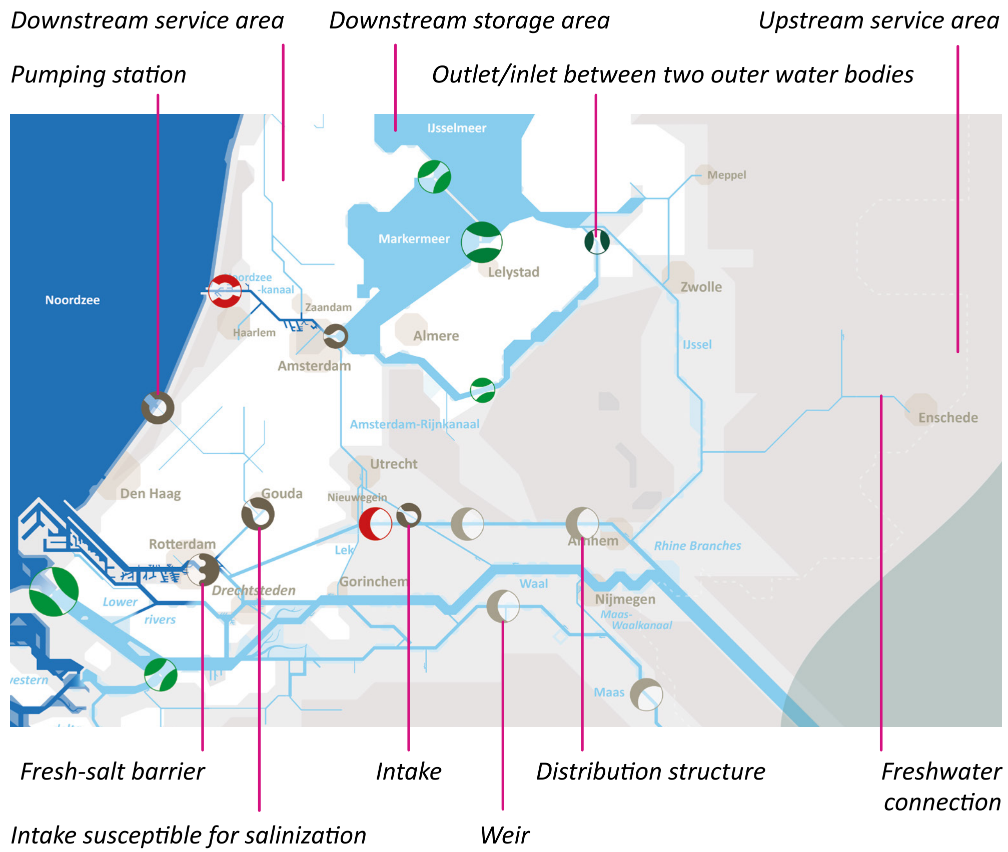


4.1.1 This chapter completes this part of the thesis as explained in chapter 1 (figures 1.15 and 1.16 on pages 40 and 42).

4.1a The freshwater conveyance system

Freshwater sections outline

The two freshwater sections have the same structure as the flood risk chapter: freshwater is described using the *historical systems analysis* framework, working towards relationships with and similarities to the flood risk system, to find one or more general trends (see figure 4.1.1). The next introductory subsection gives a definition and some essential general information, the next section treats five *system components* in turn: service areas, intakes, freshwater connections, storage areas and control structures (see figure 4.1.2). Each component is described by ways to assess or represent the



4.1.2 The five essential freshwater system components in this thesis and in Flowz. The freshwater system becomes more detailed like a *fractal*; a service area on the *national level* consists similarly of conveyance connections, storage areas and intakes on a *regional level*, etcetera.

component's *state* (or *characterise* the component) and by the main types of the freshwater system component *modifications*, focussing on modifications which affect the flood risk system, and flood risk system modifications affecting the freshwater system.

Examples are mostly drawn from the development of the tidal rivers, the adjacent upper rivers and Southwestern delta since 1986.

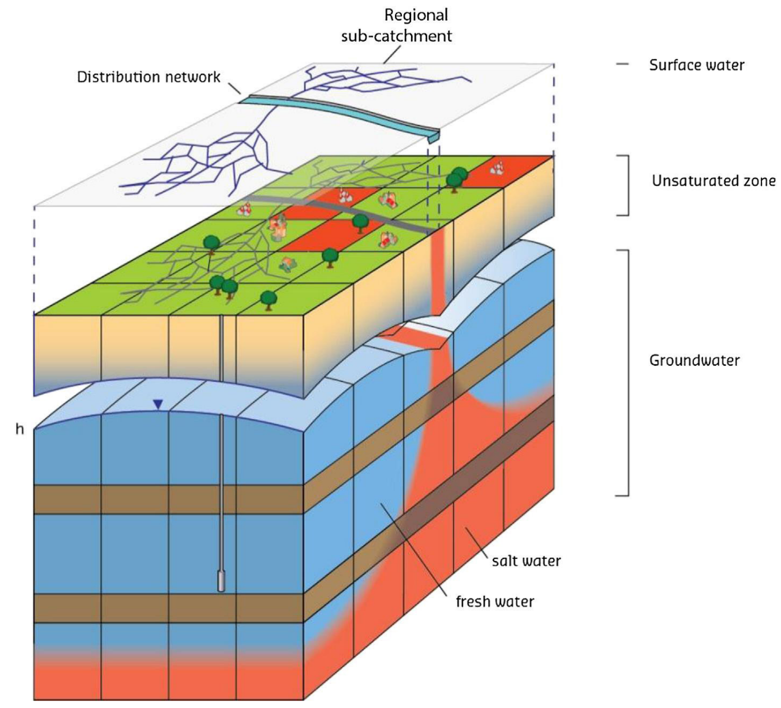
The three subsections of the freshwater *objectives* section (4.2) treat the questions:

1. how fundamental freshwater system objectives are expressed and how these fundamental objectives are operationalised for decision-making,
2. what the main trends in system modifications (building projects) and changing attitudes about the freshwater system have been since 1986,
3. which general conclusions can be drawn about the relationship between the freshwater system and the flood risk system,
4. whether the thesis systems analysis framework as described on page 36 is available or possible for the freshwater system.

A discussion and the general conclusion from all flood risk-related objectives (the second main trend) is drawn at the end of the chapter (and not at the end of each subsection).

The freshwater conveyance system

A freshwater system is an interconnected assembly of geographically bound freshwater users, interconnected by a water distribution network. The water users receive and discharge water from above (precipitation/evaporation), from below (groundwater extraction/repletion, seepage) and from the side, by a partly man-made infrastructure system of rivers and channels, storage lakes and control structures (see figure 4.1.2, 3 and 4). This infrastructure is a system of *arteries* and smaller and smaller *veins*, and in a low-



4.1.3 The Netherlands Hydrological Instrument computes hydrological water balances and fluxes and presents parameters like groundwater levels, seepage fluxes, water levels in canals and ditches, percentages of externally imported water, and salt concentrations. Currently, the model is based on a 250x250 m grid and consists of 8500 local surface waters. Model timesteps range between 10 minutes and 10 days (Klijn et. al. 2012).

4.1.4 The backbone of the Netherlands Hydrological Instrument is the national distribution model, which determines the optimized surface water distribution in the national system based on water availability, water demands, priorities and distribution agreements (the 'waterakkoorden' and the 'verdringingsreeks').

lying country like the Netherlands, the freshwater arteries largely coincide with the *outer water* (see page 108) of the national flood risk system.

The freshwater system description in this thesis focusses on the national freshwater conveyance infrastructure and it's interaction between the freshwater users or *service areas*, which 'suck' water out of the national (outer water) system through the primary *freshwater intakes*.

In a regular summer, on average, about 2250 m^3/s enters the Netherlands via the Rijn river and 250 m^3/s is distributed and used in service areas throughout the country. In an exceptionally dry year like 1976, with a probability of about 1:100, 1100 m^3/s enters on average, and about 225 m^3/s is used (ter Maat 2014).

The first comprehensive national freshwater system computer model for the entire Netherlands, for hydrology as well as policy analysis, was made under the Policy Analysis of Water Management for the Netherlands (PAWN) project (Pulles 1985). This model and way of thinking have been expanded and improved over the years. Since 2005, regional and specific models have been incorporated in the national model, resulting in the comprehensive Dutch National Hydrological Instrument (NHI 2014) and the Delta Model (HDW 2014), which adds impact assessment modules to the NHI (Klijn, van Velzen, et al. 2012; De Lange et al. 2014; Prinsen et al. 2014; ter Maat et al. 2014) – see figures 4.1.3 and 4.1.4. The NHI is, however, still not as precise as many regional and local models and has a certain rigidity – it is mostly suitable for national assessments and distribution issues (Hoes 2016).

The following system description is largely based on these documents, and furthermore on Noort (2003), SRK (2004), RIZA (2005), Loucks et al. (2005), van Beek et al. (2008), de Vries et al. (2009), Bulsink (2010), Visser et al. (2011), Zethof (2011), Deltaprogramma Zoetwater (2012 and 2014) and ter Maat (2014).

▸ 4.1.5 How to express the system state of a freshwater service area? A relevant outcome of a model like the NHI is the difference between supply and demand for a certain timeframe (from the driest second of the driest year to the long-term average). This graph shows an *archetypical* dry year (as identified by e.g. Beersma & Buishand 2004) ; in reality, the curves for supply (based on river inflow and distribution agreements) and demand (based mostly on precipitation patterns) are much more erratic, see figure 4.1.6 for the dry year of 1976.

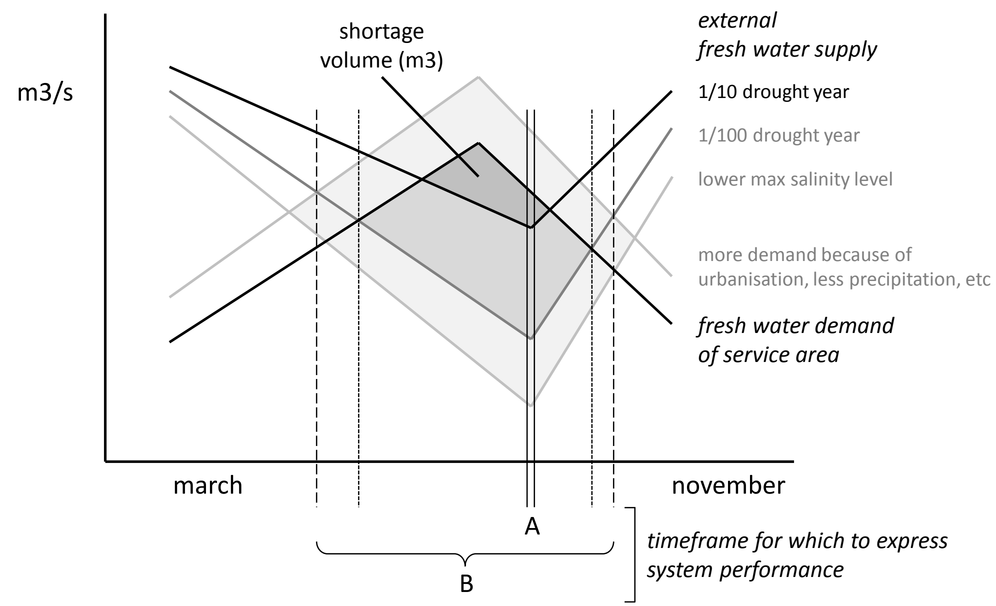
4.1b Freshwater conveyance – system components

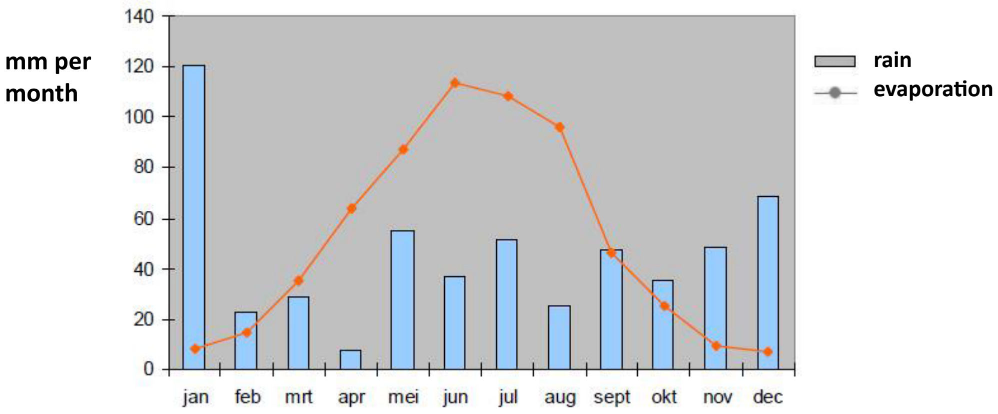
Service areas

A service area is a collection of one or more water users, interconnected by regional or lower-scale freshwater conveyance infrastructure and by groundwater flows. In the National Hydrological Instrument and the Delta Model these users can be agriculture, terrestrial and aquatic nature, drinking, industrial and cooling water, infrastructure and recreation (and the special user *navigation*, which will be treated in the next section). There are two types of service areas: lying above and below the national (outer water) system. In the Netherlands, the *high grounds* or *upstream* areas mostly consist of sandy soils which drain by gravity, with fluctuating groundwater levels; the low polders or *downstream* areas consist of clay and peat, are drained by a dense network of surface waters controlled by flushing and pumping, with rather stable groundwater tables.

Klijn et al. (2012) boil usage down to three types of service area demands from the national infrastructure: 1) water to maintain desired water levels (mostly upstream service areas), 2) water to flush salinization and eg. blue-green algae (mostly downstream service areas) and 3) water for irrigation (down- and upstream service areas).

The *state* or *condition* of a service area can be characterised by lack of supply relative to demand – see figure 4.1.5; in total (from above, below and the side) or limited to





4.1.6 Precipitation and evaporation in the year of 1976, the dryest year in the last half century in the Netherlands. Freshwater demand from the national system is related to the difference between precipitation and evaporation.

the demand on the national infrastructure (from the side only), per year or in summer only, as a long-term average, for an average year or eg a 1:10 or 1:100 year, for a couple of typical very dry weeks, for the total period, or per second. It can be stated in absolute numbers (m^3 per time unit), or divided over the size of the service area (mm per time unit).

In the freshwater system analysis of this thesis, service areas are *modified* when freshwater demands change, for example when a city grows or an industry expands. Through the 20th century, industries demanded lower maximum salinity levels and higher water quantities (the grey line in figure 4.1.5): 'water follows function'. In the 21st century, freshwater users are encouraged to adapt their business to *higher* maximum salinity levels and *lower* quantities: 'function follows water' (but it is not clear whether this is really happening).

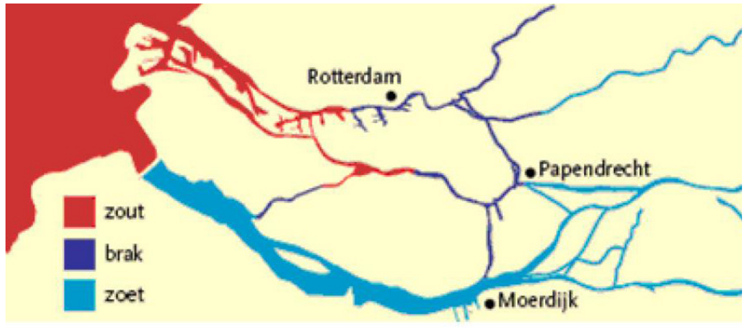
The *relationships between the freshwater conveyance system and the flood risk system* are initially very strong: the shape of dike rings strongly determines the shape of service areas. Once these are in place, however, changing flood risk and freshwater risk profiles have little influence on each other in decision-making.

Freshwater intakes

Freshwater intakes and/or pumping stations (in the Netherlands not so much, in dryer and mountainous countries much more) supply service areas with freshwater from the national freshwater infrastructure. Permanent or temporary pumps may be used either to reach upstream service areas, or when water levels in the water supply infrastructure are too low due to low river inflow. In the Netherlands, small intakes are special constructions; most large intakes are ship locks or special constructions located near ship locks. Letting freshwater in can create high flows which may disturb ships. Many ship locks let freshwater in only during the night, when fewer ships want to pass.

How to represent the *state* an intake is in? One measure would be the technical lifetime of the construction (usually gates), but this is not very critical and often not available. In a representation like Flowz, the colours of intakes could represent the total (modeled) *duration* when the intake does not let as much water in as desired (at times of drought or salinization), or, even better, the total volume of the lack of desired water. Often one service area is fed by multiple intakes, which can complicate this assessment.

The water to be taken in at intakes near the sea may be susceptible to 'external salinization' – see figures 4.1.2 and 4.1.7. The important Gouda intake for example is



4.1.7 External or 'backward' salinization in the Rhine-Meuse estuary during the 2003 drought (Klijn, van Velzen, et al. 2012).

closed when the water has a Chloride level of 250 mg per litre. Drought studies often show the duration during which such an intake would be closed when the outer water is too salt. Interesting information, but it is not sure how problematic a long closure duration is, as there are often alternative routes to reach the service area behind the particular intake. More encompassing would therefore be to present the total water shortage of the service area behind the intake for a 'design year': a historical dry period or a statistically representative year.

Intakes can be added or closed and *modifications* to intakes are increasing intake and/ or pumping capacity and changing the ship passage interference scheme.

An intake can be a weak spot in a *flood defense*, but in the Netherlands these are typically very strong constructions.

Freshwater connections

Freshwater connections are rivers, channels and pipelines with capacities determined by cross-sections, length-profiles, gradients (for open channels) and pressure (for pipelines). Open channel gradients are limited by maximum and minimum water levels, and these lie close together in the Dutch polders with their highly controlled water levels – see figure 4.1.8. The regional freshwater connections lie behind the intakes at the edges of the national ones, which largely coincide with the *outer waters* as described in the flood risk chapter. The outer waters allow large gradients and their capacity is never a problem.

4.1.8 In most Dutch polders, minimum and maximum water levels, like for the river Schie in Delft in this picture, lie close together. This limits the maximum gradients (slopes) and thus the transport capacity of the freshwater connections.

The *system state* of a freshwater connection would be an assessment describing the difference between the available capacity and the desired capacity for a certain drought or salinization period, when high capacities are particularly desired.

Existing freshwater connections are *modified* by increasing the capacity (in one or more dimensions). This is never needed for the Dutch *national* system, since capacities are dimensioned on discharging excess water or shipping. In the *regional* systems, channels can surely be too tight (see Flowz figure 4.1.17 at the end of this section) or pipelines too small. A special type of modification to a freshwater connection is one nearby a bifurcation which would influence the low water discharge distribution, for example to increase river inflow into a seasonal storage area. A *new* conveyance connection can be a newly excavated canal or a new pipeline. It can also be created by a sea dam which blocks salt water intrusion and lengthens a freshwater connection all the way to the sea (like the Haringvliet, which used to be a salt and brackish estuary and now is part of a freshwater connection between the Meuse and Delfland).

Relationships between *excess (flood) water* and freshwater connections are little, except for the multiple benefits of dams. In the Netherlands (with flood risk as the main objective) the geometric shape of the *outer water* is hardly ever changed for freshwater conveyance purposes alone (this is different in foreign systems with freshwater conveyance as the main objective). The other way around, of all flood risk reduction measures related to freshwater conveyance connections, the *Room for the River* measure *deepening the waterway* to reduce high water levels has an impact on upstream freshwater conveyance intakes: this also lowers water levels in dry times, and may thereby impair freshwater intake under gravity.

Storage areas

Seasonal freshwater storage to flush saline polders, maintain surface water levels and for irrigation throughout the summer, requires a water body which is closed (e.g. the Haringvliet is not), which has a large surface area (e.g. the Brielse Meer is small), a high acceptable fluctuation (e.g. the Volkerak-Zoommeer has little) and which is sufficiently fed and flushed by good quality river water (most Dutch lakes are hardly) – considering these demands, in the Netherlands only lake IJssel provides serious seasonal freshwater storage. In mountainous countries, upstream *reservoirs* behind dams provide seasonal storage too, as they have high acceptable fluctuations, are filled by river water and can be large.

The Netherlands have many small river water storage basins for *drinking water*, to bridge periods of poor river water quality of up to two months, but drinking water needs far less volume than required to flush saline polders or to irrigate farmland. Special types of drinking water storage are the groundwater infiltration systems under the dunes along the coast. In the Netherlands, drinking water shortages do not occur.

The *capacity* of a storage area is storage volume, in total or available for a particular purpose. The *state* of a storage area would be the total time the storage volume is empty during a particular (modeled) dry period, or the difference between the total volume desired by all surrounding intakes and the total volume the basin can provide.

A storage area is created by dams and/or dikes and embankments. *Modifications* are changing the shape and the minimum and maximum water levels, and the flushing regime. *Relationships with flood risk* are very strong: a dam usually changes flood risk profiles dramatically, and a higher storage basin level increases flood probability, which is why storage basin levels are typically low in winter, the storm season, and high in summer, the drought season.

Control structures

Finally, control structures for the freshwater system are weirs, intakes or pumping stations between two (outer) water bodies, other distribution structures, and fresh/salt barriers.

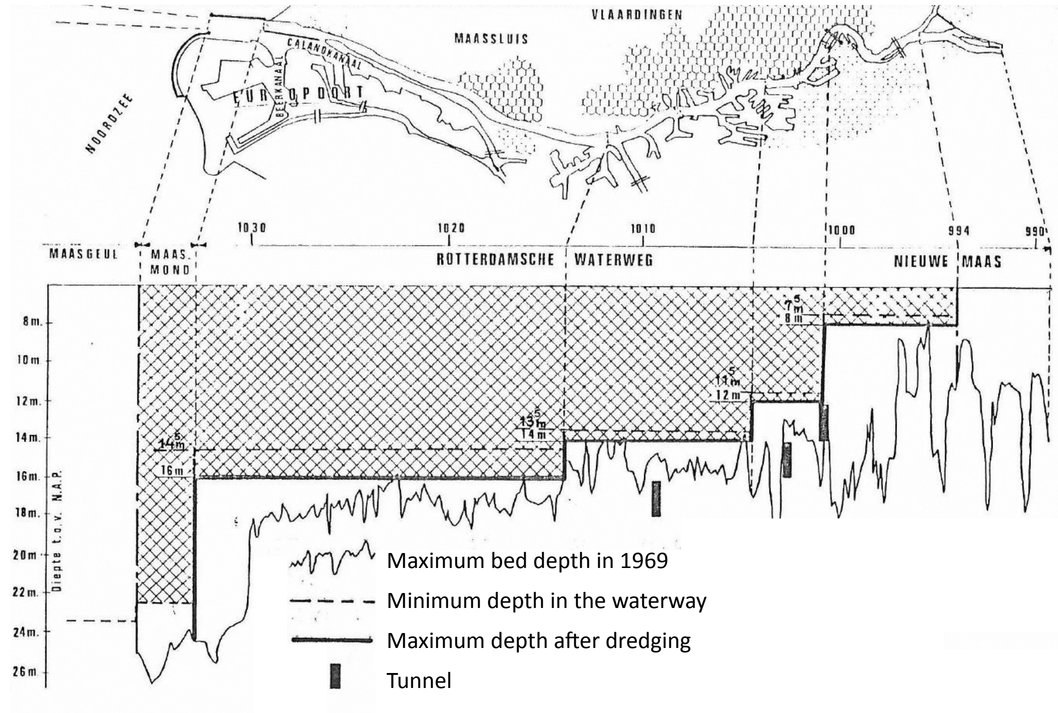
In the national distribution system, *weirs* mainly serve shipping, but also the freshwater system. They keep river water levels high relative to the thresholds of the intakes. A weir nearby a bifurcation can direct water in a desired direction (like towards the IJsselmeer, by the famous weir at Driel, see figure 4.1.9). In the Dutch outer waters there

4.1.9 The weir at Driel in the river Nederrijn-Lek. Some weirs have more impact on the flood risk system than others: the Driel weir can be raised to improve navigation or to lower resistance for high water discharge. Regular weirs like in the river Meuse and upstream in the in the Rhine cannot do this (they can be opened for high water discharge, but ships always have to pass through locks).

are in total 10 weirs (3 in the river Lek, 7 in the Meuse).

Intakes (or reversed outlets) in dams direct freshwater from one basin to another, like from the IJsselmeer to the Markermeer, and drain freshwater surpluses to sea, like from the IJsselmeer to the Waddenzee – in the Netherlands, there are 13 such gates. Other *distribution structures* could be spillways near river bifurcations to direct free river flows, but these do not exist in the Netherlands.

A fresh-salt barrier can be a ship lock specially designed to prevent salt water from entering a freshwater channel or basin – there are multiple of these in the Netherlands (the most famous are the Krammersluizen). A fresh-salt barrier not hindering ships is a dredged or sand-nourished *ladder line*, or a *bubble screen*. Since the 70s there is a ladder line in the Nieuwe Maas – see figure 4.1.10, but it has worn down and salt intrusion (or



4.1.10 A fresh-salt barrier: the 'ladder line' in the Nieuwe Waterweg and Nieuwe Maas. The target depth is the dark line, which can lie up to 10 meters above the actual (maximum) depth (Kuijper & v.d. Kaaij 2009) (Kuijper et. al. 2009).

external salinization) in the province of Zuid Holland remains a problem (Kuijper et. al. 2009 and 2010). The Delta Programme neither suggested to restore the ladder line (costs estimated € 53 million), nor implement a bubble screen, but deemed freshwater supply from the east by upgrading small polder canals more cost-effective (the KWA+ project, costs budgeted € 40 million – Deltaprogramma Zoetwater 2014).

How to express the *system state* of control structures? Similar to the intakes, an assessment could revolve around remaining *technical lifetime*, or, rather differently, around the timespan during which the required function can not do what is desired: water tables drop despite the weir, there is not enough freshwater to let in through an inlet, a bubble screen does not always succeed in keeping salt intrusion out.

System modifications are adding, removing or altering these objects, or changing operations. Since 1986, no new freshwater control structures have been added to the Dutch national system. Of the 20 freshwater projects concerning the Dutch outer water system proposed by the 2015 Delta Programme until 2022, 15 concern modifying or changing operations of existing control structures and intakes (Deltaprogramma Zoetwater 2014) (see the next subsection for the other projects).

Which *relationships between flood risk* and freshwater control structures can be identified? A weir in a river bed blocks high water flows, so these are usually built where it can be lifted entirely during high water and/or where the river winter bed (cross-section) is wide. Outlets can be used to not only direct precious freshwater in designated directions during dry times, but also excess water during wet times. The outlet in the Volkerak dam between Haringvliet and Volkerak, for example, was built to flush lake Volkerak-Zoommeer for freshwater supply of Zeeland and Brabant. Under Room for the River, the outlet was designated to direct high water into the lake as emergency storage. It appears, however, that because of high flow velocities the gate cannot be closed at the moment when Lake Volkerak is full, which may have a negative effect on flood probability of the dike rings surrounding the lake. If the gates would have been constructed both for freshwater conveyance ánd emergency storage purposes, the design would have been different.

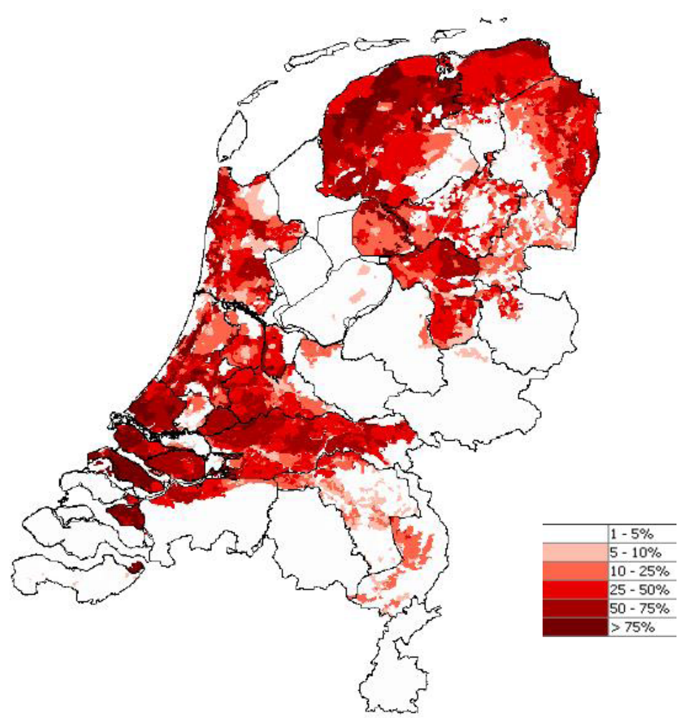
▸ 4.1.11 How powerful is the freshwater conveyance system? The red patches in this map represent areas where Rhine, Meuse and other river water from abroad has entered as a result of distribution efforts by man. For the period between April and September, for a 1:10 drought year, in the current climate, this can be more than 75%. Farmlands not connected to the national freshwater conveyance system (white on this map) are more susceptible to drought and salinization; lands which are connected (red on this map), easily yield ten times more agricultural outputs (de Vries 2014).

4.1c Freshwater conveyance – system objectives

Fundamental freshwater system objectives

In the PAWN study (Pulles 1985) and its successors, mainly the Droogtestudie (DroughtStudy – 2002-2008) (Droogtestudie Nederland 2003; RIZA 2005) and the NHI/Deltamodel work done for the Delta Programme (2009-2015) (Klijn et al. 2012; Deltaprogramma Zoetwater 2012 and 2014), the fundamental freshwater objective has been more or less the same: *minimize damage* due to freshwater *shortage*; the gap between an ideal amount of freshwater supply which meets all demands by all users, and the actual supply. An additional objective is to *maximize benefits* of freshwater conveyance, which adds *new or expanding users* made possible by improved freshwater conveyance – once new users and new infrastructure are added, total damage due to occasional shortages can be more than it was before, but this can well be compensated by more benefits as a result of the improved supply. This can be a narrow (only clear monetary costs and benefits) or more broad analysis (including additional environmental and societal aspects).

Demand for precipitation and external supply is predictable, supply and precipitation are stochastic. Freshwater demand (users) cannot easily be 'designed'; freshwater supply (infrastructure) on the contrary is under government control and can be operated and engineered (see figure 4.1.11 for the reach of the Dutch supply infrastructure). Knowing

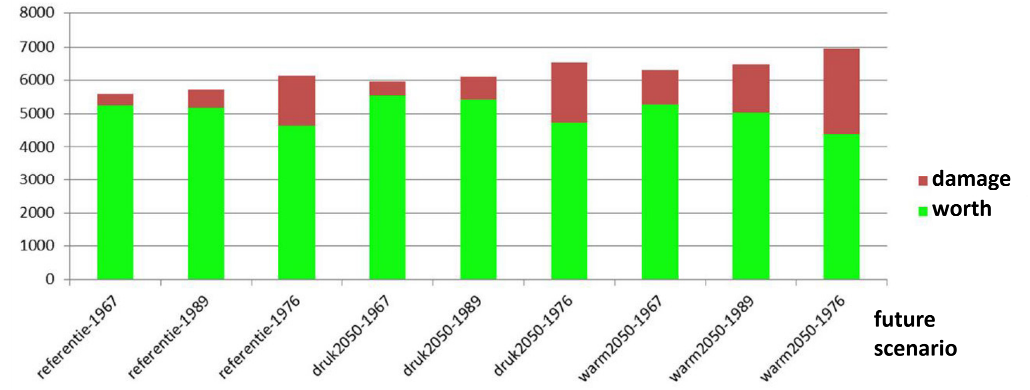


this, how is damage quantified to determine when damage is *minimal* or benefits are *maximal*?

Damage is done by insufficient water *quantity* and *quality*; water quality consists of salinity and properties like levels of pollution and eutrophication. Water quality is, in the systems analysis of this thesis, considered a property of the *nature/ecotope system* (evaluated by, in the Netherlands, the Water Framework Directive – see section 4.3c). There are of course strong relationships between quality and quantity and between salinity and other water qualities. Assessments of the freshwater and nature systems indeed overlap in the PAWN and later freshwater conveyance models and frameworks.

Damage to *agriculture* is often expressed as loss relative to full potential crop yield (which may be over 70% in an extremely dry year for the driest regions), or in damage in euros. In the Netherlands, at times of water shortages and/or too high water temperatures, *industry*, *power plants* and *drinking water systems* are hardly ever shut down, but additional costs may have to be made for alternative treatments or supply. Damage to *nature* is expressed in hectares nature, 'nature points', or numbers of creatures, plants or species, suffering from irreversible drought damage (yet the scientific modeling for nature drought damage is still in a stage of infancy – ter Maat 2014). The numbers are *annual expected values*, summed annual damages weighed by probabilities like 1:10 for the year 2003 and 1:100 for 1976. Future hydrological circumstances and probabilities may be modified according to a climate scenario. Models might also use a hypothetical *probabilistically archetypical* drought year like in figure 4.1.5 on page 165, but Dutch drought modelers prefer to use historical years (like 1976 in figure 4.1.6).

More than 90% of the total annual expected damage to agriculture occurs in the years with return periods under 30 years; a year like 1976 counts for only 4% (Bulsink 2010). Total annual expected agricultural damage in 2008 was calculated by van Beek et. al. (2008) as € 350 million and estimated to grow to € 625 million under climate change, and by the Delta Programme as € 400 million, growing to € 1,1 billion (Deltaprogramma Zoetwater 2012). See figure 4.1.12 for the possible effects of different climate change scenarios.



4.1.12 Agricultural yield and damage (excluding the large arboriculture sector) in million € for a number of typical years under various climate scenarios, according to the NHI model (Agricom - ter Maat et al. 2014).

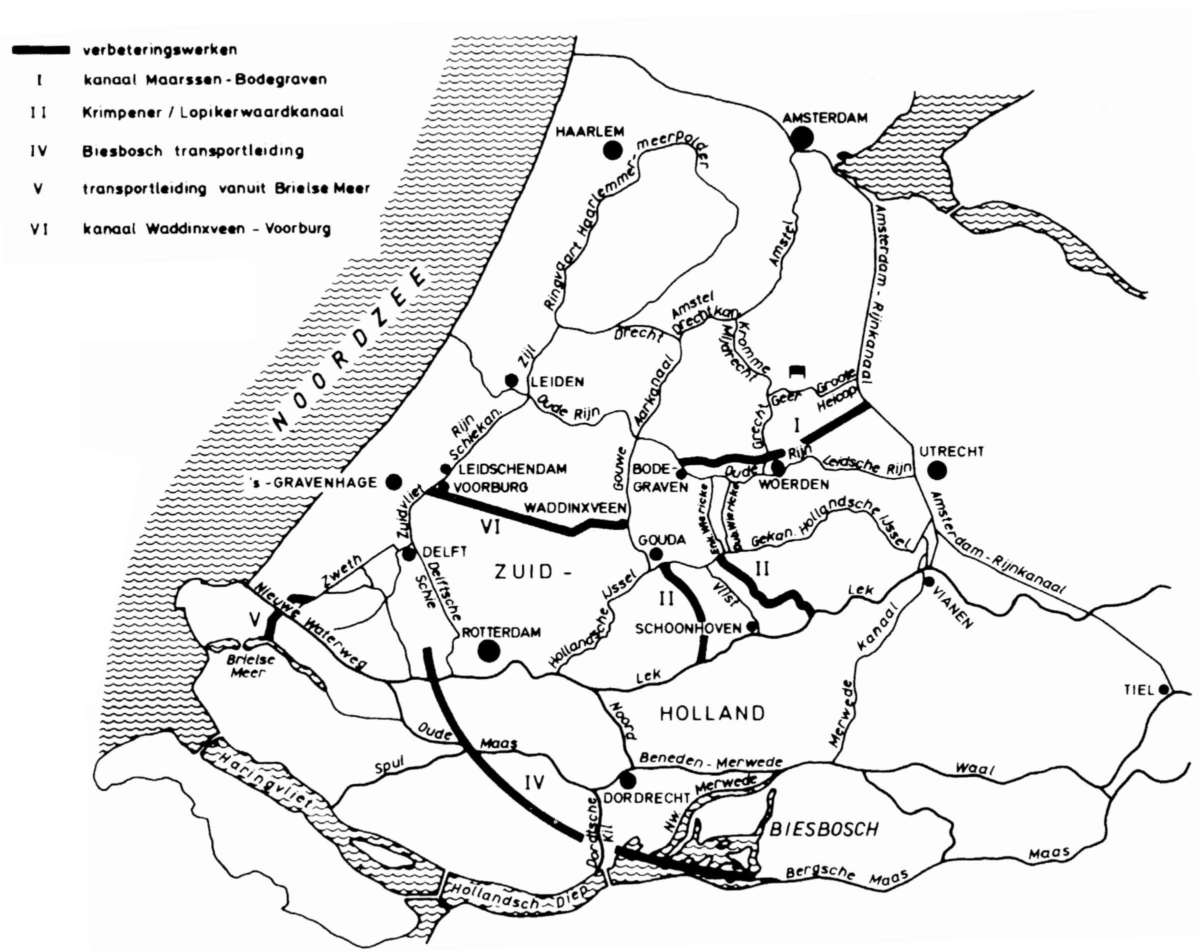
Damage is *minimal* when no system modifications remain which come at higher (investment) costs than the damage reduction or yield increase as a result of them. According to Zetland (2011) and others, *pricing* helps to have users make more effective use of the available water. In most parts of the Netherlands, freshwater is so cheap that the additional administrative costs are probably not worth the efficiency gain, but this may be different in areas with little supply from the national system, like in Zeeland (the white patches in figure 4.1.11).

Uncertainties are large, however, due to model uncertainties and many assumptions. When non-monetary costs are *minimal*, like irreversible drought or salinization damage to nature, are political issues. Uncertainty in the monetary analyses and the non-monetary costs increase the role of (subjective) political over (objective) analytical considerations in decision-making.

Freshwater and flood risk since 1986

How has the Dutch freshwater system been modified since 1986? From the technical and policy documents studied it seems that many *minor* system upgrades, like small increases in regional system component capacities and updated distribution agreements, have since 1986 continuously been implemented by the water boards as part of their regular operations.

Major upgrades to the national freshwater system, like the Afsluitdijk (1932), the Haringvliet dam (1970) and the Lek canalisation/Driel weir (1970), have not been built over the last 45 years. The First National Water plan of 1968 made a longlist of major improvements to the freshwater system, which were in 1979 estimated by PAWN to cost about € 1.5 billion. Yet, of these measures, the estimated *strictly cost effective* ones amounted in total only € 60 million (price levels 1984). Most of the PAWN recommendations were adopted in the Second National Water Plan of 1984 (Huisman 2015). Figure 4.1.13 shows six new regional conveyance connections proposed under PAWN in mid-west Netherlands. Of these six projects, only the Brielsemeer pipeline (nr. V) has been implemented (in 1988). This project, which brings water from the Meuse and Rhine all the way into Delfand and sometimes Rijnland, is probably the most prominent freshwater system upgrade of the last decades (Noort 2003).



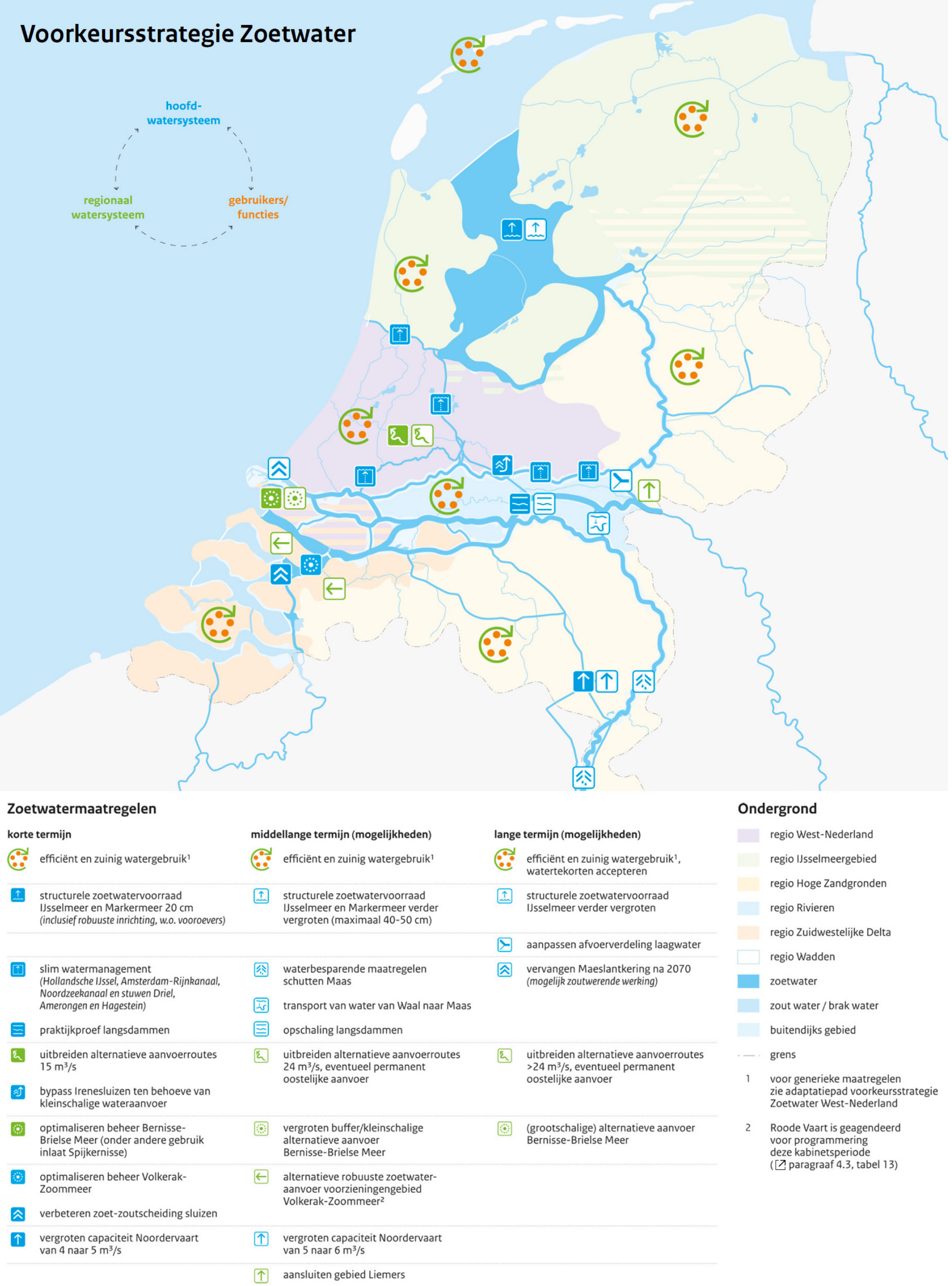
Since about 2007, the climate change discussion has had a major impact on freshwater model- and policymaking. The Dutch Deltacommittee of 2008 proposed to raise the level of Lake IJssel along with the rising sea level up to a maximum of 1.5 meter, which would strongly increase the lake's buffer capacity, and along with this to improve the connection between the IJsselmeer and the mid-west Netherlands. This would be the largest national freshwater system upgrade since the Delta Works and the Lek canalization, but the Delta Plan Freshwater of 2014 listed the idea as a potential future upgrade dependent on the pace of climate change. For the short term (2022), a 0.20 meter storage increase is recommended, which requires physical modifications at costs of about € 20 million (Deltaprogramma Zoetwater 2014). Drastically improving the north-south freshwater connection from lake IJssel will not happen on the short nor the long run; it is estimated that there will be enough Rhine water flowing into the Netherlands to distribute in other ways than through lake IJssel, as long as those other seasonal buffers remain: the snow packs and glaciers in Switzerland.

Nevertheless, the 2014 Delta Plan Freshwater proposed to spend a total of about € 0.5 billion on freshwater system upgrades in the entire country between 2015 and 2022, which would be a spending boost relative to the last 30 years (Deltaprogramma Zoetwater 2014). Many of the proposed projects have been proposed before. Investments in the freshwater system can be cost-effective again because of climate change, a broader approach to cost-efficiency, or more freshwater allocations related to nature/ecotope improvement projects.

The largest proposed projects in the lower Netherlands are the KWA+ project (€ 40 million) (an upgrade of option II in figure 4.1.13, see also Flowz figure 4.1.17 at the end of this section) and the freshwater reroutings necessary for the salinization of lake Volkerak (about € 120 million), but the Volkerak salinization is arguably more a nature

◀ 4.1.13 In the '80s, PAWN investigated five new conveyance connections for Zuid Holland and Utrecht, plus an improved pumping station at Leidschendam and a bubble screen in the Nieuwe Waterweg. The Brielse Meer pipeline was estimated the best option for Delfland, and it was built in 1988, complemented with an improved connection between the Spui and the Brielse Meer (the Bernisse river). The other upgrades have not been implemented.

▼ 4.1.14 Freshwater measures proposed by the Delta Programme (Deltaprogramma 2014).



project than a freshwater project. Apart from this project, the relative changes to the national infrastructure remain small compared to the projects in the '30s and '70s.

Section 4.1b presented the relationships between freshwater measures and flood risk measures. It can be concluded that since the dams and canalizations of the Delta Works, there have been no large freshwater measures implemented or proposed which have affected the flood risk system. The other way around, small interactions exist between some Room for the River measures and resulting lower water levels near the freshwater intakes, in the management of the Lake IJssel level, and in operations of some inlets/outlets. When sea level rises, perhaps the Hollandse IJssel storm surge barrier will be replaced by a dam (Welsink 2013). This could turn the Hollandse IJssel into a small freshwater reservoir for mid-west Netherlands, similar to the Brielse Meer (see Flowz figure 4.1.17).

The general conclusion about the freshwater system would be that the backbone of the current system will probably not change too much anymore to support classic users like agriculture and cities, unless climate change hits hard. If the freshwater system itself will change only little, and interactions between freshwater and flood risk are small, the effect of the freshwater system on the flood risk system is even smaller; a conclusion shared by experts in the Delta Programme (ter Maat 2015). More significant freshwater system modifications serving the relatively new user *nature* can be expected, and via the nature/ecotope system, some relationships to flood risk exist – see the next sections.

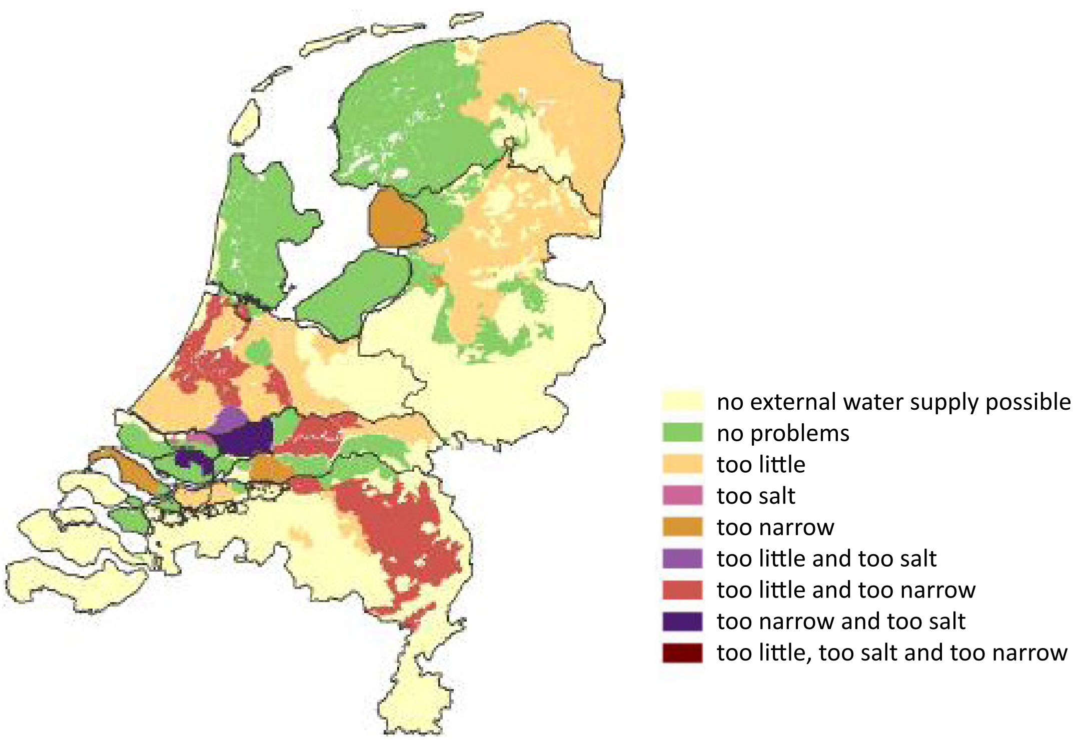
Applying systems analysis framework of this thesis to the freshwater system

The last question of this section is whether the approach used for the flood risk system – mapping the system state relative to system requirements, preferably in a probabilistic analysis – are available or possible for the freshwater system. Let's recall the advantages of this approach: 1) problem analysis is separated from generating solutions (resulting in a better analysis and more varied solutions), 2) the entire system is assessed equally and with the best available national models, 3) national policy-making is better served, for example to benefit remote regions.

The outcomes of the PAWN and subsequent studies are typically maps with drought and salinization damages, and tables with cost-benefit analyses of measures, ranging from national infrastructure upgrades to promoting salt-intolerant industries to become less dependent on surface water. With some adaptations, the data could be turned into system state maps, but this is not commonly done. What are the fundamental differences between the freshwater and flood risk system approaches?

Both approaches address the same fundamental objectives: minimising flood and drought risks. Since flood protection standards are the outcome of a (narrow or broad) cost-benefit analysis, fixing a weak spot can be expected to have a positive benefit-cost ratio, just like the assessments on freshwater system modifications. Yet, not meeting a requirement usually has more political weight than just a positive benefit-cost ratio. This is probably the result of a fundamental difference between the two risk profiles: freshwater shortages don't kill anyone and damage builds up gradually with every raindrop not falling and often affects only a small group, while flood damage has dramatic discontinuities in damage profiles and hurts either no one for a long time or a large group at once, even with casualties.

These differences are reflected in the policy documents studied: for freshwater conveyance, the Dutch government has an 'effort commitment' (*inspanningsverplichting)* rather than a 'result obligation' *(resultaatsverplichting)* to achieve, the Delta Programme of 2015 has committed to 'at least maintain existing supply levels' and aims at 'improving the dialogue' (between local, regional and national entities) rather than setting national requirements (ter Maat 2015). This explains why the studied freshwater documents did not show nation-wide assessment maps based on national benchmarks. Flowz map 4.1.17 is an adaptation from the only map found (figure 4.1.15) which could be interpreted as a system assessment.

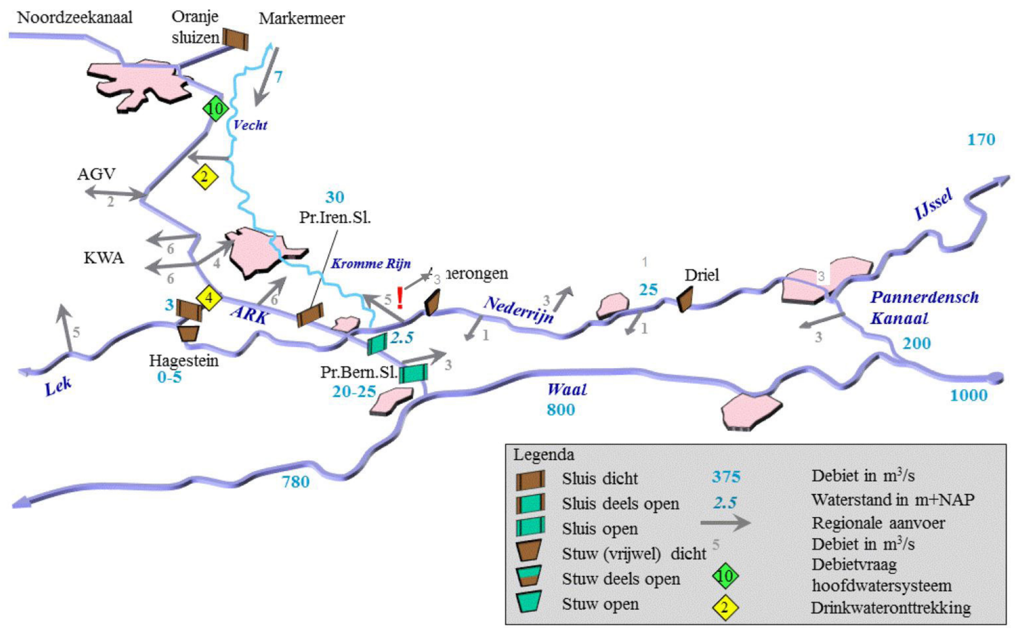


4.1.15 This maps shows problems within the Dutch freshwater system (for a 'very dry year' under the current climate) (Klijn, van Velzen, et al. 2012). The map does not show whether the problems are *optimal or minimal*, like the national flood risk maps do which compare system states to system requirements.

Nevertheless, the Delta Programme did start a discussion on a new more quantitative risk-based national policy framework revolving around the concept of *supply levels*, which 'provide information to water users related to the availability of freshwater and probabilities for shortages, in normal and dry situations' (Deltaprogramma Zoetwater 2014). It is not yet clear what exactly a 'dry situation' is, how to acknowledge different users with different demands and regional differences, and what the policy implications of large shortages within this new framework would be.

The supply levels approach reveals a growing interest in an approach more similar to flood risk and the previous section showed that that existing models are technically able to inform such an approach; so what could national *freshwater system requirements* look like?

Some existing maps show conveyance schemes at times of low Rhine inflow (like figure 4.1.16). These represent flows through the system of veins and main arteries based



4.1.16 The distribution scheme at times of a Rhine inflow of 1000 m³/s. The exact distribution and the resulting damage depends on the total precipitation and discharges of the preceding weeks and even months (Hydrologic 2012).

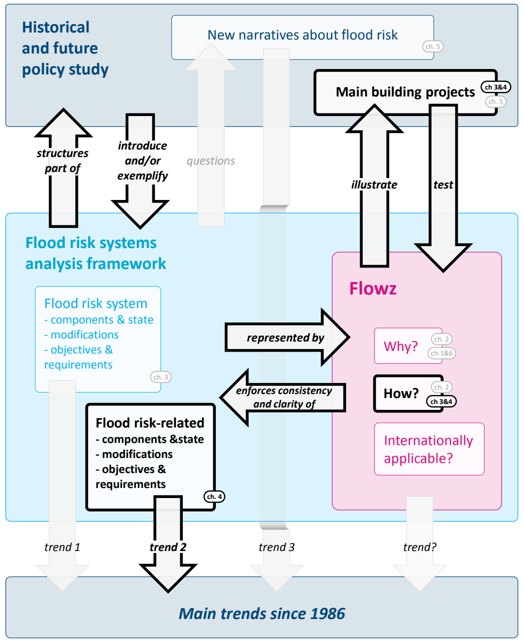
on various distribution agreements and national priorities between freshwater users (the 'waterakkoorden' en the 'verdringingsreeks' (Helpdesk Water 2014)). These depend on the distribution of water demand, which depends on the precipitation distribution which had preceded the low river inflow. With the existing (NHI) model, maps could

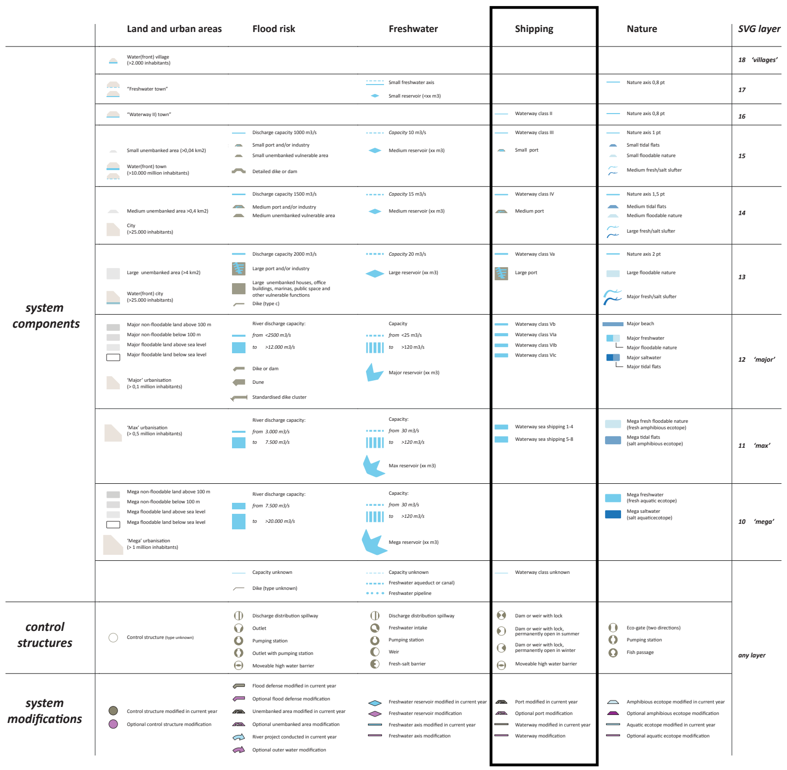
be made which show *differences between supply and demand* in a particular timeframe, an average of multiple timeframes or in an 'archetypical' or 'synthetic' situation, where both water supply and water demand would not be copied from a certain year, but be samples from probability distributions. The related *requirements* for different regions in such a map could be the probability- and/or consequence component of the total risk: 1) the *acceptable exceedance frequency* of the drought event underlying the map, 2) the *acceptable water shortage* (durations or volumes, in total or per service area square kilometre) or 3) the total risk: summed tolerable shortages times the return periods of these shortages.

The height of these standards would, similar to flood risk, be determined by *non-monetary* risk objectives) and *economic* risk objectives. Non-monetary risks for flooding are be *local individual risk* and *group risk* (see page 87) and for freshwater *salinization* and *water level (peilbeheer)* risks; economic risks concern flood damage and damage to agricultural yield, respectively. Non-monetary risk standards are determined for example by comparisons to other societal risks; economic risk standards result from optimizing the ratio of the costs to heighten the standard (investments in alternative freshwater supply) and the resulting reduction of the risk. For freshwater this analysis is more complicated than for flood risk because costs for improved freshwater conveyance vary much more between rejected intakes than between rejected dikes.

Summarising: national standards at first require an agreement on which risk component is standardized, and the *supply level (voorzieningenniveaus)* discussion has not even resulted in this. They furthermore require an agreement on the height of the standards. This would require a very high quality of the models of which the standards are the outcome (it would mostly require improved 'hydro-economics', according to ter Maat (2015)). Considered that risk profiles for freshwater seem more complex and less dramatic than for flood risk, chances that national standards will ever be applied to the freshwater system are small. Maps like Flowz map 4.1.17 which *reveal* weak spots rather than legally *enforce* upgrades will probably remain the best we have – but these type of maps can surely be improved as a result of the *supply level* research efforts in the years to come.

◂ 4.1.17 The freshwater system of the central western part of the Netherlands (Holland). The shades of red and green are an interpretation of figure 4.1.15. In very dry years, saltwater advances from sea all the way to the inlets Gouda and Bernisse. In purple, optional projects listed by PAWN (figure 4.1.13), the Delta Programme (figure 4.1.14) and others. Important system upgrades not drawn here are control structure operation modifications ("smart water management").
Design consideration: the purple system modifications don't contrast much to the existing system components when these are dark red. System modifications are best displayed against the existing system components in the neutral Flowz Brown colour.



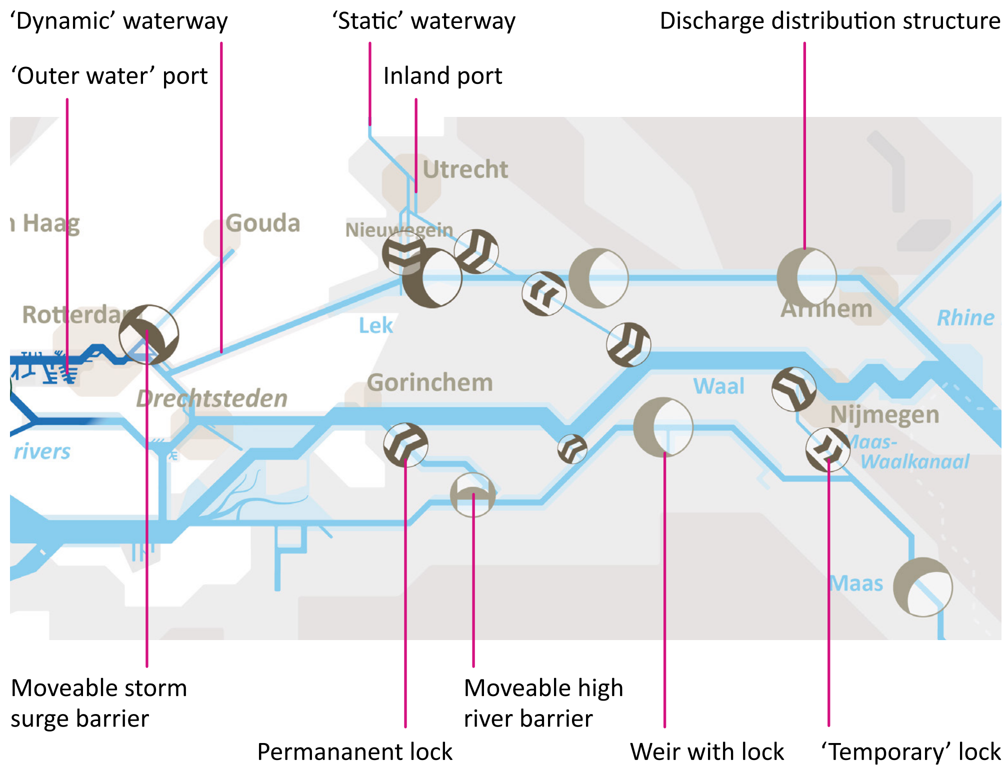


4.2.1 This chapter completes this part of the thesis as explained in chapter 1 (figures 1.15 and 1.16 on pages 40 and 42).

4.2a The shipping system

Shipping sections outline

The two shipping sections follow the same structure as the flooding (and freshwater) chapter: shipping is described using the *historical systems analysis* framework, working towards relationships with and similarities to the flood risk system, to find one or more general trends (see figure 4.2.1). The next introductory subsection gives a definition and some essential general information, the next section (4.2b) treats three *system components* in turn: ports, shipping axes and control structures (see figure 4.2.2). Each



4.2.2 The essential shipping system components in this thesis and in Flowz: ports, waterways, permanent and temporary locks, moveable storm surge or high river water barriers and discharge distribution structures.
Design consideration: a river weir and a ship lock are integrated in a single icon. They have two different effects on the shipping system: a weir positive, a lock negative. Only the lock is shown, since a user will understand that a lock in the middle of a river has to be a weir. A temporary lock in a river is a temporary weir opened in winter. A temporary lock in a flood defense is temporarily opened in summer.

component is described by ways to assess or geographically represent the component's *state* (or *condition*, or to *characterise* the component) and by the main types of the shipping system component *modifications*, focussing on modifications which affect the flood risk system, and flood risk system modifications affecting the shipping system.

Examples are mostly drawn from the development of the tidal rivers around the port of Rotterdam and the adjacent upper river Waal towards the industrial Ruhr area in Germany. Corresponding to this thesis' objective, the time period studied starts in 1986 (but occasionally a peek further back in history is made). The system description fits the Netherlands but keeps other systems in mind; representing foreign systems with the same universal language and symbols is investigated in Rijcken and Christopher (2013).

The three subsections of the shipping *objectives* section (4.2c) treat the questions:

1. how fundamental shipping system objectives are expressed and how these fundamental objectives are operationalised for decision-making,
2. what the main trend covering system modifications and changing attitudes about the shipping system have been since 1986,
3. which general conclusions can be drawn about the relationship between the shipping system and the flood risk system,
4. whether the approach for the flood risk system as described in chapter 3 (mapping the system state relative to system requirements), is available or possible for the shipping system.

A discussion and the general conclusion from all flood risk-related objectives is drawn at the end of the chapter (and not at the end of each subsection).

The shipping system

A shipping system is a network of *ports* connected by *waterways*, containing *control structures* like locks. Each port or waterway serves a particular part of the entire spectrum of ship types (from barges to supertankers), by maintaining certain water depths, widths, bend radiuses and facilities like mooring and cargo handling systems. Like all water systems, the shipping system also consists of 'arteries' and smaller and smaller 'veins'. The shipping system description in this thesis focusses on the *national arteries*, which largely coincide with the 'outer (often largely uncontrollable) water' of the national flood risk system (as defined in section 3.1, pages 108-111).

The Dutch shipping system consists of 11 sea ports (Breskens, Vlissingen, Moerdijk, Dordrecht, Rotterdam, Vlaardingen, Scheveningen, IJmuiden, Den Helder, Harlingen and Eemshaven), 389 inland ports (Schweig 2006) and 3.400 km of national plus 3.900 km of regional waterways (RWS-DVS 2009). The national system has 119 locks (RWS 2014), 10 weirs (with locks) and 3 storm surge barriers (Maeslant, Hartel, and Ramspol).

For *inland* (as opposed to sea-going) cargo transport in, to and from the Netherlands, next to road, rail, air and pipeline, transport over water counts for 25 to 35% (measured in tonnes) or 35% to 45% (measured in tonne kilometres) (Bosschieter 2005; Klijn, van Velzen, et al. 2012; van Dorsser 2015). On the Rhine, the largest river in Western Europe, about 100.000 cargo ships per year transport half of all physical trade between the Netherlands and Germany (in tonnes, east plus west bound), with a total transport costs turnover of about € 640 million (Jonkeren 2009).

4.2b Shipping – system components

Ports and hinterlands

Ports are logistic hubs where cargo and passengers shift from one waterborne carrier to other water- or land borne carriers. Most ports combine logistics with storage, oil refinery, industry, offices, electricity production and other activities adding value to the goods transported. Ports redistribute to hinterlands, but serve these in more complex ways than a freshwater inlet serves a service area. The Harlingen port, for example, probably only serves the Friesland province, but ports like Rotterdam and Antwerpen serve all around Northwest Europe (including Friesland), and even ship to each other.

There are seaports and inland ports, and sea-, inland- and hybrid ships, each providing and demanding different mooring depths and different port facilities. There are vessels which are weight-dominant (maximum cruising depths dictate their reach) or volume-dominant (maximum bridge heights and bend radiuses dictate their reach). In the Netherlands (and other parts of Northwest Europe), eight classes of sea ships (1-8) and eight classes of inland ships (II, III, IV, Va, Vb, VIa, VIb, VIc) are distinguished.

How to characterise the *size* and *state* of a port? The yearly number of ships entering the port could be a measure. In all Dutch sea ports, in 2008, 57.257 sea ships entered. 63% of these were small ships weighing less than 10.000 tons, and only 1% weigh more than 100.000 tonnes (RWS-DVS 2009). Yet, these large ships soon deliver more than half of all goods. Furthermore, some goods are worth much more per tonne than others and the value added to goods in the port also varies greatly. The easiest yardstick would be the space a port occupies.

Which indicators can illustrate whether a port is in good shape relative to a reference point? Some part of the time, a port can operate below capacity due to certain conditions like storms or low water levels; this percentage could be a reference point and the statistically expected deviation from it could indicate a ports state.

An entirely different approach would be an indicator representing the ambition of a port to expand and/or host higher ship classes. This would be of use in an integrated water system approach as advanced in this thesis and in Flowz: if a port aspires to upgrade to bigger ships, not only the port itself, but also adjacent waterways have to be upgraded. In the web of water system component interactions, these upgrades might threaten or support other water system functions, like flood protection and freshwater conveyance.

A feasible port upgrade is part of an iterative interplay between more demand by the hinterlands, waterway upgrades and larger ship types. Feasibility is hard to predict and depends on forecasts, on which experts may disagree (e.g. van Dorsser (2015) foresees less growth than Modder & Jorna (2008), etcetera). For this reason, Ligteringen

& Vellinga (2012) suggest *flexible port design and planning* and Taneja et al. (2012) developed a *stochastic analysis for port expansion feasibility*, which varies all uncertain inputs and results in a distribution of the possible outcomes with the likelihood of their occurrence – the outcome of such an analysis may be a superior indicator of a port's state.

How can port *modifications* affect the flood risk system and vice versa? When a port expands away from the waterway in the direction of the polders, the dike in between may have to be relocated. A deeper port basin can lead to higher waves or seiches, which increase the design load on adjacent flood defenses. The other way around, river projects may contribute to more sedimentation in ports.

Stronger interplays occur when an expanding port requires an upgraded waterway. Digging the Nieuwe Waterweg in 1872 required large upgrades of the adjacent northern flood defenses (Meyer 2003). An open and deeper Hartel canal since 1982 required a strong upgrade of the southern Brielse dike (Projectgroep Europoort 1989 and Projectbureau Europoortkering 1992a).

Dams and storm surge barriers affect ports negatively and flood protection positively. The Europoort barrier (18 km dikes and two storm surge barriers, see figure 3.13 on page 93) protects the cities east to the barrier, but cuts right through the port of Rotterdam. Its construction had been advanced in the early 1950s, and again in 1969, but was considered too complicated to weave in with the extensive port upgrades of the 60s and 70s (CSW 1987b). It was eventually adopted by parliament in 1987 and completed in 1997 (TAW 1989; Huisman 2010).

The Hartel canal was closed on two sides by dams with locks until 1982, open on the eastern side until 1997 and is now open on both sides. Since 1997, the Hartel canal and the Nieuwe Waterweg are closable by the Hartel- and Maeslant storm surge barriers – see also figures 3.13 1a-2b on pages 92-94.

Waterways

Ports are interconnected by *waterways*. Dutch and most European large rivers are *normalised* or *canalized* by groins, dredging, riverbed works, bend cut-offs and/or weirs, to make them less shallow and more predictable than natural rivers. Some canals have been excavated entirely through former land, sometimes even parallel to a natural river (see figure 4.2.3).

4.2.3 In southern Limburg, the natural river Maas was not normalized, nor canalized. Instead, the entirely separate Juliana canal was dug parallel to the Maas. This is also frequently seen along the Rhine and many other rivers with intense urbanization.

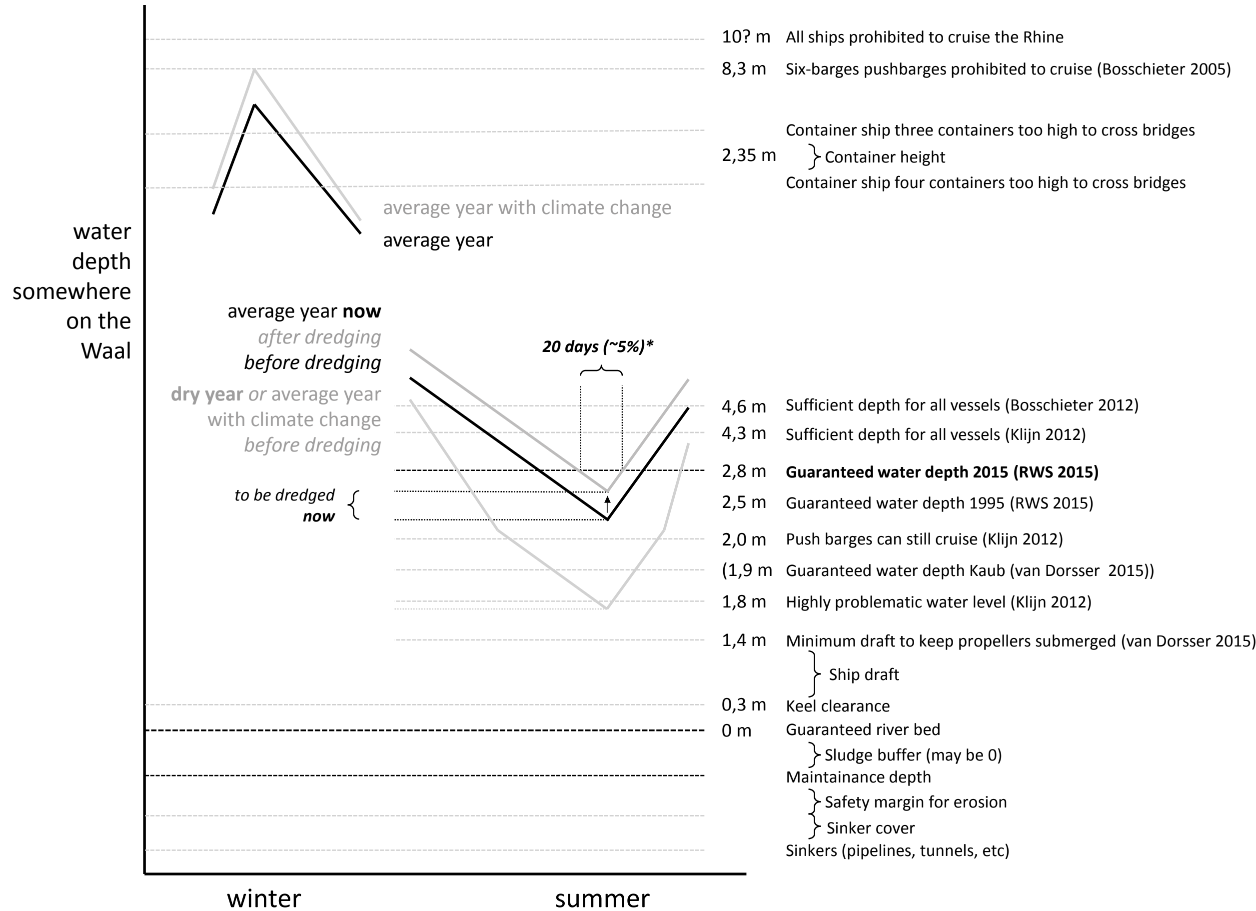
Which parameters indicate to what extent a waterway is in a condition or *state* we would like it to be in? This question will be answered from the perspective of the infrastructure manager or designer and not the skipper.

Roughly the waterway system consists of large and ever smaller classes as presented in the previous subsection. These classes however do not *dictate* the dimensions of mooring areas, waterway depths, widths and height and bottlenecks like bends and locks, but are rather a *model* or *image* of the system.

The state of a waterway is the difference between the preferred dimensions and

the actual dimensions. The first part of this difference are the insufficient *horizontal* dimensions: widths and radiuses; the second part are *vertical* dimensions: depths and bridge heights. For dynamic waters (not for highly controlled canals) the vertical dimensions are *stochastic* variables. The state of waterways should therefore be assessed at times of low-frequency hydraulic circumstances, similar to assessments of dikes and freshwater axes.

Low water levels in summer reduce ship drafts, high waters in winters reduce the space remaining under bridges – see figure 4.2.4. In the tidal rivers, storm surges possibly



4.2.4 In an average year, water levels in a river rise to a peak in winter and drop in summer. Different thresholds exist for different ships: container ships suffer from high waters, heavy deep ships from low waters.
*The 20 days criterion of 1908 determines, with the discharge probability distribution of over 100 years, the Agreed Low Discharge and the Agreed Low Water levels.

coinciding with high river discharges may impede ships in various ways. Along the upper rivers, at times of extremely high water, a shipping prohibition is proclaimed to safeguard dikes from bow waves. Waterways could also freeze up, but this has become rare because of the river normalisation and the cooling plants along the river. These weather problems lead to restrictions in load, speed, the number of dumb barges used in push barge combinations, mooring problems in ports and other disadvantages.

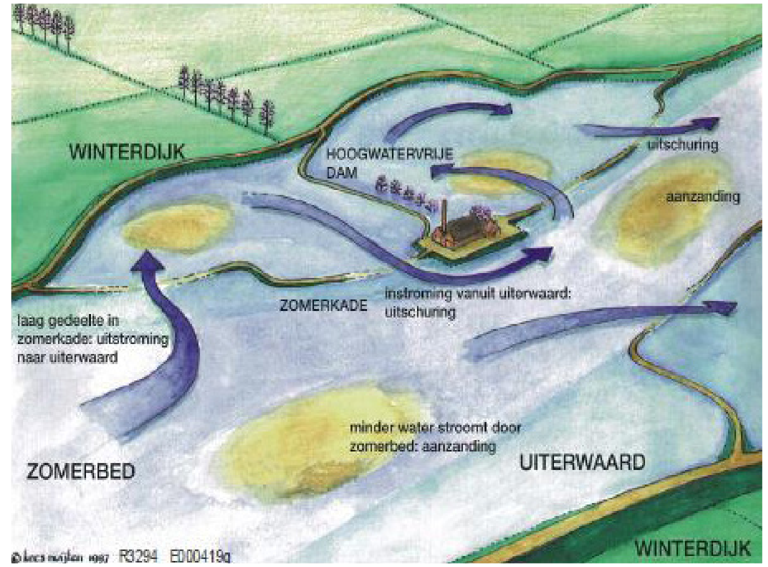
The aggregated damage suffered from these circumstances increases with weather severity in a *gradual* manner, mostly because the ship drafts are highly diversified over the entire fleet and because with reduced draft, ships can keep cruising (with less cargo).

How to present the extent of the stochastic weather disturbance in one number? Dominant in damage profiles are the low water levels, which for the rivers Waal and IJssel revolve around the *Agreed Low Discharge* (Dutch: OLA) at Lobith, near the German border. This value is a function of the discharge distribution (e.g. over the last ten years, hundred years, or a modeled future distribution under a climate change scenario) and a chosen exceedance level: since 1908, 20 days in an average year. Since 1932, the Agreed Low Discharge has been 984 m^3/s, but it was changed to 1020 m^3/s in 2002 (Koolwijk 1992; Stuurman & Koolwijk 2003).

From the Agreed Low Discharge and the river geometry (Q-h relations) follow *Agreed Low Water levels* (Dutch: OLR) along the river (the tidal rivers use the different but similar OLW and LLWS). The Agreed Low Water level at Lobith has dropped from 9,10 m in 1931 to 7,52 m today, mainly because of scouring of the river bed as a consequence of normalisation (Koolwijk 1992; van Dorsser 2015).

With the Agreed Low Water levels (an absolute height), for discharges higher than the Agreed Low Discharge, the governments along the Rhine strive to maintain *Guaranteed Water Depths* or *Least Available Depths* (a relative depth). These range along the river Rhine between 4,50 m (the canalised section near Basel), 2,80 m (the river Waal in the Netherlands), 2,50 m (the river IJssel) and 1,90 m (the rocky river bed near Kaub).

From the Agreed Low Water levels, the Guaranteed Water Depth and the *actual* river bed level, follow *dredging operations*, or, possibly, other measures. Dredging only works to level unevenness, a 'patchwork of erosion and sedimentation' (van Vuren et al. 2015). This is particularly created at times of high river water, when not only the normalised summer bed (including the waterway) is filled, but also the winter bed, which includes the floodplains (see figure 4.2.5). The winter bed is much less regular than the summer



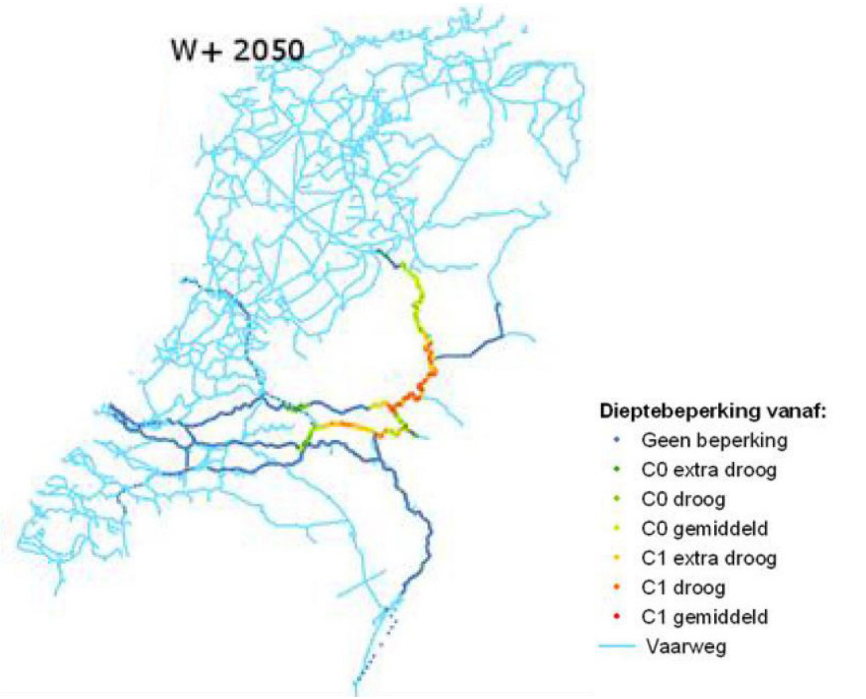
4.2.5 Room for the River measures in the floodplains, like side channels, add to overall dynamics in the river and this increases sedimentation and erosion in the waterway (Quist et al. 2011).

bed, which creates local gradients in flow velocities and thus sedimentation and erosion – this has become even more so, since the Room for the River projects in the floodplains further diversified rather than normalized the winter bed (van Vuren et al. 2015; Kisoensingh 2015).

From all this, the *yardstick* to determine the '*vertical*' component of the state of a dynamic waterway segment could be the river bed's *average deviation from the Guaranteed Water Depth* (in cm). The total level of insufficiency, including desired upgrades in the *horizontal* plane, can be expressed as lacking square meters (for cross-sections) or volumes (for stretches). In most shipping models, levels of insufficiency are expressed by lost cargo volume, time or turnover, but these values usually don't show where the problems are located *geographically* – this could however be extracted from the models. One map found shows a derivative from the deviation from the Guaranteed Water Depth: to-be-dredged volumes (in m^3) (figure 4.2.6).

4.2.6 (System state) map for the river Waal, based on the dredging volumes calculated by Kruitwagen & van der Graaf (1996).

Next to studies into dredging operations or other short-term measures, recently numerous studies have been conducted to obtain insight in the long-term effects of *climate change* on shipping (including, in the terms of this thesis, on the *system state* of the waterways). An interesting parameter is the *period while a depth or height limit is exceeded* (in days), which varies for different waterway segments. For example, between 2002 and 2008, the number of days when shipping faced blockades on the Rhine in Germany due to high water, varied between 1 (in 2008) and 7 (in 2002) (Krekt et. al. 2011). The documents studied, however, focused on aggregated damages and presented no maps or tables with geographic diversifications. The only map found is shown in figure 4.2.7.



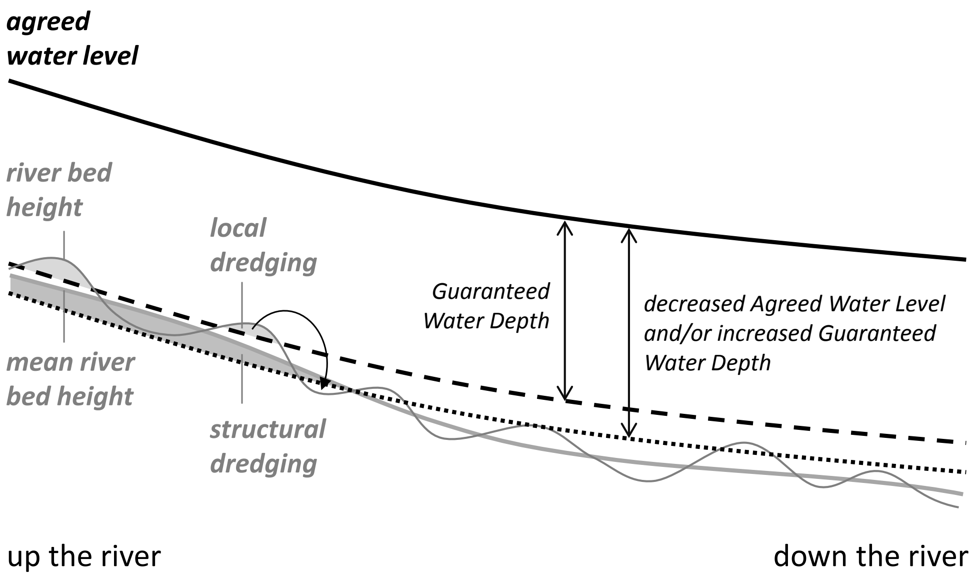
4.2.7 (System state) map showing waterway segments with depth limitations in six categories under the 2050 G climate scenario (Klijn, van Velzen, et al. 2012). The map probably reveals the shallowest parts of the Waal and IJssel.

What are ways to *modify* or *upgrade* waterways in order to achieve better system state assessments and how do these measures relate to flood risk measures?

First there is *dredging*. The effectiveness of dredging depends on the morpholical dynamics of the water body, which is low in excavated controlled canals and high for tidal and riverine waters. For rivers, figure 4.2.8 shows two types which could be called *local* and *structural*. The years before 2006, under the 2,50 m Guaranteed Water Depth, the annual amount dredged on the Waal was about 50.000 m³. After, the amount was about 400.000 m³ (van Vuren et al. 2015). To compare: in 2008 maintenance dredging in the Dutch salt waters was about 20 million m³, in the fresh waters 2-3 million m³ (RWS 2009).

(RWS 2009)) – the rise can largely be attributed to the Guaranteed Water Depth increase to 2,80, but also to dredging away the additional irregularities by the Room for the River projects (van Vuren et al. 2015; Kisoensingh 2015). Costs of dredging vary between a few euros to more than 10 euro per cubic meter. On some locations, structural underwater revetments can stabilise the river bed and avoid dredging.

The other way around, *summer bed lowering* (zomerbedverlaging) to reduce water levels at wet times (as currently done in Room for the River along the river IJssel), could possibly coincide with structural dredging (see figure 4.2.8) to increase water depths at



4.2.8 The river bed may be seen as a slowly (decades) changing average bed with rapid (years) variations around the average. When the agreed water level gets below a certain point, dredging is not anymore only about 'scraping the surface', and dredging volumes go up dramatically. When dredging would lead to a lowering of the water level altogether it would have no net effect; this is one of the reasons why dredged material cannot be taken out of the river but is relocated from shallow to deep river parts. Dredging for shipping purposes could, in particular cases, coincide with dredging for flood risk purposes.

dry times. The amount dredged for summer bed lowering in the IJssel river is about 1,6 million m^3.

Tightening a waterway by *expanding groins* increases water depths at dry times but slightly increases flood risk at wet times (moreover, it could lead to too narrow and thus unsafe passages along river bends). The reverse, *lowering groins* (as currently done in Room for the River along the river Waal) or increasing their permeability, slightly increases overall sedimentation.

Side channels in the floodplains can create crossflows and enhance sedimentation near the side channel entrance (see figure 4.2.5) and thus disadvantage shipping – this may be compensated by inlet structures, guide bunds, etcetera. The side channels and the other floodplain projects in Room for the River projects have increased overall maintenance dredging with 16% according to Kisoensingh (2015) and 100% according to van Vuren et al. (2015). The new concept of *parallel dams* (langsdammen) claims to provide the same benefits for ecology as side channels without the disadvantages for shipping, as well as the same benefits as groins for shipping without the disadvantages for flood risk (Lammers 2015).

PIANC (2009) reports the following additional measures from which both navigation and flood protection can benefit: 'maintenance of vegetation, sediment management, floodplain measures which increase flow conveyance and flow regulation such as retention basins or canalization'.

Last, a river can be, entirely or partially, *stowed* with weirs – this dramatically both increases water depths and decreases passability. The decision to stow the Meuse was made in 1915. The Lek is stowed since 1970 with special *visor weirs* (see figure 4.1.9 on page 170), which increase water depths in summer and maintain free passage in winter. River weirs may, as an additional obstruction in the river bed, increase flood risk, but this is usually taken into account with location choice and design of the work.

In estuaries and tidal rivers, *dams* drastically modify flood risk and waterways, usually positively regarding water depths and currents and negatively regarding passability.

Control structures in the shipping system

Four control structures are identified for the shipping system: two types of *locks*, *moveable storm surge or high river water barriers* and *discharge distribution structures*.

A *lock* is a device used for raising and lowering watercrafts, usually revolving around a closable water chamber separating two water bodies with different water levels, often located in a a dam or next to a weir. The same physical ship lock can simultaneously be a flood defense, a freshwater inlet and a fish passage. Of the 119 locks in the Dutch national waters, 14 separate two outer water bodies, the rest connect outer and inner water. The first lock on the river Rhine (outer water) is located 334 km up the river, in a river dam near Rastatt.

From the shipping perspective (next to freshwater conveyance and hydropower perspectives), an *upper (non-tidal) river* dam or weir is built when the low water levels *without the weir* are deemed a larger problem than the obstruction of ships *with the weir*. Some weirs are only closed in the low water season (summer) but are open in the high water season (winter); at that time ships can pass unimpeded and the locks are unused. Some of the time, the river between two *closed* weirs flows so slowly, that locks connecting that river section to adjacent tributary rivers or canals may remain permanently *open* – for example where the Amsterdam-Rijn canal (permanently fixed level) crosses the river Lek (fixed level in summer).

A *lower (tidal) river* dam near the sea with locks is built after balancing safety, shipping, freshwater and nature interests.

The *importance* of a lock is most easily determined by the ship class it can serve, then by the number of or total volume of the lock chambers and ultimately by the total number of ships or summed ship size or amount of cargo passing yearly.

The *system state* of a lock can be the remaining lifetime as estimated in projects like VONK (Tosserams 2013; Deltaprogramma 2013c). It could also be the degree by which passing ships are delayed, as an absolute time span or as a percentage of travel time. Averaging over the year reveals the advantage of a temporary lock over a permanent one. According to the National Mobility Plan (Nota Mobiliteit) 2004, accepted delay time for a ship is 30 minutes (on average and not caused by incidents) (V&W 2004). With this reference point, problematic locks are identified according to the *intensity/capacity (I/C)-ratio* yardstick (V&W 2004; Quist et al. 2011) – see figure 4.2.9.

4.2.9 Locks in the Netherlands with a low intensity/capacity (I/C)-ratio in 2008 and projected for 2020 according to a low and a high economic growth scenario.

Lock *modifications* are changing operations, increasing capacity (enlarging or adding a chamber) and adding an entire lock to the system, or removing it. Up the Rhine, more frequent low summer water levels under climate change might result in new weirs with locks to further canalise the Rhine (mentioned in e.g. Bosschieter 2005; Jonkeren 2009; Krekt et. al. 2011; van Dorsser 2015). This would probably happen *step by step* in downstream direction from Rastatt with climate change increasing. *Temporary* locks, like in the Dutch river Lek, could ease the pain.

The tidal rivers contain the busiest locks in Europe, the Volkerak locks, getting busier after the planned upgrade of the connection between Gent and the French Seine river.

Delay time is currently about 45 minutes (de Jong 2009) (about 3-5% of the travel time between Antwerp and Germany). Indeed, a € 157 million plan for a fourth lock chamber has recently been made (MIRT 2014). Climate change studies have investigated damming the Nieuwe Waterweg with large sea ship locks (e.g. Stijnen & Slootjes 2010; Rijcken 2010; Slootjes & Jeuken 2013). Spaargaren (Biesboer 2014) added the entire *removal* of the Volkerak locks to this idea. This could save € 14 million in shipping delay costs annually (de Jong 2009). How much would the sea ship locks cost? The new Terneuzen lock (427 x 55 x 16 m) and IJmuiden lock (500 x 65 x 18 m), both currently under construction, are budgeted € 1 billion and € 850 million respectively (Rijkswaterstaat 2015; De Ingenieur 2012). A dam in the Nieuwe Waterweg would cost two to three times as much and on top of this, if permanently in use, result in annual delay costs of € 95-320 million, according to a Delta Programme study conducted by Ecorys (2012). Resistance to the dam in the Delta Programme has resulted in discarding the idea in an early phase (Stuurgroep Rijnmond-Drechtsteden 2014).

Relations between lock modifications and the flood risk system are first of course that, apart from locks in river weirs, locks are the focal points where the both linear flood defense and waterway systems overlap. Furthermore, between two outer water bodies, an added lock chamber can increase high water outlet capacity a little bit, as holds for example for the Volkerak locks between the Haringvliet (high water area) and the Volkerak (additional storage area). In the river bed, weirs and dams can be obstructions, leading to higher river flood levels.

Storm surge barriers diametrically differ from locks: they hardly ever block shipping, but when they do, they block completely. Some storm surge barriers, like the Eastern Scheldt barrier, do not allow ship passage at all and are thus not relevant to the shipping system. Relevant storm surge barriers in the Netherlands are the Ramspol, Hollandse IJssel and Hartel barriers and of course the famous Maeslant barrier. The Hartel- and Hollandse IJssel barriers have locks aside, which, from a shipping system perspective, could turn these control structures into *temporary locks*. (This holds for the Hollandse IJssel barrier lock, but not for the Hartel barrier lock, which has a capacity far less than would be required, as it is just a remainder from the period until 1982, when the Hartel canal was fully closed.)

Occasionally closing *high river water barriers* are different from weirs, as weirs do not block river water at times of high, but low discharges. They have a similar effect on the shipping system as storm surge barriers. Only one is found the Netherlands: the Kromme Nol barrier (but this barrier does not block a busy shipping route). More are currently not planned to be built, but were advanced by the 2008 Deltacommittee (see figure 3.35 on page 120).

An easy *importance indicator* for high water barriers would be the size of the gate opening – see table 3.34 on page 119 for more indicators.

The *system state* of a storm surge barrier could be its technical lifespan (as estimated

in the VONK programme), the closure frequency or the total closure duration over a long enough period. The current closure frequency of the Maeslant barrier is 1/10 years (Muntinga 2009). Stijnen and Slootjes (2010) calculated a closure frequency of 1/3 years for 35 cm sea level rise – see the next section on shipping objectives for when a closure frequency would become unacceptable.

High water barrier *modifications* are adding a barrier (removing one has never happened), and changing operations; mostly the *closure (water) level*. For the Maeslant barrier, this level is 3,00 m in Rotterdam (with 2,90 m in Dordrecht). With rising sea levels, this level is expected to rise (e.g. Rijcken et al. 2010; Botterhuis, Rijcken et al. 2012).

Weirs, moveable high river water barriers or *spillways* near river bifurcations may influence the *discharge distribution*. The discharge distribution has an impact on water levels on the different river branches, which determine maximum ship drafts (for low water levels) and cargo height (for high water levels) – a famous example is the Driel weir (see figure 4.1.9 on page 170). Modifying a spillway could thus be a solution for an inadequate waterway. In the Netherlands however, since 1986, control structure modifications for this purpose have hardly been topics of debate.

4.2c Shipping – system objectives

Fundamental shipping system objectives

The shipping infrastructure system aims at the *fundamental objectives* of optimal port configurations, minimal transport costs per tonne freight, maximal fleet utilization under seasonal variations and maximum delivery reliability (next to objectives which have no connection to flood risk, like ship safety, pollution, energy efficiency, etcetera). The main *system dimensions* are certain dimensions for ports and widths, bridge heights and the Guaranteed Water Depth with exceedance frequency (20 days per year) for waterways. Locks have a maximum acceptable delay time (related to the intensity/capacity ratio) and barriers a maximum closure frequency. How are these dimensions derived from the fundamental system objectives?

The current ship classes and related dimensions are considered *reasonable and achievable* by the Expertise- and Innovation Centre Inland Shipping (EICB 2015), but this qualification is not the result of a national cost-benefit framework for the entire shipping system built on the fundamental system objectives, similar to the national flood risk framework. The shipping system dimensions are the result of subsequent damage studies, policy analyses and cost-benefit studies conducted for *single* shipping system components and modifications. On a national level these are integrated in a way described in complexity theory (Page 2010) as 'emergent': bottom-up rather than top down.

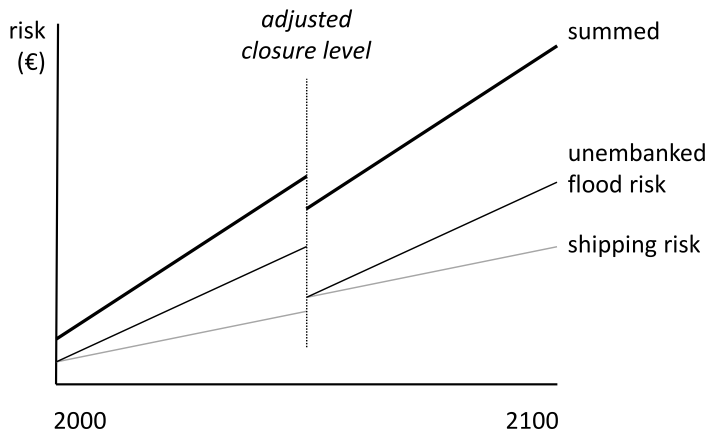
For the largest Dutch inland shipping system component, the river Waal, dimensions are *economically justified* by the Central Commission for Rhine shipping (Stuurman & Koolwijk 2003). Jonkeren (2009) estimates the average yearly *welfare loss* due to load restrictions to have been € 32 million during the period 1987 – 2004, almost 5% of the total turnover. In the dry year 2003, the loss was € 114 million (price levels 2015). According to van Vuren et al. (2015), in general, depths of 0,3 m less than the Guaranteed Water Depth reduce *transport capacity* about 10%. The policy analysis for the comprehensive Waal project (1996-2006) aimed at finding a reasonable increase of the Guaranteed Water Depth. It was estimated that an increase from 2,50 to 2,80 m would result in a *transport cost reduction* of € 60 million or more, against costs of € 25 million (per year, price levels 2015). Increasing the Guaranteed Water Depth further would impose additional problems, like too much hindrance for the cargo ships by the dredging ships (RWS Gelderland 1993). The numbers by van Vuren et. al and RWS Gelderland are higher than the welfare loss of Jonkeren – this is probably mostly due to differences between *welfare loss* and *transport cost reduction* and to a larger (projected) increased average ship size compared to the period 1987 – 2004.

During the last decade several *climate change* damage studies have been conducted, mainly to determine how climate change affects system objectives and whether system dimensions will have to be changed. Based on certain fleet compositions, Bosschieter (2005) estimated an average of 4% *load capacity reduction*, Krekt et. al. (2011) 7%, Jonkeren et al. (2009) 5.1%, in 2050 under middle climate scenarios; van Dorsser (2015) 10%-16% under the G+ scenario in the year 2100. Jonkeren et al. (2009) predict an increase in the *average annual number of days with load factor restrictions* to 182 in the W+ climate scenario in 2050, relative to 103 on average between 1987 and 1995. The studies advance various measures to reduce the damages but do not elaborate this towards 'tweaking' the Guaranteed Water Depth and/or the related exceedance probability, to find new optima between risk-reducing measures and the resulting risk, as is the current approach in thinking about flood risk.

Lock modifications are triggered by the Intensity/Capacity ratio (for inland shipping) – the threshold of 0,5/0,6 (V&W 2004), roughly corresponding to 30 minutes, is presented without an economic justification (but this may exist). For sea ship lock and other large lock upgrades, cost-benefit analyses are surely made – the IJmuiden lock upgrade for example was estimated *not* to be economically feasible by the Netherlands Bureau for Economic Policy Analysis (CPB), but is nevertheless currently built (Milikowski & Hoekstra 2012).

For *storm surge barriers*, De Jong & Vellinga (2010) calculated an according shipping damage per closure of the Maeslant- and Hartel barriers of € 2,5 million now and € 3,2 million euro in 2050, confirmed in a subsequent study by Ecorys (2012) (between € 2,8 and 4,3 million in 2050). Vellinga & de Jong (2012) furthermore state that too frequently closed barriers would have high indirect costs and result in a reduced reliability and image damage of the port of Rotterdam as a whole. An unofficial reference point is that a closure of more than once a year is surely not acceptable by the Port of Rotterdam (Rijcken et al. 2010).

Storm surge barrier design and operations have a direct relationship to flood risk. The high failure probability of the Maeslant barrier was the price paid for excellent ship passage. The *closure (water) level* for the barrier determines the shipping obstruction frequency on the one hand and the unembanked flood risk of the hinterland on the other. Every four years, the optimal closure scheme for the Maeslant- and Hartel barrier is estimated by balancing these two. In 2009, it was decided to maintain the then prevailing closure level (3,00 m in Rotterdam and 2,90 m in Dordrecht). With rising sea levels, this optimal level is expected to change, depending on the changing ratio between shipping risk and unembanked flood risk (e.g. Rijcken et al. 2010; Botterhuis, Rijcken et al. 2012) – see figure 4.2.10.



4.2.10 The current closure level for the Europoort (Maeslant+Hartel) barrier is supposed to balance the flood risk of the unembanked areas (caused by an open barrier) with the shipping risk (caused by a closed barrier). When the first rises faster than the second (for example under sea level rise), the closure level can be adjusted to rebalance the two.

Many policy documents and scientific studies advance *environmental benefits* of shipping over road transport: ships have a better CO_2 mileage, and more road transport would increase road congestion. Low water levels can enhance a shift from the waterway to roads (modal shift) and thus have additional environmental damage on top of economic loss; this effect is estimated 1-2% (Jonkeren 2009).

Jonkeren & Rietveld (2009) report varying findings on how the shipping sector values the objectives of reliability and related risk aversion. This would be more important on short distance transport, and is considered very relevant by some but not that important by others.

Shipping and flood risk since 1986

After the canalisation of the Rhine started in the 18th century, ship, port, waterway and control structure dimensions have increased persistently in an intricate interplay. Absolute cargo volumes kept rising until today, but since 1950 the market share of inland ships relative to rail and road declined and left inland shipping almost only for low valued bulk products. Van Dorsser (2015) writes that the shipping sector in the 70s and 80s was often perceived as a 'slow, old fashioned, and little service oriented mode of transport, bound to face a long gradual decline'. Yet, looking at the period after 1986, the shipping system turns out quite dynamic.

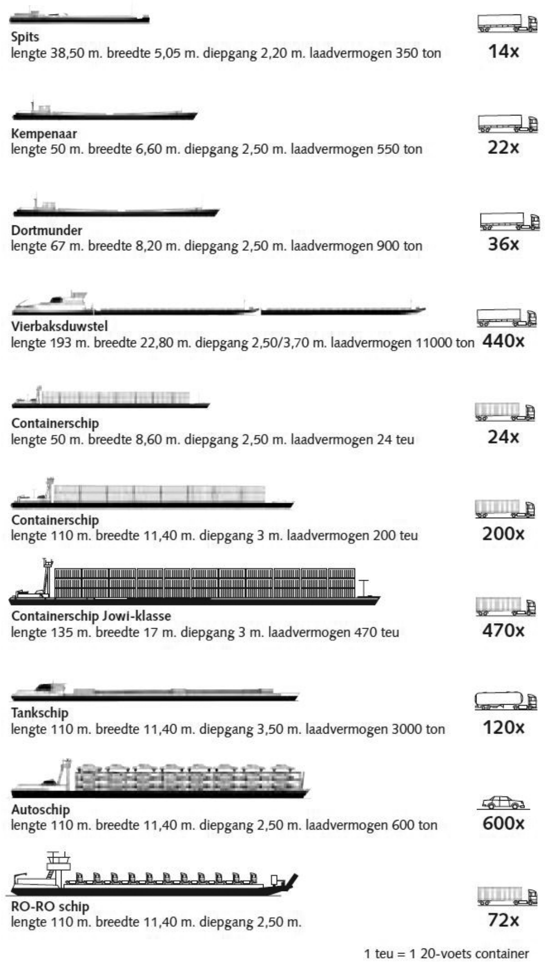
Sea ports kept expanding because of overall world trade growth (De Langen et al. 2012). Increasing environmental awareness and rising fuel prices advanced inland shipping relative to transportation over the road. In the year 2000 the shipping transportation market had been completely liberalised (van Dorsser 2015) and now has 'characteristics of a perfectly competitive market' (Jonkeren 2009), which further increased the market share of inland shipping, particularly for container transport. This growth asked for water infrastructure upgrades primarily for shipping and to reduce negative side-effects to shipping pertaining upgrades primarily for other objectives, like flood risk.

The major *upper rivers* upgrade was the increase of the guaranteed water depth from 2,50 to 2,80 m on the Waal and Rhine between Werkendam and Duisburg; a large effort, which took between 1996 and 2006 to complete and included comprehensive structural river bed enforcements in the Waal bends near St. Andries and Erlecom.

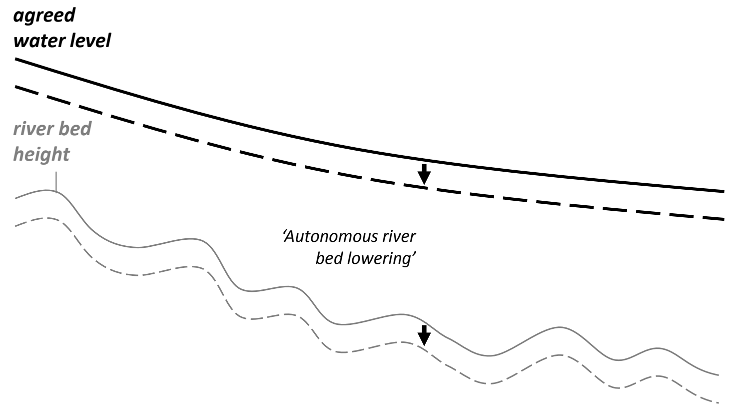
Perhaps in interplay with these waterway expansions, in 1998 the then largest inland cargo vessel was introduced on the market: the Jowi (see figures 4.2.11 and 12), a ship that sparked the construction of a new wave of large container barges for containers five or six wide. The Dutch national fraction of containers transported by barge increased has increased since 1994 to 33% in 2002 and is expected to keep rising, but this has little impact on the water infrastructure since the draft of volume-dominated ships is lower than weight-dominated ships.

What are the relations to flood risk? The 'autonomous sinking of the river bed' (from 7,95 in 1985 m to 7,70 in 1991 and further), caused by the continuous normalization (see figure 4.2.13), has a small positive effect on flood risk. Similarly, the deepening of the waterways in the 2000s could be considered a river profile expansion like the Room for the River summer river bed river lowering (see figure 3.28 on page 113), but mentions of this connection by both sectors has not been found. The other way around, river expansion projects in the floodplains (under Room for the River, NURG as well as the Water Framework Directive) enhance sedimentation in the waterway and thus imply even more maintenance dredging. According to van Vuren, Havinga et al. (2015), this phenomenon was largely disregarded during Room for the River but now gains support.

4.2.11 The Jowi (Henken 2015).



4.2.12 The enormous size of the Jowi becomes clear particularly in comparison to other ship types (V&W 2004).



4.2.13 The 'autonomous sinking of the river bed' is attributed to the river normalization: on the one hand, less sediment is added to the waterway; on the other hand, increasing flow velocities scour the river bottom.

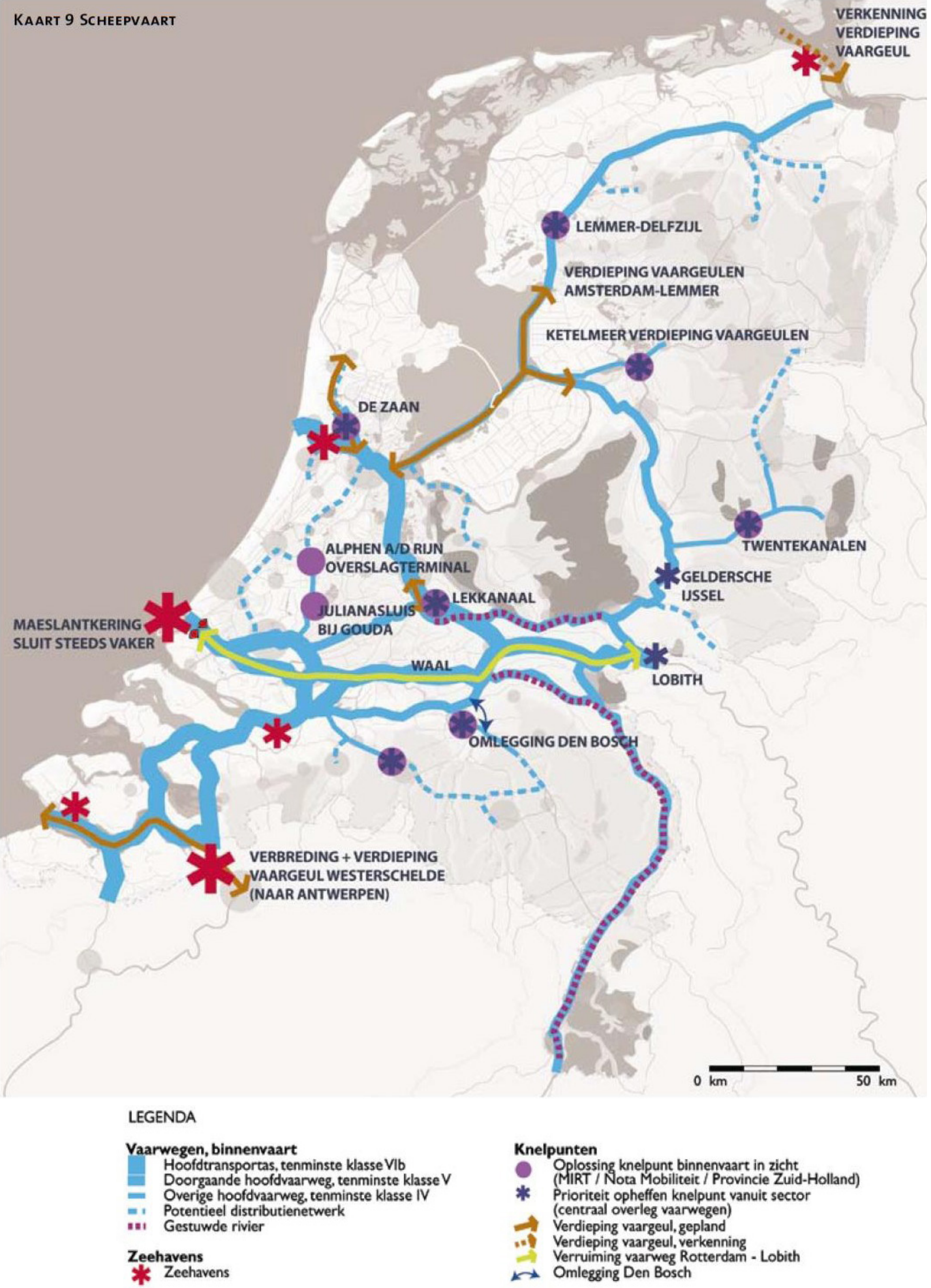
The history of the *tidal rivers* shows an even more intense interplay between the shipping- and flood risk systems. The overarching design choice has (not always, but eventually) been to dam most parts, but to leave two shipping axes open (the Oude and Nieuwe Maas). These waterways were deepened and widened to facilitate sea ships to the heart of Rotterdam and even all the way to Moerdijk (total dredging around the Port of Rotterdam is 15 to 20 million m³ per year – Vellinga & de Jong 2012), but the expanded waterways allowed deeper penetration of storm surges.

The idea to construct a storm surge barrier between the northern South Holland and southern Briel dike rings had been proposed for the first time in the early 1950s, and again in 1969, but was considered too complicated to weave in with the extensive port projects of the 60s and 70s (CSW 1987a; CSW 1987b). In 1987, the decision for the Europoort barrier was finally made and in 1997 the building activities were finished, comprising not only the famous Maeslant barrier, but also the Hartel barrier and the dike enforcements through the industrial port sites in between (Projectgroep Europoort 1989; Projectbureau Europoortkering 1992a) – see figures 3.13 1a-1d on page 92-94.

So far, the largest upgrades since 1997 have been the second Maasvlakte seabound port expansion, the further deepening of the Nieuwe Waterweg/Nieuwe Maas and the additional lock chamber at the Volkerak dam. The largest shipping system upgrades in the other Dutch sea-dominated areas since 1987 have been the deepening of the Westerschelde and the Eems, and the new ship locks at Terneuzen and IJmuiden. These have little effect on the flood risk system.

What can be expected for the future? Shipping expert Schweig (2006) and the ministry of Infrastructure and Environment (figure 4.2.14) see many feasible future infrastructure

▼ 4.2.14 Major national shipping system upgrades, conducted and projected (Modder & Jorna 2008).



upgrades. These do not seem driven by climate change projections, despite the many climate change shipping studies during the last decade. For the upper rivers, interestingly, new statistical insights led to an *increase* rather than *decrease* of the Agreed Low Discharge in 2002 (Stuurman & Koolwijk 2003). Still, when summers would become dryer and sea level would rise, current policy prescribes less dredging along the tidal rivers and more dredging along the upper rivers.

From the documents studied, the impression arises that one or two decimetres more dredging could be possible, but not more. When this point is surpassed, most climate change authors advance new solutions, like computer-aided logistics and convoy guidance along river shallows. The engineering response to lower water levels would be additional weirs, starting up the river and moving downwards over time, and tightening the waterway by expanding groins. The latter will cause safety problems for push barges in river bends. Perhaps the crucial new balance will therefore be between a lower Guaranteed Water Depth and a smaller maximum push barge container size. This new balance should take into consideration that expanding groins increase flood risk and shallower rivers clash with sedimentation-enhancing Room for the River measures.

When the Autonomous Sinking of the River Bed continues, hard structural elements on the river bottom can become a bottleneck. Klijn et al. (2012) expect this to be a bigger problem than climate change.

For the lower rivers, the Deltacommittee (2008), Rijcken et. al. (2010), Spaargaren (2015) and others developed plans to drastically redesign the Rhine-Meuse estuary with major effects on both shipping and flood risk – see for example figure 3.35 (page 120). If measures like these would be implemented, both the shipping and the flood risk systems change dramatically.

Finally, it can be questioned whether the projected growth of global and bilateral trade will keep increasing, will slow down or even reverse. Van Dorsser (2015) argues that transport growth is unmistakably linked to economic growth, and economic growth will slow down at some point in the future. When the increase of average ship size would also come to a halt, this will somewhat reduce some of the friction between shipping and flood risk.

Applying the systems analysis framework of this thesis to the shipping system

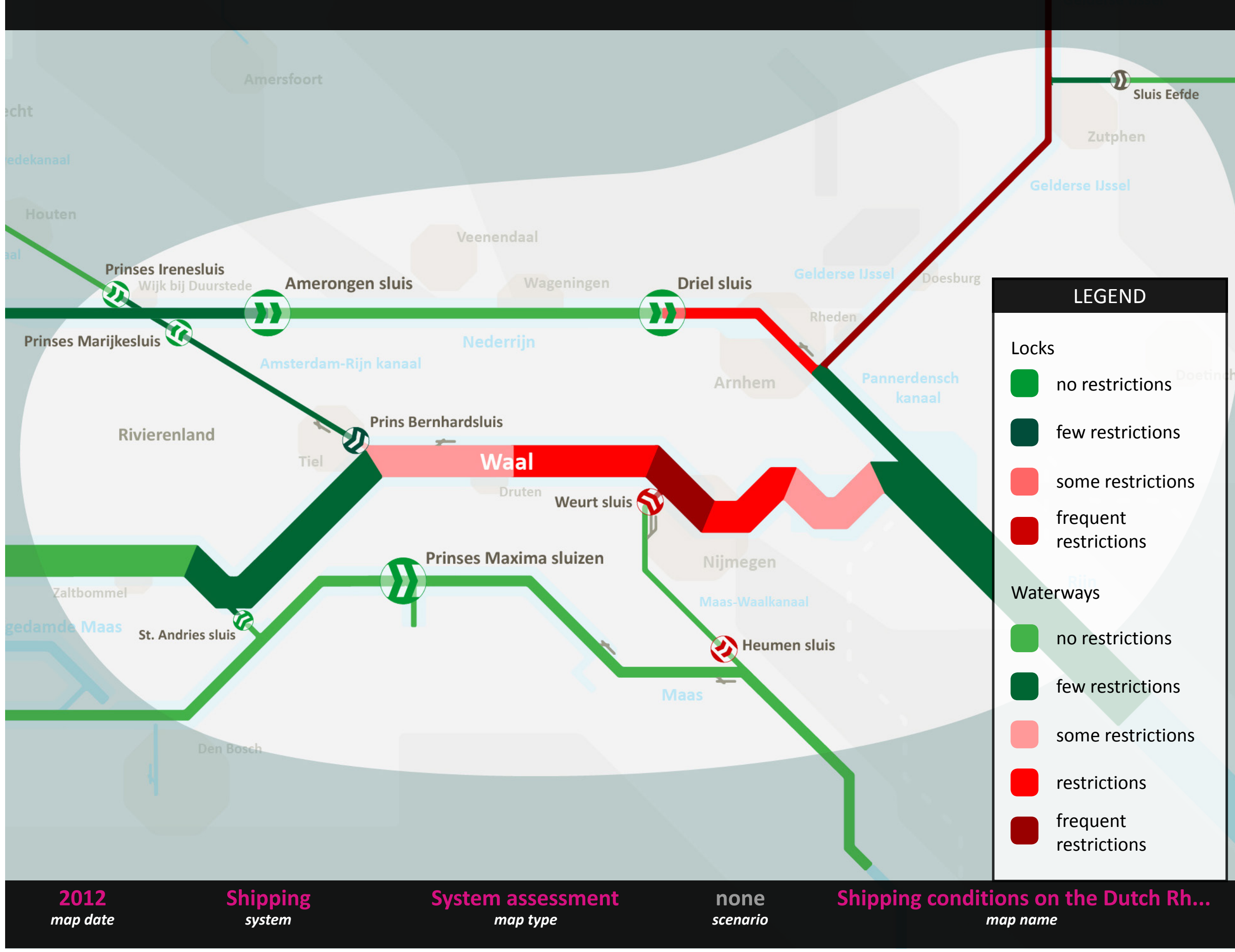
As mentioned before, the systems framework in this thesis revolves around national geographically indicated *system state* indicators based on *system requirements* derived from *fundamental system objectives*; the state of *system components* can be changed by *system modifications*. (See page 179 for the advantages of this approach.) What could this approach for the shipping system look like?

First let's keep in mind that there are waterways with *static* (depth variation a couple of decimetres) and *dynamic* (water level variation multiple meters) water levels and beds, like the Amsterdam-Rijn canal and the Waal River, respectively. Then there are two approaches.

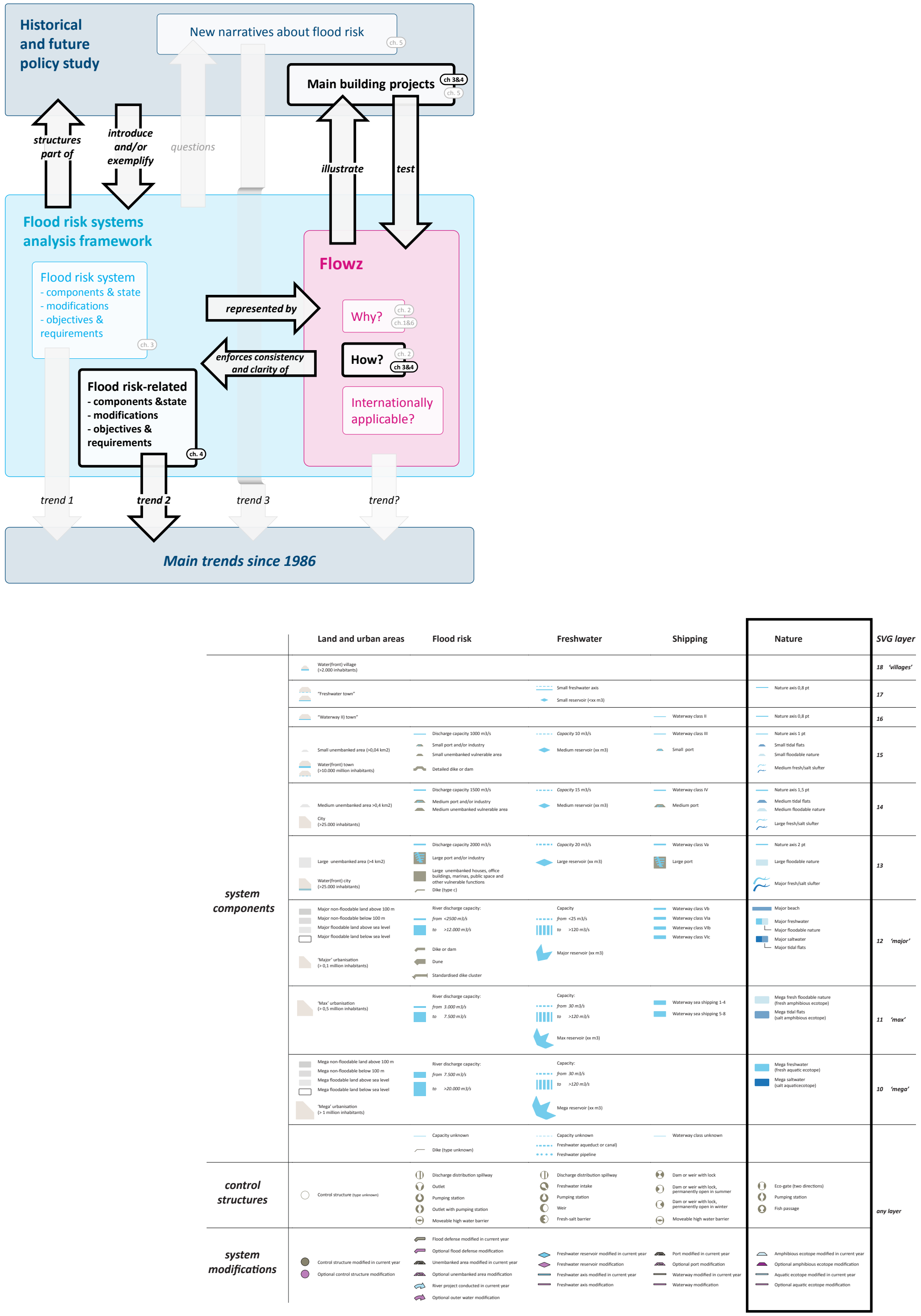
The first would be to use targets for *dimensions* (width, depth, height and radiuses) like the existing shipping class dimension requirements, which are based on fundamental objectives of acceptable monetary damage (opportunity costs) caused by underutilisation of the total fleet capacity, and then measure and model to what extent these targets are met. Flowz figure 4.2.17 is an attempt to do this, based on the maps of figures 4.2.6, 7, 9 and 14. The requirements are the supposed shipping class or waterway and port dimensions, the assessment is the extent to which these are met, indicated quantitatively (like in figure 4.2.17) or preferably in lacking cubic meters. For the *static* waterways, these are straightforward volumes. For the *dynamic* waterways, this requires additional requirements: the Guaranteed Water Depth twinning with the (20 days) exceedance period for an average year, resulting in a total deviation from a reference depth in centimetres *x* days (these days could also be turned into a percentage, for example 100 days lacking 10 cm equals 2,6 cm for one year). Measures can be implemented to mitigate the highlighted weak parts.

The existing models and frameworks are able to generate this output, with an additional probabilistic approach, like developed by van Vuren et al. (2015).

The second approach revolves around *transport costs* given a fixed amount of cargo to be shipped over a system with certain dimensions, a known fleet composition, certain climate circumstances and dredging schemes based on the Guaranteed Water Depth. Again, the requirements are the supposed shipping class or waterway and port dimensions plus the Guaranteed Water Depth and the exceedance period for the dynamic waterways. A geographically dispersed assessment would reveal sections where large ships *should* be able to cruise but *can't,* because of insufficient static dimensions, and sections of the dynamic waterways where transport costs during extreme days of the year deviate from the costs at normal days for the same cargo. The assessment unit is damage in euros or as a percentage of full capacity not met. Implementing measures results in mitigating these damages.



4.2.17 In Flowz, a user sees ports, waterways and control structures, some or all of them coloured. This map is an interpretation of maps 4.2.6, 7, 9 and 14. Clicking on a red waterway reveals ways (in purple) to improve that section (by dredging or for example by changing the discharge distribution). The *ports* in this map are browngray, but they can also be coloured: green ports are happy, red ports desire to host a higher ship class; clicking on a red port reveals required waterway and control structure upgrades (in purple).



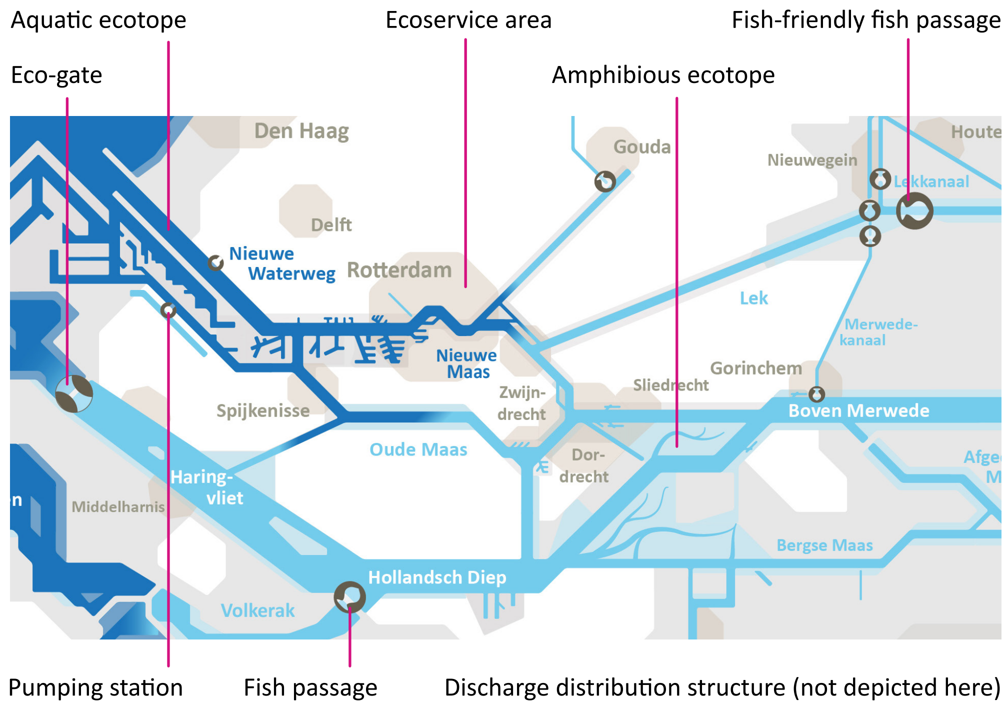
4.3.1 This chapter completes this part of the thesis as explained in chapter 1 (figures 1.15 and 1.16 on pages 40 and 42).

4.3a The aquatic nature/ecotope system

Nature/ecotope system sections outline

The two aquatic nature sections follow the same structure as the flood risk chapter and the freshwater and shipping sections. Aquatic nature is described as a system, using the *historical systems analysis* framework, working towards relationships with and similarities to the flood risk system and finding one or more general historical trends (see figure 4.3.1).

The next introductory subsection gives a definition and some essential general information. The next section (4.3b) treats four *system components* in turn: ecoservice areas, aquatic ecotopes, amphibious ecotopes and control structures (see figure 4.3.2).



4.3.2 The four essential aquatic nature/ecotope system components in this thesis and in Flowz. In the Flowz background, the dark blue amphibious ecotopes are salt or brackish beaches and tidal flats – these can almost always be considered “nature” as land user. The light blue amphibious ecotopes contain more than 50% freshwater vegetation (agricultural grasslands and amphibious nature), next to buildings, industry, etcetera. When aquatic nature/ecotope system *maps* are clicked, it becomes clear what the ‘nature value’ of an amphibious nature patch is.

Each component is described by ways to characterize a component's importance, to assess or represent a component's *performance* (or *state* or *condition*) and furthermore by the main types of the nature/ecotope system component (man-made) *modifications*, focusing on modifications which affect the flood risk system, and flood risk system modifications affecting the nature/ecotope system.

Examples (mainly for the period since 1986) are mostly drawn from the development of the Dutch Southwestern delta, tidal rivers and the adjacent upper rivers. The system description fits the Netherlands; representing foreign systems with the same universal (Flowz) language and symbols is investigated in Rijcken and Christopher (2013).

The three subsections of the aquatic nature *objectives* section (4.3c) treat the questions:

1. how fundamental nature/ecotope system objectives are expressed and how these fundamental objectives are operationalised (possibly with system *requirements*) for decision-making,
2. what the main trend in system modifications and changing attitudes about the nature/ecotope system have been since 1986,
3. which general conclusions can be drawn about the relationship between the nature/ecotope system and the flood risk system,
4. whether the approach for the flood risk system as described in chapter 3 (mapping the system state relative to system requirements), is available or possible for the nature/ecotope system.

A discussion and the general conclusion from all flood risk-related objectives is drawn at the end of this chapter (and not at the end of these subsections).

The aquatic nature/ecotope system

A broad definition of nature would be anything caused by a non-human driving force. In this thesis, and in many Dutch discourses about water and planning, the word *nature* is used in a narrower sense: as an *occupant of space*, or *land user*, similar to agriculture or airports. A plot of nature contains wild, diverse and/or rare plants, and/or is particularly designated to provide living space for wild animals. Nature may be the primary or only occupant, or a secondary co-occupant. This thesis focusses on aquatic and amphibious nature outside of the areas embanked by primary flood defenses. According to the national waters management plan (Beheersplan voor de Rijkswateren – RWS 2009), all Dutch unembanked outer water bodies are considered nature. Unembanked areas which are sometimes or usually dry can be nature, like tidal flats, but are often occupied by other land users, like agriculture or sometimes dwellings, offices or infrastructure.

There are arguments to consider *agriculture* a particular form of nature, but according

to the narrow definition of nature used in the systems analysis of this thesis, nature is a land user next to agriculture. According to the broad definition, nature is omnipresent and can be found even around airports and skyscrapers and surely on farmlands. In this thesis and in Flowz, this would be considered *multiple use of space*.

The term nature as an occupant of space feels comfortable to most Dutch water professionals, but to speak of a *nature system*, like a shipping system, does not. The word *system* is however crucial to the systems analysis framework of this thesis.

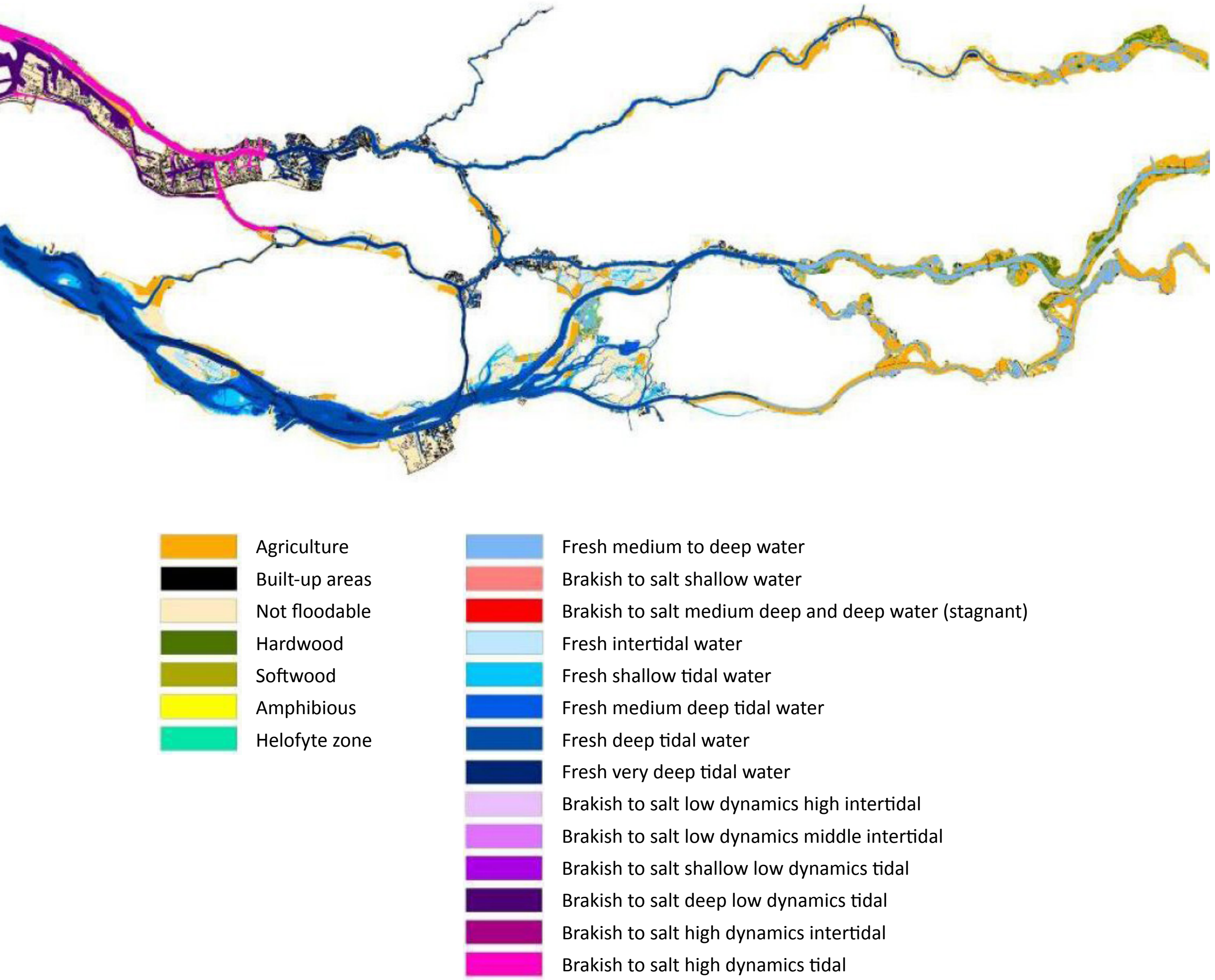
An aquatic *ecosystem* revolves around a food chain (Starosolszky 1991): nutrients, carbon dioxide and solar radiation enable algae and plants to grow, which feed zooplankton, Crustacea, fish and animals, who die and are decomposed into nutrients by bacteria. *Nature* is an occupant of space, *ecosystems* are found in all occupants of space; in different qualities, spreading their tentacles in complex ways into many environments, even airports.

Similar to the flood risk, fresh water and shipping systems, the components of the nature/ecotope system in this thesis have to be *geographically* defined. Nature as an occupant or user of space is by definition geographically bound. An *ecosystem* has a *biotic* (living) component and an *abiotic* (non-living) component. Geographical borders of biotic ecosystem components are hard to pinpoint; they change and move gradually through multiple abiotic spaces. Abiotic circumstances are hydraulics, soil and sediment dynamics, and chemical in- and outflow, which are combined for geographical differentiation into a limited number of *ecotopes* – see figure 4.3.3 for an ecotope classification of the Dutch tidal rivers.

This thesis' systems analysis focusses on the Dutch area outside the Dutch dike rings (the 'outer water') and then makes a primary distinction between permanently wet *aquatic* ecotopes, and *amphibious* ecotopes, which are sometimes wet and sometimes dry. The borders of Dutch aquatic and amphibious ecotopes are largely determined by the location of dikes, dams, unembanked amphibious areas, shipping waterways and gullies.

The term *nature/ecotope system* is introduced to avoid confusion with the term *eco*-system, and is defined as an interconnected system of aquatic and amphibious ecotopes, with *nature* as the officially recognised primary or secondary occupant of space, serving adjacent (ecoservice) areas. The Dutch nature/ecotope system is typically strongly influenced by the control structures for flood protection, freshwater conveyance and shipping.

About 28% of the Dutch territory (the North sea excluded) is nature: 11% dry embanked nature and 4% wet embanked nature (nature in the embanked areas are no system components in this thesis' systems approach), 13% unembanked nature, about half of which is aquatic and the other half amphibious nature (CBS StatLine 2008).



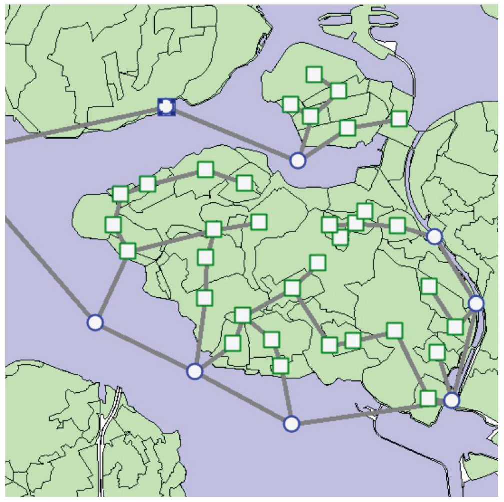
4.3.3 Current ecotopes in the tidal rivers according to Maarse (2011).

4.3b Aquatic nature – system components

Areas served by the aquatic nature system: ecoservice areas

How to define areas *served by* the aquatic nature/ecotope system, similarly to dike rings served by the flood risk system, service areas served by the freshwater system and hinterlands served by the shipping system?

In the Water Framework Directive (EP&EC 2000), areas which discharge excess rainfall and effluents containing chemicals and nutrients to adjacent aquatic ecotopes are called *capture areas* – figure 4.3.4 shows how capture areas are represented in a Water



4.3.4 Schematization of the Water Framework Directive Explorer (van den Roovaart & Meijers 2011). The squares are discharge units, located in a capture (or ‘ecoservice’) area. All discharges added up represents the load of a capture area, to be processed by the outer water aquatic nature/ecotope system (the circles).

Framework Directive water quality model. Next to having their pollution discharged, areas adjacent to outer water bodies may also benefit from the outer water aquatic ecotopes through various other *ecosystem services*, like recreation and climate regulation (Costanza et al. 1998; Reid et al 2005, etcetera); therefore, this systems approach uses the broader term *ecoservice areas* instead of the pollution-oriented term capture areas.

How to *assess* these ecoservice areas? Heavily farmed peat polders put more pressure on the adjacent water bodies with aquatic ecotopes than a forest on sandy hills. This pressure can be *quantified* by quantities or concentrations of certain substances over a certain period of time, and capture areas can be as clearly geographically defined as dike rings (see figure 3.2 on page 81). This characterisation is not about general ecological health of the water bodies *within* a capture area, only about its relationship to adjacent water bodies: a theoretical capture area which generates only mineral water, puts no pressure on adjacent ecotopes, but would score low on ecological health.

Many of the *ecosystem services* would have more value nearby a city than nearby empty lands. *Characterisations* of the potential of areas to benefit from all kinds of ecosystem services could be population, urbanisation level, or more complex variables, like potential to benefit from particulate matter (fine dust/fijnstof) reduction by aquatic willow forests.

Which relationships exist between ecoservice areas and *flood risk*? Again, in this dissertation, two systems interact when *modifications* to one system affects the other. First, nature/ecotope system component modifications may influence the flood risk system, second, measures to reduce flood risk (dikes, dams, control structures, spatial measures) may influence the nature/ecotope system.

In general, since the 70s, the Dutch capture (ecoservice) areas have become multiple times cleaner, thanks to multiple billion euro environmental programs, like the Rhine Action Programme (which started in 1987 - de Wit 1993; Huisman 2004). Emissions by factories have been strongly reduced; sewage treatment plants have improved strongly. Fertilizer policy for agriculture has been effective but further advances have recently been put on hold (Junier 2015). Pollution stored in soils is expensive to clean up and is slowly released. Yet, these developments have not influenced flood risk.

The other way around starts with the *dikes*. Ecoservice areas are often partly demarcated by dikes, and thus new dikes, removing dikes and dike relocations soon influence their characteristics. Dike *upgrades* have no effect.

Dams have no direct effect on ecoservice areas, but a strong effect on the severity of emissions into the lake created by the dam. This is illustrated by the Volkerak-Zoommeer case. The openly interconnected Volkerak lake, Krammer lake, Eendracht canal, Zoommeer and the Schelde-Rijn canal were completed by the Volkerak dam in 1970 and the compartment dams for the Oosterschelde in 1987. The first five years, water quality of this lake was considered reasonable, despite heavy phosphate and nitrogen input from the eastern farmlands. In 1991 clarity started to decline and in the summer of 1994 blue-green algae bloomed (figure 4.3.5) and ecological health deteriorated, resulting in bathing prohibitions, inability to use the lake for irrigation, bad odours and even mass bird deaths (Tosserams 2004). These problems led to concepts and policy recommendations to flush the lake with more river water or even with sea water, allowing a little tide (e.g. PWVZ & Boeters 2009). At the end of the 2000s however, the blue-green algae suddenly disappeared. This is thought to be due to seasonal variations, exotic shellfish colonisation and absorption of nutrients in the lake bed, but mainly to reduced input of nitrogen and phosphates from the capture areas (de Vries et al. 2011).

The water quality problems would not have existed without the dams, as, in ecology

4.3.5 Blue-green algae in Ooltgensplaat, the Volkerak, early 2000s (photo René Boeters, Rijkswaterstaat Zeeland).

terms, a stagnant lake is much less *resilient* (capable to cope with disturbances - Starosolszky 1991, Tangelder et al. 2012 and many others) than open sea. For the *current* decision problem between salinization of the lake and further emission reduction, relationships to flood risk are small. For a choice between a *newly* to be built dam against other flood risk solutions, like dike upgrades, expected pollution could be compensated by a *control structure*, but these are expensive and may have an impact on other water system functions (like freshwater conveyance), and thus disadvantage the dam. Yet, a high water outlet sluice in a dam, sometimes necessary for flood risk purposes, can be integrated with an outlet or intake for water quality purposes.

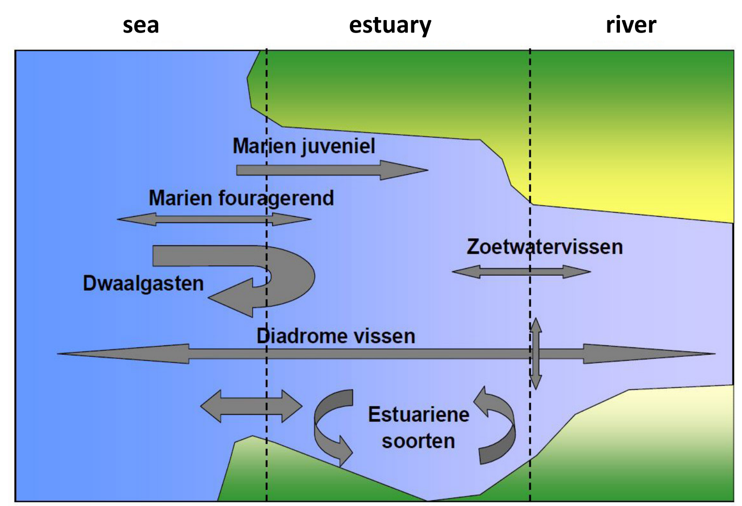
The World Wildlife Fund (WNF 2010) argues that removing the Haringvliet dam entirely, with large negative impact on flood risk (to be countered by raising dikes), benefits adjacent areas by multiple ecosystem services. The dam removal would enhance sedimentation and the growth of willow forests on new unembanked areas. These would capture particulate matters (fine dust/fijnstof) from the sky, estimated to be worth 0,2 billion euro a year. However, this benefit is worth less when Rotterdam would depopulate or finds other ways to deal with fine dust.

Finally, after dikes, dams and control structures, *spatial* (Room for the River-like) *measures* may bear a relationships to ecoservice areas. Sometimes spatial measures require dike relocations or new dikes which change the shape of the ecoservice areas. When spatial measures are combined with turning farmlands into nature, this may provide new ecosystem services to the ecoservice area.

Aquatic ecotopes

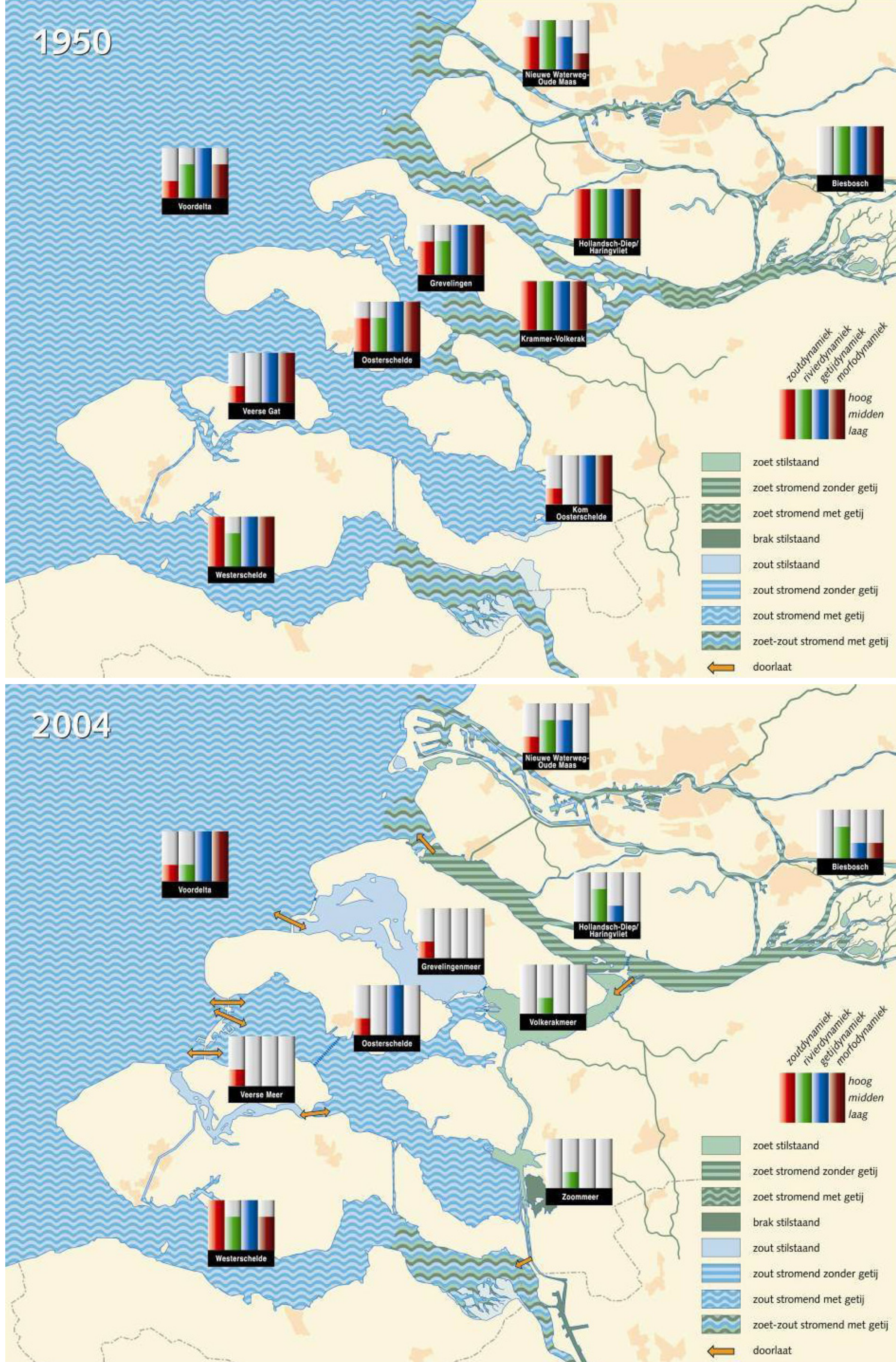
The "backbone" of the nature/ecotope system are the permanently wet *aquatic ecotopes*, which coincide with the outer water bodies as defined in the flood risk system chapter (see figure 3.23 on page 108). Water bodies located within dike rings are part of the ecoservice areas described above.

There are fluvial, estuarine and marine ecotopes, and lakes – natural or (in the Netherlands mostly), man-made. The most productive and precious are estuarine ecotopes. In these waters 'the rivers die in the arms of the sea.' This creates an abundance of food which, stirred by tidal energy, produces a biomass comparable to the productivity of tropical rain forests (Saeijs 2008). Estuaries are furthermore particularly ecologically interesting for their salt-fresh gradients, which attract rare adapted estuarine species, and for their functioning as gateways for migratory fish (see figure 4.3.6).



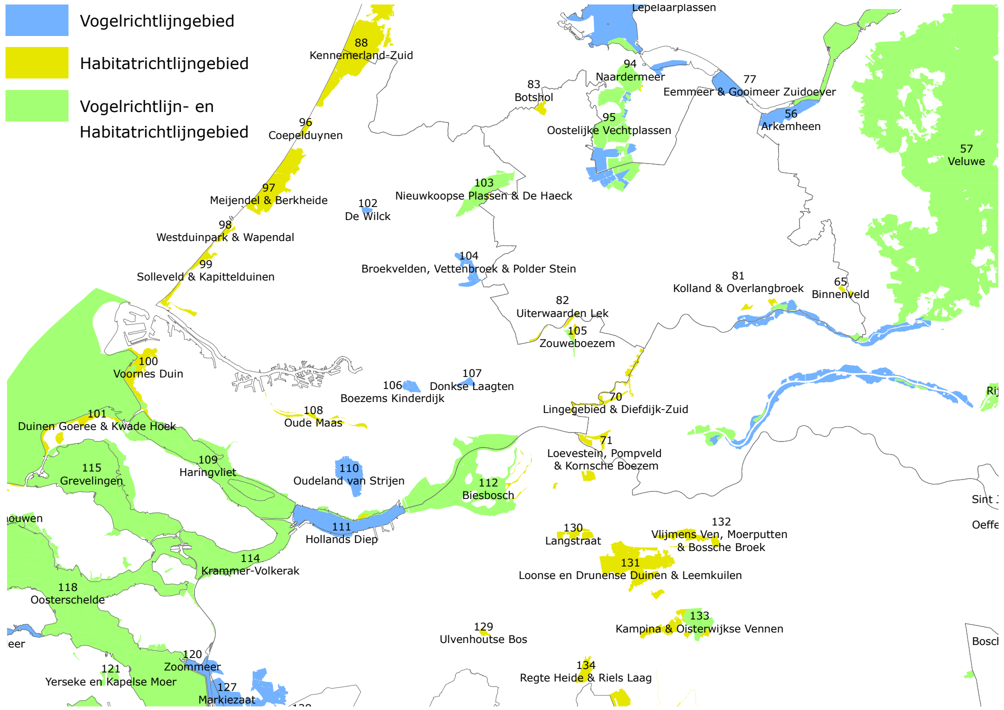
4.3.6 Natural estuaries are generally the most biodiverse aquatic ecotopes. In this image, line thickness is an indication for the number of species within a group (Baptist et al. 2007).

An aquatic ecotope can be characterised by *abiotic*, *biotic* and *integrating (all-encompassing)* variables. General abiotic variables are temperature, oxygen, chemicals and nutrient levels. The main fluvial abiotic ecotope variables are bed slope, width and depth, discharge and flow velocities, sedimentation and erosion levels. Lakes and estuaries are characterised primarily by water table behaviour, circulation and mixing versus stratification and retention time (Starosolszky 1991). Studies of estuarine ecology often address abiotic *dynamics*: river dynamics, tidal dynamics, salt dynamics and morpho dynamics (Haas & Tosserams 2005 - see figure 4.3.7). Baptist et al. (2007) add nutrient dynamics and silt dynamics to these four.



4.3.7 River dynamics, tidal dynamics, salt dynamics and morphodynamics before and after the Delta Works, according to Haas & Tosserams (2005).

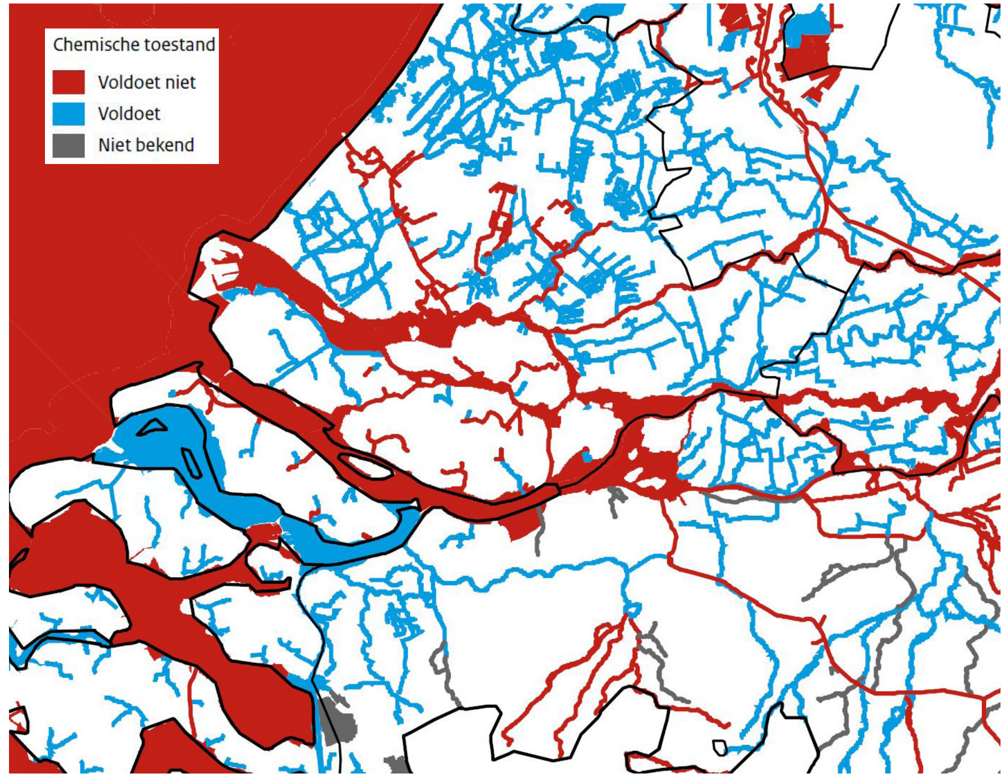
Biotic characterisations are the presence of particular animals and plants, with a certain stability, for example related to targets expressed in the Natura 2000 legislation (containing the Habitat, Birds and Ecological Main Structure (EHS) Directives - LNV 2006, IR Natura 2000 2011, etcetera) – most water bodies of the Southwestern delta are covered by this legislation, but many of the tidal and upper rivers are not (RWS 2009; Alterra 2014) – see figure 4.3.8. Presence of certain species is related to *biodiversity*, an



4.3.8 Natura 2000 areas in the lower rivers and the Rhine branches (Osieck 2014). In the Southwestern delta, the *aquatic* ecotopes are protected, but many of the *amphibious* ecotopes are not; but along the tidal and upper rivers, it is the other way around.

apparently clear and popular objective, but in practice difficult to quantify in a single number (Bouwma et al. 2014). Biodiversity indicators are the total number of species, and indices like the Shannon Wiener index and Pielou's index, which include the number of individuals per species (Tangelder et al. 2012).

The Water Framework Directive prescribes to assess a large number of biotic variables for chemical, physical and ecological quality – see figure 4.3.9 for "chemical condition".



4.3.9 Water Framework Assessment results for a number of particular chemical substances (one of multiple components of the overall assessment for chemical and ecological quality) per water body for the tidal rivers (van Puijenbroek 2014). Moving up from capillaries to arteries, colours should get more red, unless a large water body is fed by cleaner (ground) water from elsewhere, or an internal cleaning process is taking place.

The results of these assessments are added up according to certain rules to arrive at a certain overall score, using the QBWat software (Pot 2014). This is, however, not yet available for the outer water bodies.

Finally, there are characterisations encompassing both biotic and abiotic variables. *Clarity* or *transparency* (versus *turbidity*) combines the presence of suspended abiotic mud as well as biotic algae and is easy to measure. Low clarity can be an indicator for low ecosystem health or biodiversity. Other integrating variables are *naturalness* (resemblance to the state before the interference of man), *diversity* (within or between ecotopes), *connectivity* (between ecotopes) (Maarse 2011) and *uniqueness* (compared to other ecotopes) (Tangelder et al. 2012). Ecosystem *resilience* and *robustness* describe the capacity to cope with disturbances like pollution, extreme weather, earthquakes, fires, landslides, etcetera (Starosolszky 1991; Tangelder et al. 2012 and others).

These integrating characterisations are difficult to quantify in a single number. The Water Framework Directive (EP&EC 2000) has probably resulted in the largest dataset useable for single indicators for the performance of ecotopes: over one hundred different indicators are distinguished. The first assessment was in 2009, the next will be in 2015. According to the 'one out-all out principle', in 2009, only 3 out of 719 Dutch water bodies were approved. To achieve a more informative view (and to appreciate improvements made despite subsequent negative assessments), the Netherlands Environmental Assessment Agency (PBL) classified the water bodies in more than just two categories (van Puijenbroek 2014); see some results in Flowz figure 4.3.25 at the end of section 4.3c.

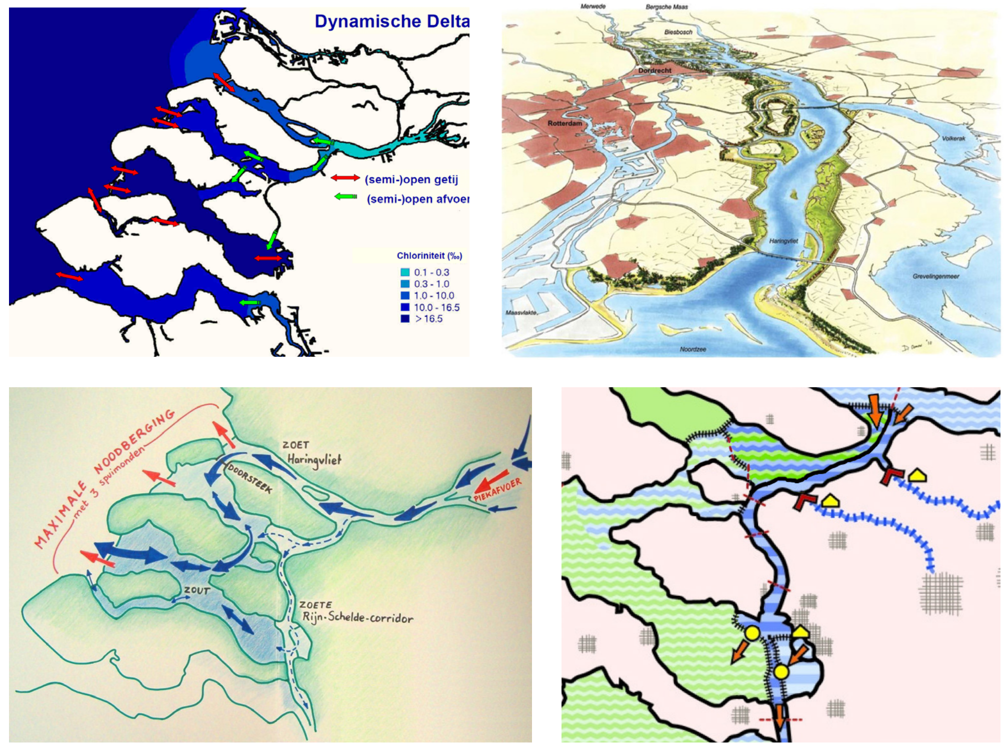
Results of an assessment may hint towards effective *system modifications*, which may or may not have an *impact on flood risk.*

High levels of phytoplankton (eutrophication) for example can be countered by reducing nitrogen and phosphate input from the adjacent capture (ecoservice) areas or by introducing plankton eaters; low scores on macro fauna (like fish) can be improved by modifying the water body and/or the control structures surrounding it (van Puijenbroek 2014). Problems may also stem from polluted beds of the water body itself, as had been the case for the Hollandse IJssel river (see Flowz figure 4.3.25), for long the most polluted river in the Netherlands, but declared clean in 2011 (MINI&M 2011).

Cleaning up capture areas, outer water bodies or river beds has no impact on the flood risk system, unlike redesigning the *geometry* of a permanently wet ecotope (widening, deepening or relocating). In the Netherlands, quite some small canalised straight rivers, like the Berkel river (van de Ven 2003), have been redesigned towards meandering curved ones. The largest aquatic ecotope restoration project is the Regge river project (30 kilometre). Floodplains were added, many meanders restored. The floodplains will flood 10 to 20 days a year and the increased floodplains result in 6,5% lower design water levels than the formerly canalised river (Medenblik et al. 2008).

Under the Room for the River project, new permanent water bodies have been created and connected to the main rivers. In the systems analysis of this thesis, these are not considered a major change in the geometry of the aquatic ecotope nature/ecotope system, but a redesign of the amphibious (unembanked) river ecotopes, connected as patches to the outer water axes. Dramatic aquatic ecotope geometric redesigns for the lakes of the Southwestern delta to improve ecology, like removing dams, have been proposed by the World Wildlife Fund (Saeijs et al. 2004; Braakhekke et al. 2008; Stroming & WNF 2010), the Deltacommittee (2008), the Borm&Huijgens group (see figure 4.3.10) and others, but have not been implemented up to date – for many reasons, probably mostly that the changes are expensive and the results are uncertain.

The other way around, how do measures to reduce flood risk impact aquatic ecotopes? All measures which change the *horizontal* demarcation of water bodies impact aquatic ecotopes; dike and dam *vertical* upgrades change a water body volume in a vertical



4.3.10 Redesigns of the Southwestern delta proposed by Baptist et al. (2007), WWF and Stroming (2010), Adviesgroep Borm&Huijgens (2011), and Rijcken with Stelling (2011).

direction, which impacts aquatic ecotopes very little. Changing operations of a control structure for flood risk purposes has very little impact on aquatic ecosystems, as control structures for flood risk are used rarely, while for ecological flows they operate daily. It may, however, have practical advantages to integrate a flood risk control structure upgrade with an ecological flow improvement. Enlarging a gate, for example, could benefit both the nature and flood risk systems.

Amphibious ecotopes

From an ecological viewpoint, occasionally overflowing *amphibious* areas are interesting and rich: they attract rare flora and fauna, specifically adapted to amphibious circumstances, like the famous Norwegian Vole (figure 4.3.11). When covered with

4.3.11 The Norwegian Vole is a mouse species adapted to amphibious circumstances. It is endemic in the Netherlands and therefore put on the Dutch (however not worldwide) endangered species list. According to some, this mouse has never been seen at all by recreationists, only in traps and on billboards (Vrijling 2015).

water, sediment and nutrients are deposited, fertilizing flora and feeding fauna. Fluvial amphibious ecotopes are for example alluvial forests and river dunes; examples of estuarine and marine amphibious ecotopes are salt marshes and tidal flats (see also figure 4.3.3 on page 216).

Most Dutch unembanked amphibious areas get wet daily at high tide, like the beaches along the North sea and the vast tidal flats in the Wadden Sea. Some get wet only a couple of times a year, like most floodplains of the upper rivers. Some very rarely, like certain unembanked areas along the tidal rivers. The ecological quality of amphibious ecotopes depends first on water quality, second on the frequency and duration of high waters (de Wit 1993; van den Brink et al. 1993). Special parts of amphibious ecotopes are the shores bordering the outer water (interesting ecotopes), and the foreshores bordering the flood defenses (can contribute to flood safety).

When is an amphibious ecotope in good shape? First, since nature is by definition an occupant of space with no or little impact by man, floodplains occupied by agriculture have poor ecosystem quality. For the value of nature, different approaches exist. Many of the Dutch non-built-up unembanked amphibious areas are covered by the *Natura 2000* species and habitat protection legislation, also the agricultural lands (Alterra 2014; IR Natura 2000 2011) – see figure 4.3.8. To achieve this legal status, an area is first put on a list of protected areas by the European Union, so it can be designated by the Dutch government as an official Natura 2000 area. A management plan for conservation then has to be made in cooperation with relevant stakeholders, a process of weighing costs and benefits between different parties (sometimes even fought over in court). There are no indicators to express the state of an unembanked amphibious patch according to this legislation in a single number, for comparison to a reference point (objective or requirement) and to each other. It should be possible to create three categories: amphibious ecotopes not covered by Natura 2000, areas which are fine according to Natura 2000, and areas which require major modifications. Maps with this categorisation do not exist, according to the relevant Dutch ministry (Osieck 2014).

According to Baptist et al. 2004; Peters et al. 2006; Peters et al. (2008), very old fluvial forests have low ecosystem quality and this could be improved by management according to the concept of *cyclical succession* (simultaneously reducing roughness for high water discharge – Smits 2008). Man should artificially introduce dynamics to enhance demolition and support the young succession stadia. Assessments could be made as the difference between the actual succession stage relative to a desired stage.

In the Netherlands, since the 90s many revetted shores or quays have been turned into *nature-friendly shores* (CUR/DWW 1994; CUR 1999; STOWA 2011) to increase attractivity and diversity (and yet, interestingly, some revetted shores, like bridge pylons, provide particularly rich substrates for rare species and are considered the best Dutch diving spots - Tangelder et al. 2012). Potential for nature-friendly shores could be mapped with linear elements and redesigns, but quantitative indicators do not exist.

Amphibious ecotopes are not assessed in a quantitative way similar to national flood defense or water quality assessments. To assess and map their system state, or to view the ones most desirable to modify, would require a creative way to combine existing information, or new analyses into for example biodiversity. It would be interesting to somehow include potentials to turn unembanked agricultural lands into nature, and/or the effort required for that conversion. Despite the difficulty to apply a general quantitative yardstick, many modifications to the Dutch amphibious ecotopes have been proposed and made since 1986.

How do amphibious ecotopes influence flood risk, and vice versa? The most famous redesigns of unembanked areas have undoubtedly occurred along the Dutch upper rivers. These redesigns usually aim at turning agricultural land into nature, and sometimes at creating more frequent and diverse inundation patterns.

In the 80s, ideas emerged among policymakers and experts to improve the deteriorated biotic conditions of the strongly 'normalised' Dutch large rivers, as part of widely shared care for the environment and desire for more recreational areas. In 1985, the EO Wijers Foundation issued their (first) landscape architecture competition, on redesigning the river landscape (EWF 1985); the winner was Plan Stork (Plan Ooievaar), which became the first large scale fluvial nature restoration project. In the decade that followed, the NURG (Nadere Uitwerking Rivierengebied) programme was put together, which would turn 7.000 hectare (of a total of about 60.000 hectare river floodplains) unembanked agricultural land into nature between 1997 and 2015 (Feddes 2012b), for a budget of €132 million (InfraSite/MI(R)T 2011).

Part of the national financial support for the NURG programme is based on the idea that turning agricultural floodplains into nature may reduce flood risk (InfraSite/MI(R)T 2011), an idea also associated with the Room for the River project (2007-2015). In the early nineties however, hardly any attention was given to this relationship. For example, none of the 13 articles of the Journal of Nature Conservation and Management special Rhine issue (van der Velde 1993), nor the foreword, mention it. The Living Rivers plan by World Wildlife Fund (Helmer et al.) in 1992, was the first to advance the connection between the two objectives. A subsequent study by the ministry (Silva & Kok 1994) concluded that the riverine forests which were to grow on excavated former farmlands would increase bed roughness and thus nullify the high water level reduction effect of the excavations (for large floodplains, 50% forestation yields about 50 cm design water level increase).

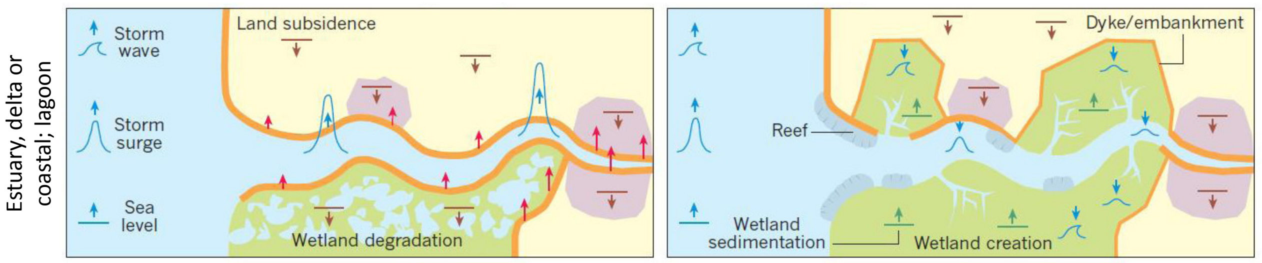
The eventual Room for the River projects demanded such low roughness to be effective, that the Room for the River landscape quality advisors wrote that 'eventually there appeared little room for nature development' (Q-team 2009, p.13). In 2011, the maintenance project Stroomlijn (streamline) was initiated, to monitor the roughness of unembanked floodplains and keep it below certain levels by detailed cutting schemes of mainly bushes, reeds and the low parts of trees, in the high-velocity parts of the rivers (Stroomlijn 2014).

Summarising: along the upper rivers, replacing agriculture in the floodplain by nature increases flood risk. The negative effects of increased roughness can be compensated with either excavations, dike upgrades or relocation and/or continuous maintenance (mowing and cutting). The other way around, spatial measures influence inundation patterns and thus fluvial ecotopes. Dike upgrades have by themselves no impact on amphibious ecotopes, yet they could *allow* for amphibious nature to grow freely.

In estuaries and tidal rivers, high river discharges are less of a problem than storm surges and wave attacks. These types of water bodies store river water until surges at sea pass. Here, turning unembanked farmland into nature, like the large Tiengemeten project (figure 4.3.12), does not affect storm surge intensity and storage capacity; roughness

4.3.12 Tiengemeten Island under Rotterdam, the largest nature development project in the Netherlands (Wikipedia 2016). Between 1997 and 2007, 7x2 km of embanked agricultural land has been turned into unembanked nature (impression by Studio Nuijten 2015).

does not halt a surge and local excavations are usually insignificant contributions to total storage volume. Wave attack, however, can be reduced by natural foreshores – a popular concept, recently advanced in the journal Nature (Temmerman et al. 2013; Moller et al. 2014 - see figure 4.3.13) and currently researched in the project BE-SAFE (TU Delft/



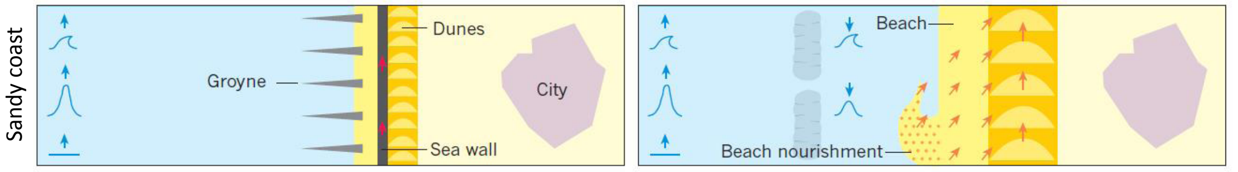
4.3.13 *Ecosystem-based coastal defence (I)* for estuaries, deltas or coastal lagoons, as published in *Nature* (Temmerman et al. 2013). For estuaries, the advantages advanced are wave energy absorption and surge attenuation into the estuary. For the latter, the surface ratio of unembanked amphibious ecotope expansion versus aquatic estuary, in this *schematic* figure, is about 4:1. This ratio in the *existing* Westerschelde estuary is 1:40, see figure 4.3.14.

4.3.14 In the Western Scheldt, one of the two remaining open estuaries in the Netherlands, the Hedwigepolder is suggested to be turned from embanked farmland into unembanked amphibious ecotope. One of the arguments is that it attenuates the surge into the estuary (figure 4.3.13). Unlike the schematics in figure 4.3.13, for the Hedwigepolder the surface ratio of unembanked amphibious ecotope expansion versus aquatic estuary is not 4:1, but about 1:40.

NWO 2014). Trees can absorb wave energy (as studied by Suzuki 2011) and *bio builders* like oyster reefs and bushy vegetation (Ysebaert et al. 2013) may increase bed roughness and have waves break sooner. On the other hand, increasing roughness obstructs the seawards bottom flow of the circular surge pattern, which pushes the surge upwards.

Either way, in the Netherlands (unlike in tropical regions) the strongest storms are in winter, when amphibious vegetation is usually gone. The strongest benefit by plants on foreshores is the sediment they collect, which on the long run reduces wave run depth and thus wave height.

For the sandy coast, *sand nourishments* are often considered measures which are 'ecosystem-based' (Temmerman et al. 2013 – figure 4.3.15) or support amphibious



4.3.15 Ecosystem-based coastal defence (II) for sandy coasts, as published in *Nature* (Temmerman et al. 2013).

ecosystems (e.g. Stive et al. 2013), and at the same time reduce flood risk. The main positive ecological effects are growth of dunes and expansion of amphibious beach flats. Yet, not all sand nourishments effectively reduce flood risk, for example along parts of the coast where the existing flood defenses are already strong enough.

Nourishments to fight the *sand hunger* of the tidal flats in the Oosterschelde and some uninhabited islands in the Wadden sea, are conducted only to benefit natural habitats (Rijkswaterstaat 2008).

Finally, how are amphibious ecotopes in seas, estuaries and the lower rivers affected by flood risk system upgrades? Dike relocations can create new amphibious ecotopes, dike upgrades have no effect, spatial measures are only effective in the upper river system and have been described above. Control structures have major effects on amphibious ecotopes when they change flow patterns. Dams have major effects, as usual: they can change a tidal flat with no vegetation into a freshwater island with trees. Since the Delta works however, no new dams have been built in the Netherlands. When flood risk control structures (see the next subsection) and their operations are modified for flood risk purposes, this usually has no impact on ecology, as flood risk events are rare.

Nature/ecotope system control structures

In a highly compartmented system like the Netherlands, *without* control structures, dikes and dams would create isolated and poor ecotopes, yet straightforward; *with* control structures, the interaction between the enclosed ecotopes can make the man-made nature/ecotope system acceptably healthy, but at the same time complex.

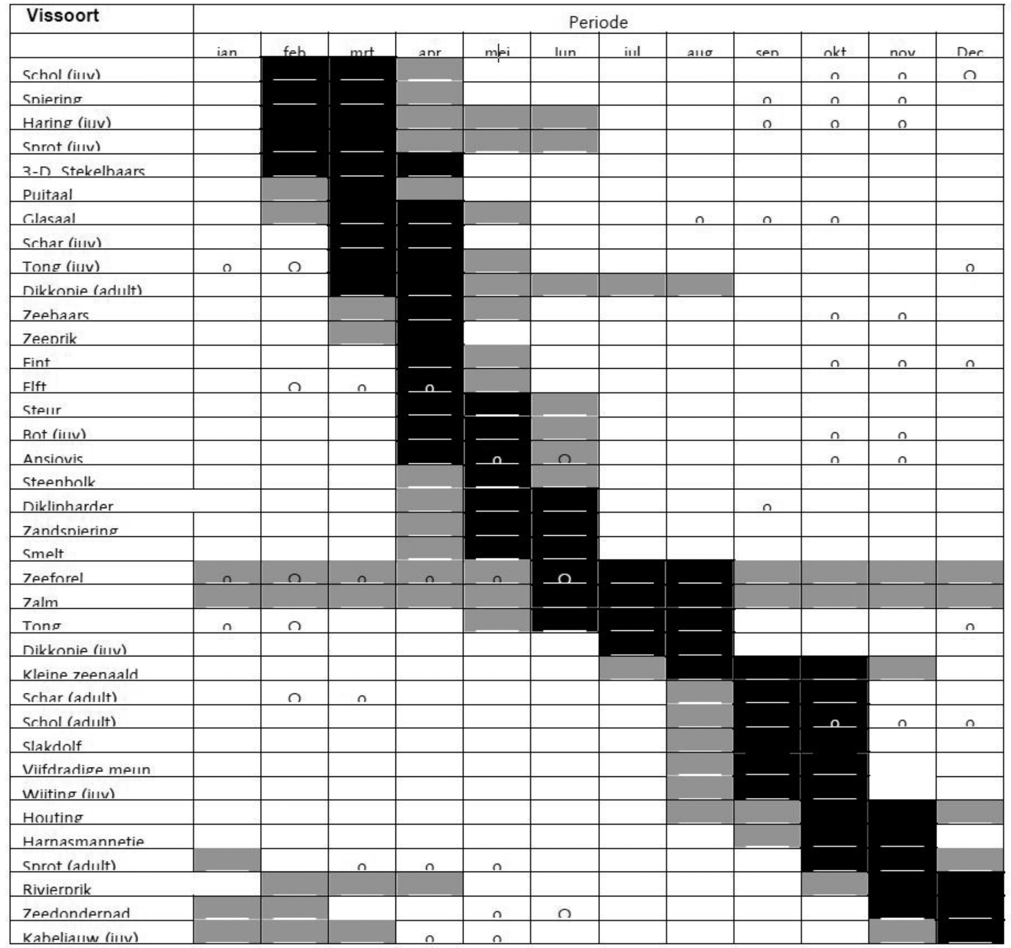
Control structures for nature are often the same physical objects as the control structures for flood risk or shipping. Some are adapted, like fish-friendly pumping stations, and some are solely built for the nature/ecotope system, like tidal gates or fish passages. Control structures for flood risk are used only under extreme circumstances, while control structures for nature operate daily.

Control structures for ecological purposes can be categorised in many ways, since there are many ecological flows to influence. Technically, all are gates (intakes, outlets or both), pumping stations (fish-killing or fish-friendly) or fish passages. Some control structures work partly during the year, like some ship locks and the fish passages along the rivers Lek and Maas.

Similarly to the control structures in the flood risk system, there are control structures connecting the aquatic and amphibious unembanked ecotopes to the ecoservice areas (*category a* – see subsection 3.1), and control structures connecting different unembanked (outer water) ecotopes to each other (*category b*, or simply *located in dams*). Of category a, there are hundreds in the Netherlands, of category b, there are currently 26 (excluding objects with relatively large openings which close only very occasionally, like the Maeslant barrier).

How to determine the *condition (state)* of a control structure? This could be done for the state of the object *itself* (an assessment outcome, reliability or remaining lifespan), or concern its positive or negative effect on *adjacent* water system functions. Ideally an assessment would vary per addressed function: a gate could be assessed inadequate under projected extreme high waters, but reliable enough for daily ecological flows. Current Dutch control structure assessments are, however, not specified for different functions. The available data are *failure probability* (for the flood defense function – VNK2 2013) and *remaining lifetime* (for various functions under RINK and VONK – Tosserams 2013), discussed in the previous chapter. These variables are relevant for the rest of the water system because they indicate when the object needs an upgrade, which could be combined with a physical or operational redesign or a redesign of related other water system components.

Aquatic nature control structures can also be characterised by the extent to which they block environmental flows like fish migration. This can range from total passage time through a ship lock (open short but daily), obstruction by closed outlets (permanently closed for weeks on end in a dry summer), or a percentage of fish being killed while passing a pumping station (up to 50% depending on fish size, pump type, rotation speed and other factors - STOWA 2012). This becomes more complex knowing that different fish species migrate at different times during the year (see figure 4.3.16).



4.3.16 Fish migrate mostly in fall and spring – fortunately for the fish not in summer, when many control structures close more frequently (SRK 2004).

Relationships between the flood risk system and adding, modifying or changing the operations of category b-control structures for ecological purposes, are strong. A dam or dike crossing a water body usually heavily affects aquatic ecotopes. An opening mitigates this effect, but has to be closable at least under extreme circumstances, and usually more frequently to protect unembanked areas. Once a dam and a control structure are in place, operations are the rotary knob to balance interests.

The tidal gate in the Brouwersdam for example was the first (completed in 1978) Dutch ecosystem-directed system modification (see figure 4.3.17). It connects the

4.3.17 The tidal gate in the Brouwersdam is located right to the center of this picture (taken during the yearly Concert at Sea (Volkskrant 2014)).

Grevelingen to the North Sea with two closable underwater cuvet gates with the aim to reduce stratification, increase oxygen levels and allow fish to swim between the North Sea and lake Grevelingen. The gate openings are automatically adjusted to keep water levels in the lake between a 30 cm range. The maximum capacity of the two gates is 405 m^3/s; the daily average through flow is 123 m^3/s (Deltares 2008a). If it wasn't for preventing flooding of the unembanked shores and islands in the lake, there could be stronger flows and more tide. At this moment, policy proposals are made to change operations of the current gates, add additional gates and redesign the lake, its shores and the unembanked areas (I&M 2014).

The largest eco-gate on the planet, the 62 Oosterschelde gates, completed in 1986, also stems from a conflict between ecology and flood protection. The current total gate size under water is about 20.000 m^2 – about 25% of the total opening size before the dam (for the Grevelingen, these numbers are 54 m^2 and less than 1%). Now that the barrier is in place, operations are in favour of ecological flows: with a closure level of 3 m at sea, the barrier has closed 22 times during 28 years, and is thus open more than 99% of the time (Deltares 2008a, RWS 2014).

In 2004, a tidal gate was added to the Veerse Gat dam to salinize and flush the Veerse Meer. For the other control structures in the Southwestern delta, design and operations are hardly directed by ecological desires. The Volkerak Zoommeer salinization project may change this. The proposed changes to the control structures surrounding the lake have no interference with flood risk of the *embanked* areas, but the *unembanked* built-up areas around lake Volkerak restrict tidal fluctuations to 30 cm (PWVZ & Boeters 2009; I&M 2014).

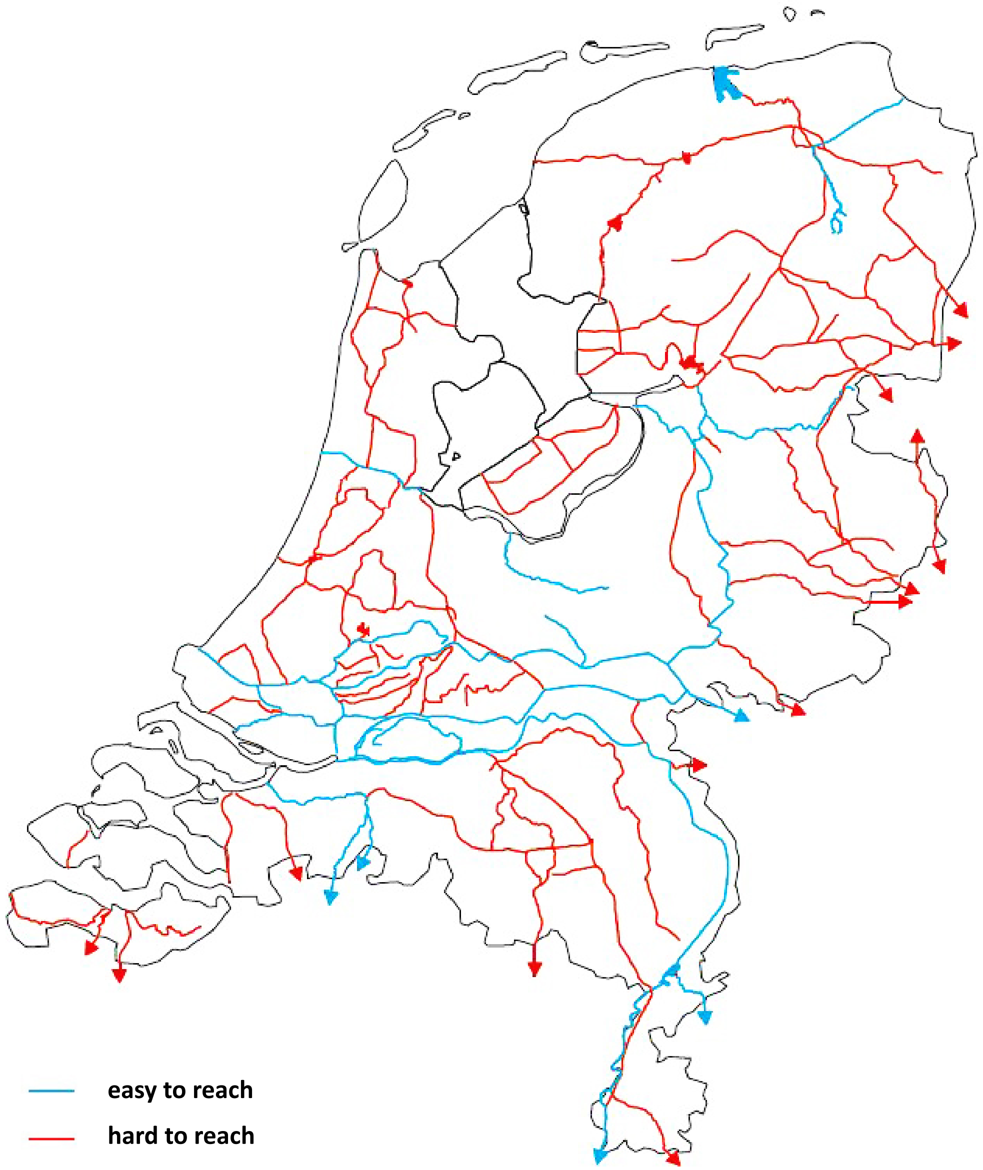
Many Southwestern delta nature/ecotope system redesigns have been proposed and modeled since 1986 (Draaijer et al. 1994; de Leeuw & Backx 2001; Haas & Tosserams 2001; Blauw et al. 2004; Haas & Tosserams 2005; Baptist et al. 2007; Maarse 2011; Nolte et al. 2013; Ysebaert et al. 2013). In the studies, often stretching very far into the future, dams are removed, control structures redesigned and operations changed. An advanced model is the 1D particle flow model by Nolte et al. (2013). Output is (under daily and extreme circumstances) flows, fresh-salt gradients, tides, nutrient flows and primary biological production; stratification, oxygen levels, growth or decline of tidal flats have to be judged by experts. This is input for the final effects on habitat types and qualities, like established by Ysebaert et al. (2013) for the work by Nolte (2013). Nolte notes that *optimisation of the control structures* is not modeled but is expected to enhance results greatly.

Fish are an important indicator for ecosystem quality and control structures have a very direct impact on fish migration. The largest and most famous Dutch fish migration restoration project is the policy strategy to set the Haringvliet sluices ajar (SRK 2004), which should improve fish migration to spawning grounds in Germany and create a longer and more dynamic estuarine gradient around the Haringvliet dam. The operational conflict is mainly between nature and freshwater supply; there already is a passage (of 18 m^2 in size) but there is no fresh-salt gradient for the fish typical for estuaries, diadromous and migratory species (see figure 4.3.6 on page 220).

It appears that mixing fresh and salt water behind artificial gates is complex and that effectiveness highly depends on precise operations: gate opening regimes depend on specific ebb and tide levels and river inflow, gates remain closed during very dry summers, salt water is flushed out when a dry period is forecasted and even the gate opening speed and exact timing matter for certain fish and even seals. Precise and varying real-time steered operations result in a high average salt water input, but also in less stability, which might impair certain rare brackish subsystems on the eastside of the dam. The new operations will be effective in 2018 (Helpdesk Water 2013a).

Some fish barriers can be tackled with specially designed fish passages. The largest ones in the Netherlands are located next to the weirs in the rivers Lek and Maas. The Lek weirs close when the Rhine discharge is under 2.400 m^3/s, roughly between October and May. The Maas weirs close in summer, depending on rainfall in the French-Belgian catchment area (Waterdienst 2011). Currently a concept is developed for probably the largest fish passage in the world, near the Afsluitdijk (Helpdesk Water 2013c - see figure 4.3.18). When fish passages are closable, conflicts with flood risk and freshwater can be mitigated.

4.3.18 New design for a fish passage at the Afsluitdijk, probably the largest in the world if it would be built (PRW 2013).



4.3.19 The main fish migration routes in the Netherlands (PBL 2011). Interestingly, while tens of millions of euros are spent on 'setting the Haringvliet ajar', the fish migration from the Haringvliet to Germany is in this assessment not deemed problematic.

4.3c Aquatic nature – system objectives

Fundamental aquatic nature/ecotope system objectives

Why would we want to have clean ecoservice areas, dynamic, healthy and rich aquatic ecotopes, diverse and attractive amphibious areas, and as passable as possible control structures; in short, more and better nature? The debate (e.g. PBL and Schouten 2016) about what nature is, why it is important, what it is worth and how to achieve improvements is intriguing, complex and probably endless.

The *biophilia hypothesis* suggests that human beings are instinctively attracted to other living creatures (eg. Wilson 1986). 97% of Europeans find nature conservation a *moral obligation* (van Oostenbrugge & van Egmond 2012) – nature should be protected, even when we don't enjoy or experience it personally. Schouten (with PBL, 2016) quotes the idea that 'nature has a *right* to wilderness'. Vrijling (2016) summarises the shift in perspective on nature during the 20th century as 'nature: from servant to god'. These perspectives can be considered fundamental and essentially *spiritual*.

Next to spiritual perspectives, nature has an *esthetic* value when we encounter it; nature pleases our senses and calms us down. According to philosopher John Gray, "birds and animals offer us admission into a larger scheme of things, where our minds are no longer turned in on themselves. Unless it has contact with something other than itself, the human animal soon becomes stale and mad. By giving us the freedom to see the world afresh, birds and animals renew our humanity" (Gray 2011). Third, ecosystem health has *practical* benefits, like contributing to hygiene issues. This distinction, in spiritual, esthetic and practical objectives, is not straightforward: perhaps esthetic pleasure is in today's society so important it should be called a practical objective; one might consider the calming effect of an esthetically pleasing landscape to be a spiritual experience, etcetera.

The Netherlands Environmental Assessment Agency (PBL) distinguishes four perspectives on nature: vital nature (biophelia – spiritual), functional nature (focus on ecosystem services – practical), liveable nature (focus on recreation – esthetic) and amenable nature (allowing nature only in private spaces or otherwise only where there is no conflict with other land users – esthetic/practical) (van Oostenbrugge & van Egmond 2012; Bouwma et al. 2014). Van Heezik (2007) writes that the heated debate about the rivers in the 90s, boiled down to the fundamentally different perspectives of anthropocentric (esthetic/practical) versus eco-centric (spiritual); in the words of Vrijling (2016) to nature as *servant versus god*.

How to operationalise these perspectives towards practical policies? An important *reference point* is the state a water system component is thought to have been in before the interference of man, regardless whether that would be attractive to us or not: the *naturalness* criterion. Setting this point as an objective may be desired from a spiritual perspective, but is pragmatic, too: our experience of the way ecosystems are intermingled with human systems may be so complex, that setting reference points other than the original state is impossible. To complicate things further, static references will always be debated, because nature is always changing.

Nevertheless, the *naturalness reference* is frequently used and expressed in biotic or abiotic terms. De Jonge & de Jong (2002) suggest that the only way to restore ecosystems is to restore basic abiotic processes, like the original tidal dynamics in an estuary. It may be fundamentally impossible to *define* a reference and to *restore* an ecosystem towards it once man has entered the scene; it is however important to at least acknowledge the spectrum between what Schouten (2008 and 2010) calls Wilderness, untouched and primordial nature, and Arcadia, a green blue landscape clearly ordered and appreciated by man. The concept of 'Wabi' suggests to appreciate and cherish the impact of nature on human artefacts on all scale levels, especially when it is not foreseen yet attractive (Rijcken 2011) – see figures 4.3.20 a and b.

4.3.20a The *Wabi* concept (De Botton 2008; Rijcken 2011) revolves around attractive and harmless influence of the forces of nature on man-made artefacts, from the scale level of moss on roof tiles to wetlands in the fringes of an entire polder.
Above: in the heart of the Maasvlakte (Europe's largest port), built anew in the North Sea, a seagull breeding area soon established on an empty sandy shore (photograph TR).

The *original* (or otherwise preferred) *natural state* is usually subdivided into different elements which are easier to quantify than the whole, like the presence of particular species or occurrence of abiotic processes. Setting hard targets is difficult and debatable, but quantification is needed to set conservation targets and to be able to compare and transfer values in economic valuation and optimisation methods for spatial plans (as studied by eg. Boot (2007), Ebregt et al. (2005) and Ruijgrok (1999); STOWA (2011) uses the term *nature return on investment*. Similarly to flood risk, fresh water and shipping, nature objectives are in practice compromised towards *acceptable levels*, obtained by *acceptable effort*. Generally, the European and national government set ambitious ecological objectives, lower local governments pragmatically compromise (Boot 2007).

The largest Dutch environmental programme, the Water Framework Directive, has set targets based on naturalness, but it is acknowledged that these can be adjusted in a dialogue between policy-making and implementation about practical attainability and comparisons to other European countries (van der Molen et al. 2015).

From the fundamental perspectives on nature mentioned above, other quantifiable

4.3.20b Wabi on a regional scale: the Oostvaardersplassen once were the lowest part of the brand new Flevopolder. The area was not drained for some years, and interesting new nature appeared. Over the course of a couple of decades it turned into the Netherlands' second most valuable terrestrial national park.

references than naturalness can also be derived, but in policy-making practice these are often expressed as *narratives* and overlap with objectives which would in this thesis be considered part of *landscape quality* (section 4.4).

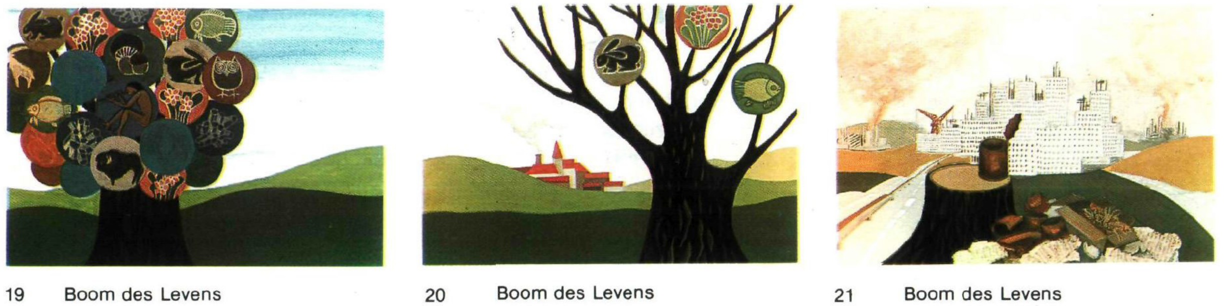
Aquatic nature and flood risk since 1986

In the 60s, 70s and 80s the Netherlands have experienced the poorest surface water quality in history – the worst environmental disasters were the Endosulfan disaster of 1969, the Kali mines salt spills and the Sandoz chemical spill of 1986. It was a time of fierce environmental activism, by NGO's as Rheinwater and the International Rhine Group, and protest events like the Rhine Tribunal in 1983. The debate started with practical arguments like the importance of healthy drinking water and clean water for agriculture and industry; esthetic arguments came later and fundamental spiritual arguments have always been a major driving force. The movement finally resulted in the appointment of official environmental boards, international treaties, in emission authorisation legislation and widespread investments to reduce pollution. It was a gradual process of activist items becoming government policy, and also of activists getting employed in government (de Wit 1993; Dieperink 1997; van Heezik 2007). In 1989, the ministry of agriculture and fishery was expanded with *nature management*.

In 1985, the influential publication Dealing With Water (MinV&W 1985) noted that flood hazard was safeguarded by the Delta Works, freshwater conveyance infrastructure needed no major new upgrades (the result of the PAWN research project – see page 176) and water quality had been improved for a total of 8 billion guilders invested in the 70s and 80s. The time had come to focus on ecological restoration, by hydraulic and morphologic system modifications like de-canalising rivers, turning floodplain farmlands into fluvial nature and expanding control structure outlet capacities. This mindset also appeared in influential visions like Plan Stork (1986) and was effectuated mainly in the NURG (Nadere Uitwerking Rivierengebied) river floodplain nature projects (as part of the National Ecological Network), local river nature projects (fish passages, eco-friendly shores, etcetera), the Room for the River project, dune restoration projects along the coast and in restoration projects in the Southwestern delta in the 90s and 2000s.

What magnitude did these unembanked aquatic and amphibious nature efforts have, between 1986 and 2015? The NURG river floodplain restoration project budget (1997-2015) has been about € 7-10 million annualy (MIRT 2014). The Veerse Meer (Zandkreekdam) outlet (2004) had cost about € 20 million (Deltares 2008b). The Grevelingen and Volkerak Zoommeer restoration project (2020 - 2028) is budgeted € 250 – 300 million (including mitigating the consequences for unembanked flood risk and freshwater conveyance) (I&M 2014), which would make this project the largest system upgrade primarily aimed at ecological improvement in Dutch history. The total Water Framework Directive budget between 2009 and 2015 is over € 2.2 billion (Projectteam Stroomgebiedbeheerplannen 2009), but these are mainly expenses made to reduce pollution and restore habitats in the water system veins inside the embanked (capture) areas. The national budget for Nature restoration (aquatic and terrestrial) in 2013 was € 200 million (Tweede Kamer 2013). The Room for the River (2007-2015) budget is € 1,7 billion (excluding dike projects) combines ecological restoration with flood risk reduction. Some sand nourishments are also claimed to combine flood risk with nature objectives. The highest expenses along the coast have been made between Hoek van Holland and Den Haag: the Delfland coast project and the subsequent Sand Engine (2008-2013) totalled € 200 million for about 10 kilometre (MIRT 2014). For the Room for the River and the coastal multi-objective projects, determining which part of the budgets can be allotted to flood risk and which parts to ecological improvements, is debatable.

Have motivations for these efforts over the last decades been practical, esthetic or spiritual? From the documents studied for this thesis and this section in particular, the impression arises that the fundamental spiritual perspective has since the 70s been omnipresent. The influential Dealing With Water document (MinV&W 1985) considers a shifting focus towards ecosystem restoration a logical course of history and uses a decaying *Tree of Life* to illustrate the underlying thoughts (figure 4.3.21). In the Plan Stork jury report (EO Wijers 1986), nature restoration is an unquestioned objective. Government documents about the Grevelingen and Volkerak project typically start with addressing poor water quality in general (spiritual) and reason towards public health and



4.3.21 Images from the key government publication Dealing With Water (MinV&W 1985): a decaying *Tree of Life* (Boom des Levens) over the years, illustrating less of a *practical* or *esthetic* but more a *spiritual* perspective on the man-made environment.

freshwater conveyance threats (practical), poor ecosystem quality for diving and other water recreation (esthetic), opportunities for shellfish aquaculture (practical) and general poor ecosystem quality (spiritual) (PWVZ & Boeters 2009; I&M 2014; Stratelligence 2014, etcetera).

It seems that the three types of nature objectives are generally highly intertwined, even more difficult to disentangle when combined with flood risk objectives. For example, the NURG projects have their origin in the National Ecological Network (EHS) policy, but are now officially called flood protection projects (MIRT 2014). The Sand Engine is sometimes called primarily a nature development project and sometimes primarily a flood protection project (Rijkswaterstaat 2011; Stive et al. 2013; Zandmotor 2014).

In section 4.3b the physical relationships between the flood risk and nature/ecotope systems have been elaborated and exemplified. A general conclusion to draw for the last 30 years is that pollution has strongly been reduced, an increasing effort was put into mitigating the negative effect of dams to aquatic ecotopes by eco-control structures, and the relationships between amphibious ecotope restoration and flood risk measures has been exploited but also been subject to confusion. World Wildlife Fund reports that wildlife population in the Netherlands since 1990 has stabilized on average, but the number of animals in and around freshwater has increased with 40% between 1990 and 2003, and has since then remained stable (numbers by Statistics Netherlands (CBS)) (WWF 2015).

From the scientific- and policy documents studied, the impression has arisen that the importance of the nature objective in water system development is more strongly *felt* than *materialised.* National investments in the nature/ecotope system undercut flood protection investments, but in general vision documents and narratives, nature-oriented arguments are omnipresent. Measures which *combine* both flood risk and nature/ecotope systems improvements are extremely popular. The Dutch political party Water Natuurlijk (Water *Natural*), established in 2008, was for two elections in a row the largest political party for the water boards. It seems likely that investments to improve the aquatic nature/ecotope system will continue or expand.

4.3.22 Poster for the victorious water board political party Water Natuurlijk (Water Natural – waternatuurlijk.nl).

Applying the thesis systems analysis framework to the nature/ecotope system

Does the nature/ecotope system already apply an approach comparable to the Dutch flood risk policy-making approach, using quantitative system requirements and system assessments? (See page 179 for the advantages of this approach.)

The Water Framework Directive could work for the *aquatic ecotope* system component. The framework aggregates biological, hydromorphological (abiotic), physical/chemical and chemical quality assessments into one single number, which is compared to a requirement: the complete natural state or a slight deviation from this state (Junier & Mostert 2012). When this is deemed impossible to obtain, for strongly artificial water bodies, a 'Good Ecological Potential' can be established instead (Junier & Mostert 2012). The requirements however are not based on a cost-benefit analysis; on the costs side the only "turning knob" is the timespan within which water managers have to obtain their goals. Furthermore, the Water Framework Directive is more geared towards the (embanked) regional and local water systems than on the (unembanked) national outer water system. For these reasons, the current Water Framework Directive is informative, but can not be the 'backbone' to the aquatic nature/ecotope system similar to the way the flood risk standards are for the flood risk system.

Of the *amphibious ecotopes*, the Water Framework Directive only addresses the shores. Some of the amphibious areas are covered by Natura2000, but this legislation offers no overall assessment or nature score for amphibious areas, like a biodiversity index per amphibious patch. The growing body of knowledge on ecosystem services should make it possible to assess amphibious (and aquatic) ecotopes on providing these services, but such assessments are not available for the Netherlands as a whole, let alone related requirements necessary for such an assessment.

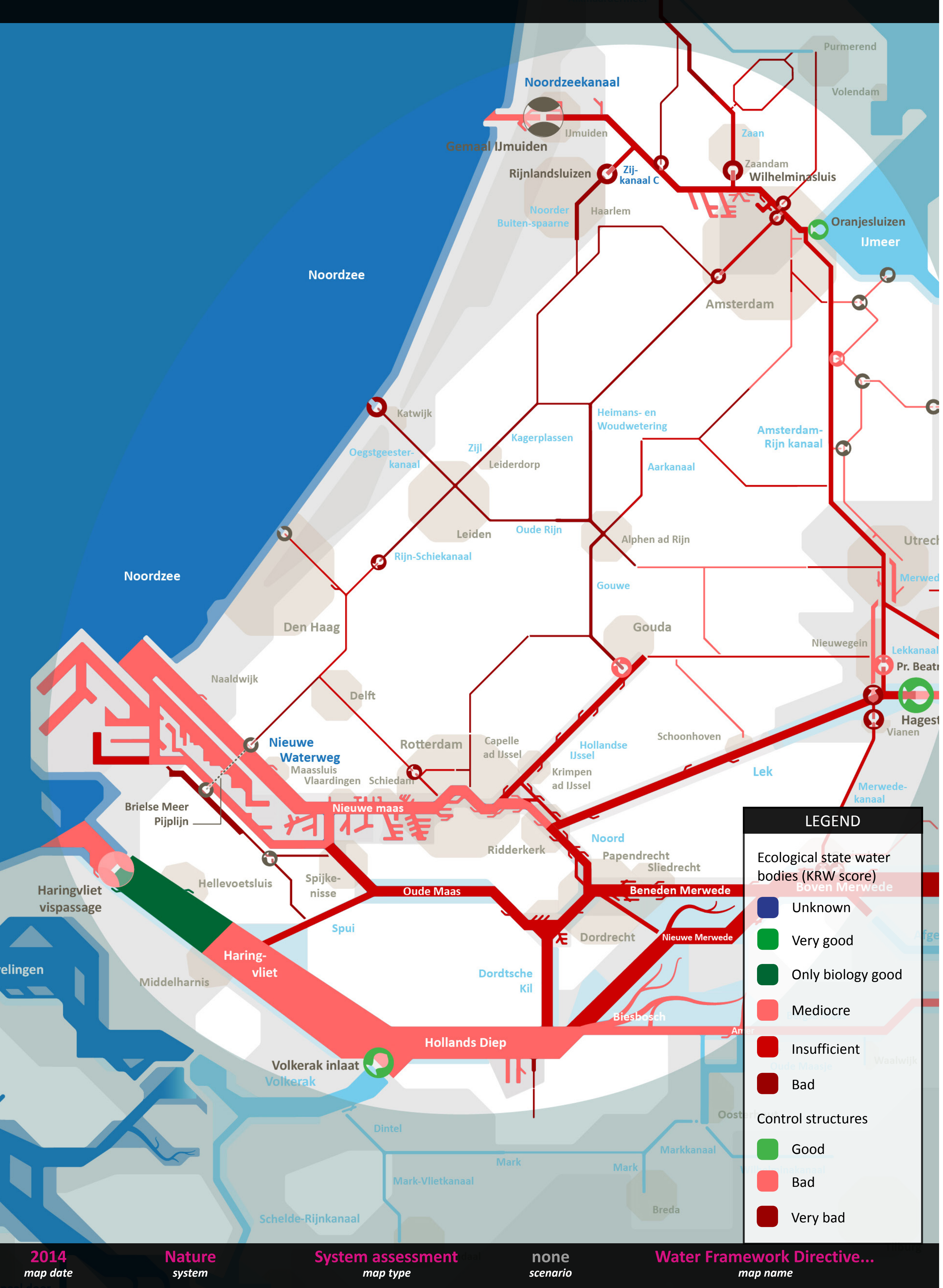
For the flood risk system, upgrades are *only* conducted as a result of the national assessment; for many aquatic nature/ecotope system upgrades, the Water Framework Directive results have hardly played a role – for the Haringvliet for example, major ecological restoration projects are advanced (see figure 4.3.23), but it was in 2009 already

4.3.23 Vision for the Haringvliet by co-operating Dutch nature funds; some of the redesigns of the unembanked areas will take place in the near future (image by Bureau Stroming, source eilandennieuws.nl).

one of the few water bodies with a positive Water Framework Directive score (see Flowz figure 4.3.25).

To support nature/ecotope system upgrades, according to ecology expert De Vries (2014), ecologists often generate a *narrative*, based on their professional insight into the system. Such a narrative addresses the gap between the current state of nature and a possible, more healthy state, and this narrative is used in political debates. Environmental effect studies and cost-benefit analyses about the Haringvliet and Grevelingen/Volkerak projects have been made, but narratives and one-liners like 'Salmon back in the Rhine', 'restore estuarine conditions'

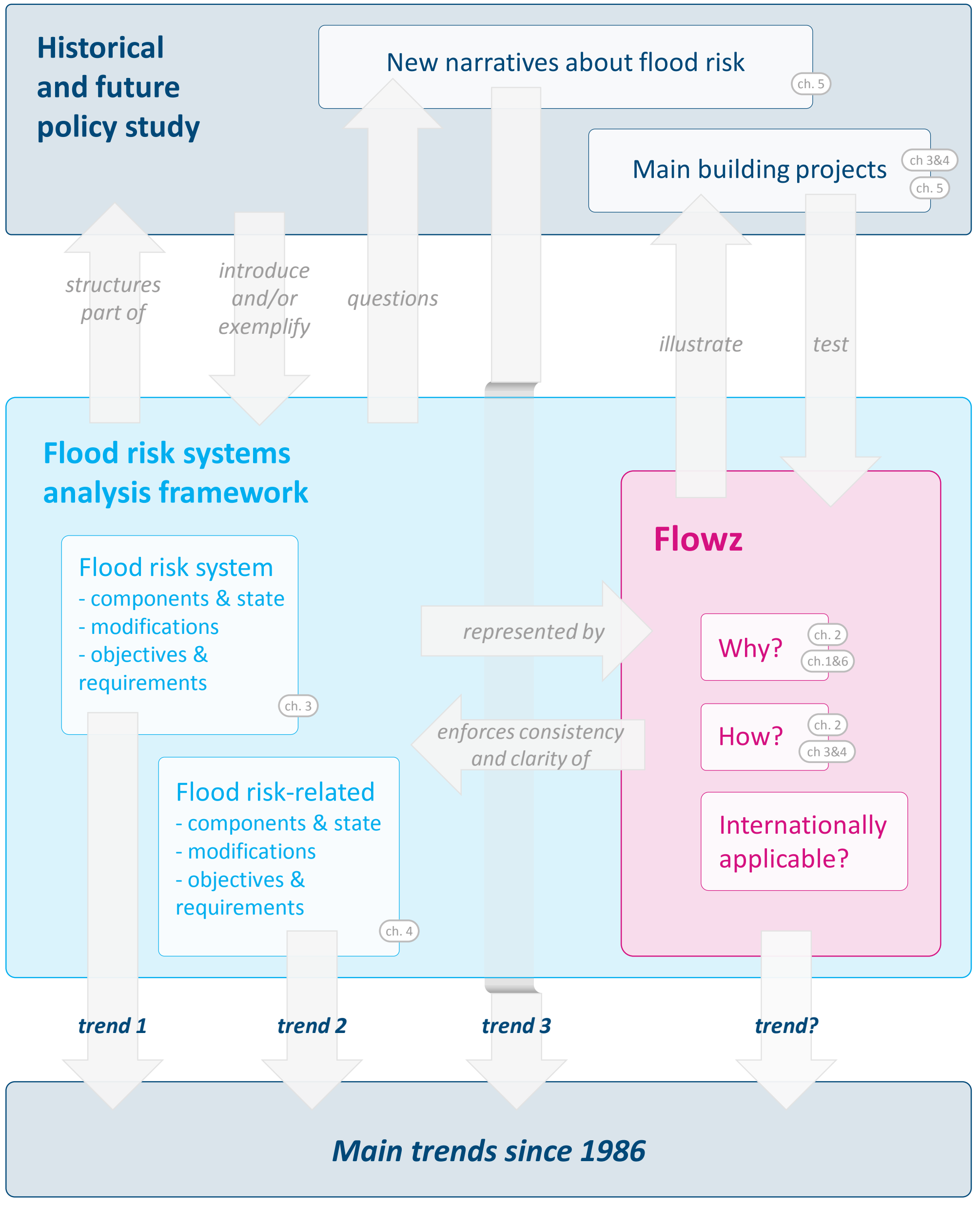
4.3.24 Drawing illustrating the powerful narrative of 'bringing a river back in it's original state', and thus 'turning a deep narrow gutter which discharges too rapidly, into a shallow and wide river bed which discharges more evenly and better dosed' (Smits 2008).



and 'make room for the river' (see figure 4.3.24) have probably been the ultimate driving forces in the debate. Narratives may be the only way to address spiritual objectives, but they are often factually debatable or may even be deceiving, as will be addressed in the next chapter.

One clear advantage of quantitative approaches is that these tend to better incorporate risk than narratives do – people generally have a bad intuition for probabilities (Ropeik 2010; Taylor 2011; Kahneman 2013). In general, in the nature/ecotope system, risk-thinking is not so prominent, because ecological conditions during normal circumstances are dominant. Many ecological issues however do have a probabilistic component – blue-green algae problems for example occur mainly in very hot summers, with a certain return period. Maarse (2011) refers to *sensitivity to events* as an ultimate way to assess ecological health, but notes that this approach is currently still in a stage of infancy.

◀ 4.3.25 Flowz representation of a 2009 Water Framework Assessment data classification by the Netherlands Environmental Assessment Agency (van Puijenbroek 2014). Control structures are assessed on fish passability according to figure 4.3.19 on page 238.



4.4.0 This chapter completes this part of the thesis as explained in chapter 1 (figure 1.15 on page 40).

4.4 Landscape quality

Landscape quality section outline

In the current approaches to the landscape quality of the water system, landscape quality is usually considered an aspect of system upgrades primarily motivated by other objectives and is not assessed nationally as a separate primary objective. Therefore, this section does not start with a separate section on separate physical landscape quality system components, like the previous sections on freshwater, shipping and nature.

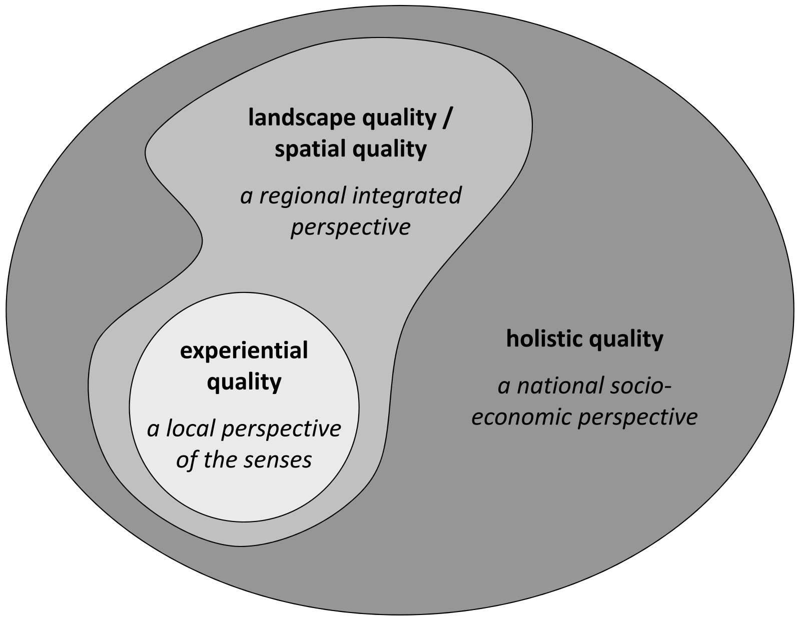
In the next subsection, the term quality and various landscape quality objectives are discussed. The third subsection treats existing *assessments* of landscape quality, which are in practice part of water system upgrades, but could be done separately (as done for the other water system objectives). The fourth and fifth subsections resonate the final freshwater, shipping and nature sections: a historical overview and a discussion about the possibility to apply the flood risk mapping approach to landscape quality.

The following questions will be answered or discussed:

1. how are fundamental landscape quality objectives expressed, what does landscape quality exclusively add to the objectives on flood risk, freshwater, shipping and nature and how are landscape objectives operationalised for policy-making,
2. what were the main trends in system modifications and changing attitudes about landscape quality and its significance since 1986,
3. which general conclusions can be drawn about the relationship between landscape quality and the flood risk system,
4. could approaches as used for the flood risk system (mapping the system state relative to system requirements to be followed up by system modifications) be possible for landscape quality.

Landscape qualities

The word *quality* has been contemplated for many centuries and is, as might be expected, not strictly defined. Terms found are *holistic quality, quality of life, landscape quality, spatial quality, design quality, landscape-ecological quality, experiential quality* and *esthetic quality* (Pirsig 1974; TAW & van Nieuwenhuijze 1994; Hooimeijer et al. 2001; ENW 2007; Peters 2009; van Linge 2009; Klijn et al. 2013). Figure 4.4.1 shows how



4.4.1 Three perspectives on the term quality. Raising the *overall quality* of the planet could be the meaning of life; this level requires a holistic economic, social or even spiritual framework. The term *landscape quality* is used in a context describing the structure and organization of functions in a particular region. *Experiential quality* is the way in which a visitor immediately perceives his environment through his senses (mainly vision).

three frequently used quality approaches depend on the scale level and can therefore be considered to include each other. For the systems analysis of this thesis, holistic quality would be too broad and experiential quality too narrow. In the Netherlands, spatial quality is the most frequently used term for water systems, but the term landscape quality better fits in an international context.

Sometimes, flood safety is separated from landscape quality: a *narrow approach*. Sometimes flood safety is embedded in landscape quality: a *broad approach*. In the engineering disciplines, quality is sometimes simply seen as 'matching requirements and wishes': a *very broad approach*. The term landscape quality was launched in the world of water infrastructure in the € 2,4 billion programme Room for the River in the mid '90s. According to the formal objective of the Room for the River key planning decision, flood risk is *not* part of quality: *improving flood safety and landscape quality* (V&W 2006). Flood safety ís part of quality according to chairman of the Room for the River *Quality Team* (Q-team) Sijmons: landscape quality is about integration of all relevant objectives, like the classical ones formulated by the Roman architect Vetruvius: *utilitas* (usefulness), *firmitas* (solidity), and *venustas* (beauty) (Sijmons 2007). In a later Q-team essay, Sijmons writes that quality is about a proper balance between *costs* and *value* (Q-team 2012). In the official evaluation for Room for the River, consultant Ecorys defines landscape quality as 'uniting hydraulic efficiency, ecological robustness and a meaningful [landscape] design' (Hulsker et al. 2011). An academic paper by the Q-team explains that safety is part of quality, but is not relevant to the work of the Q-team, since the safety objectives are already taken care of by others (Klijn et al. 2013).

Nillesen (2013) excludes hydraulic objectives from her quality mix, de Roo (2011) suggests that quality has to do with the *upper part of Maslow's hierarchy*. It is clear that approaches used in the field range from broad to narrow; the narrow approach to quality as used by Nillesen, de Roo and the Room for the River key planning decision suits the systems analysis of this thesis. When landscape quality is defined as *all additional* (content, not process) *objectives applicable to flood risk infrastructure apart from flood risk reduction, freshwater conveyance, facilitating shipping and supporting nature and ecosystems,* the systems analysis becomes all-encompassing.

In planning science and practice a modern version of *utilitas, firmitas* and *venustas* is found in the work for Habiforum (an influential knowledge network organization to advance multiple use of space, 1999-2009) by Hooimeijer et al. (2001): *usage quality, experiential quality* and *future quality*. Bos et al. (2004) divided Hooimeijer's qualities into 19 sub-qualities for use in the Room for the River environmental effect report (MER): functionality, functional coherence, economic vitality, accessibility, ecological potential, urbanisation aspects, maintenance potential; identity, orientation in time and space, attractiveness of landscape, diversity, safety experience, naturalness, image; irreversibility, development potential, multiple use of space, robustness.

Building on Bos's work, Nillesen (2013) listed the following relevant aspects for water infrastructure landscape quality: functioning as residential, commercial, recreational or public space; accessibility and routing; ecological functioning; maintainability; identity of location and surroundings; recognition of structures; cultural recognition; spatial recognition; diversity and alteration; uniqueness; logic of spatial arrangement; image; water-safety experience; attractiveness; intervention versus location scale; relation to the water; reversibility; development opportunities; multifunctional space utilisation; robustness; flexibility and durability; future value; feasibility of gradual development; experience value; colour palette; uniqueness; the logic of the spatial arrangement; lines of sight; identity; scale of the local intervention; seasonal attractiveness.

Some of these aspects are half or fully covered by the four water system functions treated in the previous sections of this thesis. Looking for objectives in the systems analysis which are *exclusively not covered* so far, the lists by Bos and Nillesen can be boiled down to the following three additional objectives.

Facilitating non-water system spatial functions. The area occupied by the flood infrastructure system is firstly used to deliver typical water system services and secondly to facilitate spatial functions which may happen to be located inside the flood infrastructure area: housing, offices and industry, roads and rails, cables, military terrain, extraction of raw materials, energy production and recreation – see also table 1.4 in chapter 1. These functions touch the previously discussed flood risk, freshwater, shipping and nature objectives, but are not the same: unembanked houses benefit from low water levels, recreation benefits from nature, but the objective of the flood risk system is not to build houses and of the nature/ecotope system not to establish camping facilities.

The 1950s to 1970s were eras of functional and sectoral segregation (Cammen 1986); since the 90s, integration between water system and non-water system elements is said to have been increasing (e.g. DG Water 2006; van der Most 2010; Correljé & Broekhans 2014), mostly under Room for the River and within the concept of *multifunctional flood defenses*. Room for the River plans typically combine flood risk reduction and new nature with recreational facilities, local roads and relocating houses (Q-team 2012). The main elements to integrate with dikes are roads and bike paths, cables, parks, recreational facilities and buildings (MFFD 2015), see figure 4.4.2. Klijn et al. (2013)

4.4.2 The most complex Dutch multifunctional flood defenses are found in Rotterdam and Dordrecht. This is a redesign of the Boompjes boulevard in Rotterdam by De Urbanisten (van Veelen et al. 2010).

River	Project	Type (+ length in km, excavation in km²)	Max. DWL red. (cm)	Function change From	Function change To
IJssel	Zutphen, Dijkverlegging Cortenoever	Levee relocation (2,4) Excavation (?)	31	Agriculture (embanked)	Ag (unembanked) Nature Recreation
	Zutphen, Dijkverlegging Voorster Klei	Levee relocation (2,8) Excavation (?)	26	Agriculture (embanked)	Ag (unembanked) Nature Recreation
	Deventer	Parallel stream (9) Excavation (0,4)	18	Agriculture	Nature Recreation
	Veessen-Wapenveld	Bypass	71	Agriculture (embanked)	Ag (unembanked) Nature Recreation
	Scheller en Oldeneler Buitenwaarden	Parallel stream (2) Quay removal (1) Adding recreational infrastructure (0,7) Relocating houses	8	Agriculture	Nature Recreation
	Westenholte	Levee relocation (3) Parallel stream (4) Quay removal (1,5)	15	Agriculture	Nature
	Bypass Kampen	Bypass	41	Agriculture	Ag (flood plain) Nature Recreation Urbanisation
Waal	Lent	Levee relocation (2,5) Parallel stream (3) Relocating houses Bridges	34	Agriculture Village	Nature Recreation Buildings?
	Munnikenland	Levee relocation (2) Parallel stream (3) Quay removal (1) Adding recreational infrastructure (1,3)	10	Agriculture Nature	Nature Recreation
	Avelingen	Parallel stream (1,5) Restructuring port area	8	Agriculture	Nature Port
	Noordwaard	Levee removal (6) Quay removal (7) Streams (8) Adding recreational infrastructure (10) Relocating houses	30	Agriculture (embanked)	Agriculture (unembanked) Nature
Lek	Meinerswijk	Floodplain excavation	7	Nature	Nature
	Uiterwaarden Nederrijn	Excavations	3-7	Agriculture	Nature
	Vianen, ruimte voor de Lek	Excavations (0,3) Removing quays (3,2)	8	Agriculture	Nature Agriculture Recreation
Maas	Overdiepse Polder	Levee relocation (7) Relocating houses	27	Agriculture (embanked)	Agriculture (unembanked)

4.4.3 Spatial function changes of the Room for the River projects under supervision by the Quality-team (Q-team 2012). DWL red. = maximum design water level reduction; Ag = Agriculture.

refer to these functions (including freshwater, shipping and nature) as *everyday functions*, as opposed to the *rarely used* flood protection functionality.

Identity and cultural heritage. A water system component could decently optimise the flood risk and freshwater systems, provide some road infrastructure, contain patches of nature and a couple of pick-nick tables, but still be boring. What makes a landscape interesting or exciting can be addressed by the words uniqueness, diversity, recognisability, recognition, culture or *identity*.

On an object level, this has two sides: protecting and enhancing *existing* iconic and/or unique cultural and historical elements in the landscape (like the Plompetoren in figure 4.4.5), and deliberately adding uniqueness to a *new* piece of water infrastructure, to make it a regional, national or international icon (like the Ramspol barrier in figure 4.4.4).

4.4.4 Architects Zwarts&Jansma designed the Ramspol barrier architecture and created a new icon for the Dutch northern flood defense system. “The dike with the control buildings and the elements of the dam on and around the water manifests itself as a new linear and technological element, projected onto the much older and naturally capricious landscape. (...) The buildings are characterized by five conical, arched shells of stainless steel, which are nested like the armour plating of a lobster. The shells increase in size towards the water, so that the structures open out towards the view. (...) The diffuse reflection of the surroundings and the sky in the stainless steel helps the integration of the buildings in the surrounding landscape.”

On a regional level, identity is sought in geographic *core qualities*, which make a landscape distinct from other landscapes. For Room for the River, for example, such core qualities are references to the geomorphological state the rivers were in in the mid-19th century (Middelkoop et al. 2003), or, more broadly, the *open* character of the river landscape in general (V&W 2006), the *wild* nature of the Waal and the *silent* atmosphere of the Nederrijn (Feddes 2012b) (see also the next subsection). The photos in figure 4.4.6 show some suggested water landscape identities.

Esthetics. In the systems analysis of this thesis, all aspects which are not covered by the previously treated objectives are put under the denominator *esthetics*, which close the systems analysis. Two projects could meet exactly the same water system objectives, facilitate the same additional functions, and address cultural heritage and identity

4.4.5 Cultural heritage and identity: this levee relocation design by Rietveld landscape architects enhances the iconic value of the Plompetoren in Zeeland by putting it back in unembanked territory and thus allowing it to flood from time to time. The concept claims to enhance the international allure of the Eastern Scheldt national park, and to increase awareness of the historical sunken villages of Zeeland (Steenhuis & de Jong 2010).

▶▶ 4.4.6 *Next pages:* pictures capturing the following water infrastructure landscape *identities*: archetypical Dutchness, the engineered landscape, recognisable historical layers, solid safety, experiencing the seasons (photography TR).

The Archetypical Dutch Landscape




The Engineered Landscape


Historical Layers in the Landscape


The Solid and Safe Landscape


exactly alike, but still the one project could be more attractive than the other. This has to do with beauty, meaning, experience, or *esthetics* (as far as these are not covered by *identity*).

What are esthetics? According to the esthetic theory of Sheppard (1987), *art* is about attractive *formal compositions* or about *eliciting emotions* (next to accurate *representation of reality*, like still lifes). Of the two vertical dike cross sections of figure 4.4.7, the second

4.4.7 A famous esthetic contribution to levee design was invented by Yttje Feddes and implemented by H+N+S landscape architects and others. A slight re-fitting of the levee profile makes the dike look as if it emerges out of the landscape instead of having been stacked on it. It also provides an experience of hovering above the landscape since one does not see the upper part of the levee while driving on it (Feddes 1994; TAW & van Nieuwenhuijze 1994; de Koning et al. 2008).

is considered more attractive by its proponents for reasons of *formal* principles on continuity and discontinuity, as well as with the *emotional* sensation of hovering above the landscape. In the horizontal plane, a long gently curved sea dike, slowly disappearing into distant dunes, can provide a soothing sense of infinity. Someone crossing a dam with rhythmic pylons and pistons, overlooking a wild sea on one side and a calm lake on the other, is aware that human control over nature is at play and may have a feeling of pride or sadness. Studies on esthetics particularly applied to the water system as narrowly defined as in this thesis have not been found. Figures 4.4.9 illustrate a couple

of esthetic principles applied to the landscape of the flood risk system as a result of a photographic study as part of this thesis project conducted between 2007 and 2014.

Identity and esthetics are perceived as individual *experiences* of the landscape. The book The Meaning of Water by anthropologist Strang (2004) extensively explores personal experiences of water: water is refreshing and reflective and "cast as a 'source of life' and as a metaphor for 'life time', water imagery is used in thinking about cycles of life and death, and microcosmic and macrocosmic circulation of various kinds (...) It provides a way of conceptualising the 'substance' of the self, emotional states of being, and social relationships.".

ENW (2007) collected various experiences people associate with the *river landscape*, of which the most typically water related ones are: horizon and perspective, silver meanders, the sound of geese, the wind in your face on the dike, lazy cows in the floodplains, a pick-nick at the river beach, witnessing high waters from the dike, sticking one's boots in the mud, turbulent flows near groins, willows with their feet in the river, ice skating on the floodplains, waiting for the river ferry, bridges, river mist…

Perhaps water esthetics, experience and meaning are best conveyed by stories, poems and art – see some selected fragments in figure 4.4.8.

▸▸ 4.4.8 *Next pages:* some attempts to capture a deeper sense of the water landscape in words.

▸▸▸ 4.4.9 *Pages 268-272:* pictures capturing the following water infrastructure *esthetic principles*: rhythm, sense of eternity, sense of openness, Wabi (photography TR).

"The Eastern Scheldt is like a lifeline, a lulling stream of life and fertility and death, a source of bliss and distress. (…) Over the course of history all Eastern Scheldt levees have been laced up to form a precious string of red coral, gazed upon with pleasure by fishermen, skippers, dikers and farmers, hikers and poets."

(Steenhuis & de Jong 2010)

"Suddenly I pictured it, like an outsider would. Arie, with his timid taciturnity, their hikes over the dike. How her hand looked for his. (…) How they had kids: first Froukje, then me. (…) He loved the beach just as much, the Wadden isle where he had biked to once, because one does not live twice and because happiness could be found in the Texel slufter, that wide sea inlet in which water was silent like a mirror and in which he could walk surrounded by lapwings and gulls. Yes, this is how I would picture it."

(Bernlef 1997)

Like water itself, toying with the idea
that you will someday, finally
know what it is.

It was rain, a river, a sea,
it was here, I saw it here

and I see water and know not what it is.

(Kopland 2005)

"On a big map of the Netherlands, schoolteacher Peereboom pointed at Lelystad. 'It is now only a small dot, but it will be a city with more than a hundred thousand citizens.' Fascinated, I looked at those artificially designed pieces of land. The old Netherlands looked like a tired body in which the Flevo Polders were planted like vital organs."

(van Casteren 2010)

I looked out across
The river today
I saw a city in the fog and an old church tower
Where the seagulls play
I saw the sad shire horses walking home
In the sodium light
I saw two priests on the ferry
October geese on a cold winter's night

And all this time, the river flowed
Endlessly to the sea
(…)
If I had my way I'd take a boat from the river
And I'd bury the old man,
I'd bury him at sea

(Sting 1991)

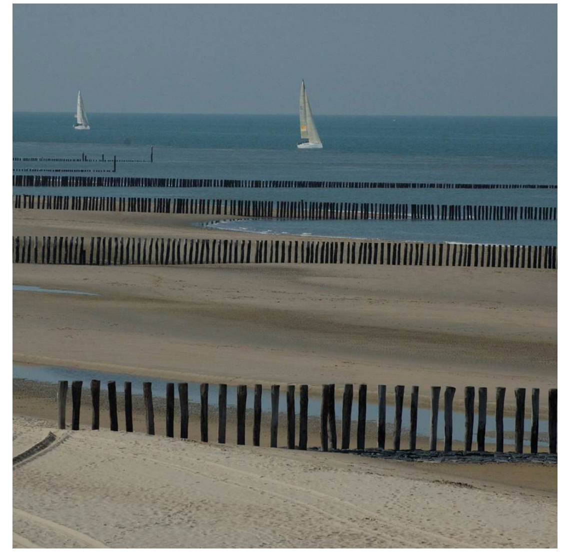
"When I was fourteen years old, my sister bore a child who died half a year later due to an unknown disease. A second child had the same fate. An elder came by and said the deaths were a punishment for her sins. At that moment, at that age, I knew I wanted to have nothing to do with those people. I disconnected from the faith and started to develop my own ideas. I escaped the closed Zeeland community, taking frequent walks over the Scheldt marshes, the accreted land on the other side of the dikes. I felt included by nature, I was free. I started to call it my 'unembanked experience': the feeling of space, freedom, simply being happy. It was a counterweight towards the "embanked experience": the anguish, unrighteousness, people in black clothes afraid of hell. I started to see that their truth was not the only truth, it was just a story."

(Moerland 2008)

Sense of openness

Wabi



Rhythm and repetition

Sense of eternity

Landscape quality assessments

System components for flood risk, shipping and water quality are subject to periodically conducted formal assessments separate from and potentially resulting in system upgrades. For landscape quality, this is not the case; on the national and regional scale levels, landscape quality is an added objective once measures have been selected based on other objectives. On the local level, landscape quality enhancing elements like benches and artworks are sometimes erected, but even these are usually part of upgrades like dike reinforcements. Major interventions like dike relocations for landscape quality reasons alone, like in figure 3.30 on page 116, have been contemplated but not executed (as far as observed during the research for this thesis).

On each of the three scale levels, there are no coordinated independent assessment programmes to evaluate landscape quality in formal separation *before* and *after* the system modifications. The comprehensive Dutch formal quality assessment by the *Quality-team* for Room for the River, primarily concerned the *design* phase: the design process and the design quality in drawings and mock-ups (Klijn et al. 2013). In 2014 and 2015, on request by the Q-team, quality advisors were introduced to secure sufficient quality in the building phase as well (Sijmons 2015b).

Assessing the quality of an existing landscape, a landscape design or a conducted project, could be done in three different ways: 1) consult one or more acknowledged experts, 2) by a methodical step-by-step analysis or a checklist of criteria, 3) consult local stakeholders and inhabitants.

Q-team chairman Dirk Sijmons is clear about his preferred approach: 'Many attempts have been made to explain landscape quality in criteria and measurements, to operationalise it for proper integration with other spatial processes, to make it measurable in benefit-cost analyses, etcetera, but the results are not too convincing. (…) Peer review is, even though limited, the best available. (…) Quality is surely not measurable, yet it is negotiable.' (Sijmons 2007). To reduce subjectivity, the Q-team insisted on independence from the Room for the River management and on the reviews to be conducted blind (Klijn et al. 2013).

Still, in a publication on landscape quality by the Royal Netherlands Academy for the Sciences the statement was made that nowadays the opinions of experts appointed by the government are not taken for granted 'the way they used to' (KNAW 2008). This may have to do with experts contradicting each other – for example, a dike is sometimes argued to create a valuable contrast between the embanked and unembanked land (H+N+S 2010), but sometimes seen as an unwanted barrier blocking the experience of the water (Meyer et al. 2014); a keenly optimised slim dike profile is sometimes considered elegant (ENW 2007), sometimes fragile (Vellinga 2008). In the same publication (Prominski et al. 2012): 'straightening and strict regulation of urban rivers is seen as lifeless and dull; steep banks, a lack of shallow water areas and strong currents make it difficult to access the water (…but…) raising banks offers safe recreational spaces and a good view of the river, charming linear rambling and cycling paths.'

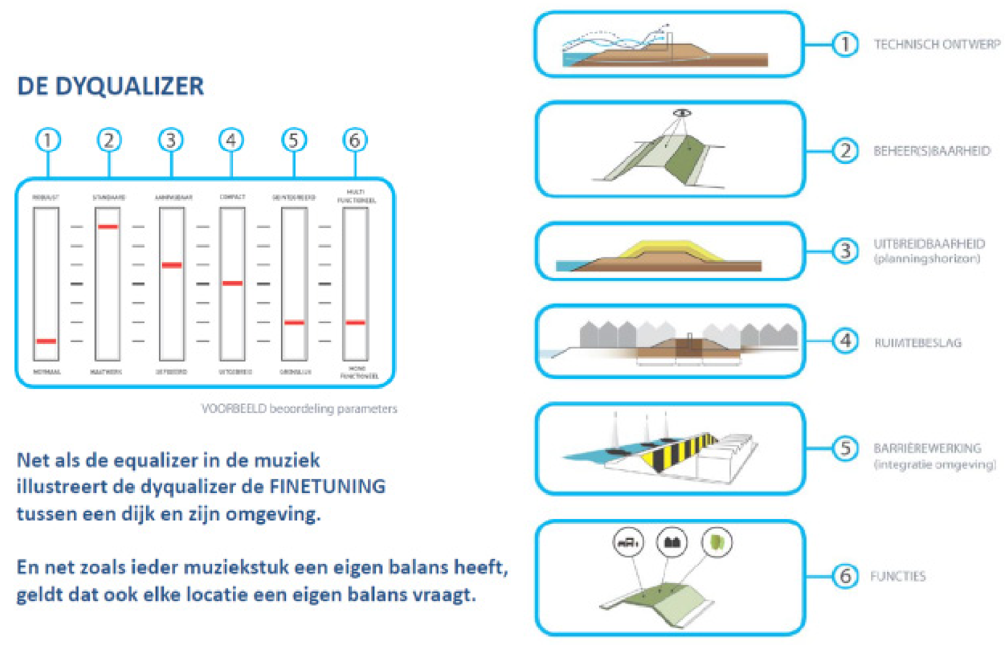
To make assessments more solid, peer reviewers publish assessment frameworks and checklists. The first government publication containing an analytical approach to dike landscape quality was on the *LNC-values* (landscape, nature and cultural heritage) to be used for *keen dike design* in the Delta Plan Upper Rivers (1995-2000) (TAW 1994; TAW & van Nieuwenhuijze 1994). Landscape, nature and cultural heritage are first each described neutrally (without evaluation) on three scale levels. They are then evaluated on each scale level, on different forms of coherence and readability (for landscape), distinctiveness, rareness, diversity, fruitfulness and substitutability (for nature), rarity, authenticity, coherence, distinctiveness and symbolic value (for cultural heritage). Levee upgrade designs are evaluated with the same framework.

The Expertise Network for Flood Safety (ENW, successor of TAW) expanded this work towards river projects in the floodplains. Starting point for unity and coherence is identifying the core qualities of the different river segments (wide Waal, meandering upper IJssel, etcetera) and from that more or less the same procedure as by TAW is followed, expanded by the *layer approach*: ideally, essential qualities of the subsoil (layer 1), the man-made landscape (layer 2) and urban settlements (layer 3) are present on all scale levels, from river to revetment (ENW 2007).

The approach by the Q-team (2007-2012) resonates that of design teachers at design schools, evaluating: 1) Ambition and organization of the planning process, 2) Analysis, 3) Conceptualization, 4) Synthesis, 5) (Iteration between) computing and drawing, 6) Styling and materialization – at four moments in time from start to finish of the design process (Klijn et al. 2013).

Other methods are for example the Dyqualizer by the Urbanisten (van Veelen et al. 2010 – see figure 4.4.10) and the checklists by Nillesen and Bos (see the previous subsection), which are combined with expert judgement and the next assessment type: stakeholder consultation.

The third assessment type is consulting a large group of laymen rather than a small group of experts (the first assessment type). The advantage of experts is obviously their experience in judging *merit goods* (products that society values and judges that everyone should have regardless of whether an individual wants them – van Ierland 2008), in interpreting design sketches and mock-ups (see figure 4.4.11) and in trying to objectify their judgement by methods (which they usually formulate themselves; experts taking pride in using a quality assessment *by someone else* were not found); the advantage of consulting local stakeholders and inhabitants is that they may have valuable



4.4.10 The Dyqualizer by the Urbanisten. 1: engineering, 2: control, 3: expandability, 4: footprint, 5: blockade, 6: added functions. "Similar to the equalizer in music, the dyqualizer illustrates the fine-tuning between a dike and its surroundings. And just like each piece of music has its own balance, each dike location similarly asks for the balance of interests to be just right."

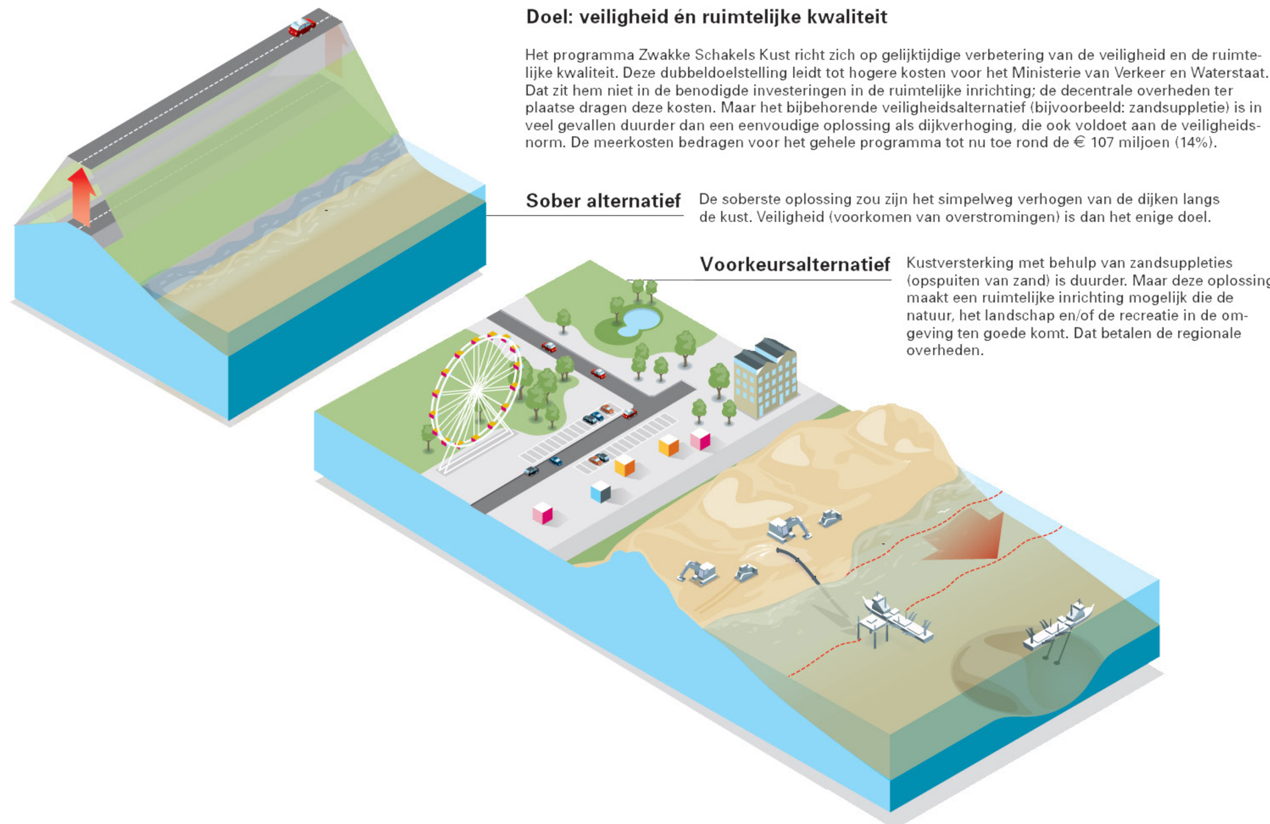
local knowledge and that, ultimately, the public are the folks who use and pay for the landscape redesign.

Involving the public can be done in many ways – from internet surveys to evening discussion sessions with stakeholders in the local café. The *hedonic pricing method*, from the domain of economics, measures changing land or real estate values before (existence value) and after (bequest value) the landscape redesign, or the travel costs people are willing to pay to visit a landscape (van Ierland 2008). 'Iconic value' could be measured by hits on google and/or the number of clicks on the World Wide Web. The term *Maeslantkering* for example scores 62.000 hits (*Maeslant barrier* 5.000 hits), *Oosterscheldekering* 145.000 hits (*Eastern Scheldt barrier* 2.000 hits) and the brand new *dijkverlegging Lent* 1.000 (*dike relocation Lent* 86 hits). Technologies like Natural Language Processing could mine the World Wide Web and find 'aggregated attitudes'.

4.4.11 The landscape architect at work. In landscape quality circles, it is implicitly assumed that designers in particular have an intuitive feel to deal with the exponential number of combinations of multiple objectives and partial solutions (picture from Pol 2012).

Landscape quality and flood risk since 1986

Historians van Campen & van Assen (2014) write that *architectural quality* has been debated in special quality committees for more than a hundred years. According to Sijmons (2008), *landscape quality* was first introduced among Dutch officials in 1982. The term entered the world of water infrastructure as a substantive objective next to flood risk, freshwater conveyance, shipping and nature/ecology in the '90s, focussing on the river landscape, as elaborated in the previous subsections. After the 2008 crisis, an appeal was made to the values *soberness* and *expediency*. Subsidies for the second High Water Defense Programme are only granted for dike projects aimed at effectively increasing safety, and nothing more (Staatscourant 2014), and the word soberness also appears in Delta Programme publications (a.o. Deltaprogramma 2010; 2011; 2013). Frequently mentioned exceptions are the Room for the River projects under execution and the coastal defense, where sand nourishment, although "14% more expensive than the sober alternative" (Algemene Rekenkamer 2009 – see figure 4.4.12), is preferred for reasons of landscape quality.



4.4.12 The Netherlands Court of Audit (Algemene Rekenkamer) assessed spendings in the *Weak Chains* (Zwakke Schakels) coastal defense project (2003-2015) in 2009. It was concluded that a total cost overrun of 14% (covered by local governments) was made to benefit the *preferred* (voorkeurs-) over the *sober* alternative. It is not clear how the Netherlands Court of Audit assumes the same safety for the two alternatives and how the two alternatives were furthermore compared. The extreme dike heightening and the strange Ferris wheel in this drawing might reveal the Court of Audit struggling with the topic.

The soberness appeal of the crisis year 2009 notwithstanding, the term landscape quality today is alive and kicking: more than 120 *quality-teams* were active in 2013 (van Campen & van Assen 2014), there are special *landscape quality advisors* for the Randstad provinces and the board of national architect advisors observe a 'broadly experienced longing for landscape quality' in and around the Delta Programme (Luiten et al. 2014).

How significant to flood risk policy has the introduction of the objective been? This question has two components. First: has the *appearance* of dikes and other flood risk reducing measures changed due to the introduction of the landscape quality objective, and second: has the landscape quality objective contributed to decision-making between different flood risk policy alternatives? In other words: did the attention for landscape quality just result in *lipstick* (term borrowed from van Stiphout 2007), or did it contribute on a strategic systems level?

To answer these questions, five ways in which the landscape quality objective has been implemented in flood risk policy-making were identified and divided between *lipstick* and *strategic*.

'Lipstick' (non-strategic):

1. Reducing potential loss of dike landscape quality caused by dike enforcements, implementing *keen* ('uitgekiend', as opposed to *blunt*) dike enforcements.
2. Improving dike landscape quality by advancing *attractive* multifunctional flood defenses (multifunctional dikes and multifunctional control structures).
3. Improving floodplain landscape quality by turning *unattractive* agricultural lands into *attractive* lands, including nature (both new nature as well as floodplain measures can also be *unattractive* (Feddes 2012b)).

Strategic:

4. Waiving or postponing potential loss of dike landscape quality by waiving or postponing dike enforcements.
5. Reducing loss of dike landscape quality caused by dike enforcements by implementing alternatives: storm surge barriers, spatial (river) projects and foreshore nourishments.

See table 4.4.13 for an overview on how these five objectives have played a role in the major flood risk projects since 1986. Looking at this table, it appears that landscape quality was an argument on the strategic systems level for the storm surge barriers, the spatial river projects, the sand nourishments and in postponing dike projects before 1995 – all together substantial. *Lipstick* played a part in the other projects (mainly dike reinforcements), with an increased belief in the idea that thoughtful dike reinforcements would not only *reduce the level of deterioration* (objective 1) but might even make the dike landscape *more attractive* (objective 2).

The 3d High Water Defense Programme, the largest (measured in euros) single flood risk programme since the Delta Works, issued a design manual on landscape quality (van Rijswijk 2014) and advanced the triad *fit, synergise, exchange*: reduce negative impact (landscape quality objective 1), connect to other spatial objectives (landscape quality objective 2) and, if possible, exchange dike project partly or entirely by a nearby river project (landscape quality objective 5).

Project	*From*	*To*	*Size (G€)*	*Landscape quality*	
				Lipstick	*Strategic*
Closure dam	1927	1932		1	Hard to say
Delta Works North		1969		1	Negative
Delta Works South	1954	1986		1	Hard to say
Remaining dike upgrades Delta Works	1986	2005	0,4	2	4
Europoort barrier	1991	1997	1,4		5
Delta Plan large rivers	1995	2000	2,3	1	
Maas works	1995	2015	0,6	3	5
Ramspol barrier	1995	2002	0,2		5
Sand nourishments sandy coast	1995	2015	0,8		5
River projects before Room for the River	1998	2006	1,0	3	
Kromme Nol barrier	1996	2001	0,1		5
Weak Links coast	2003	2015	0,9	1	
Revetments Scheldts	2004	2007	1,1	1	
Room for the River – spatial projects	2007	2015	1,7	3	5
Room for the River – dike enforcements	2007	2015	0,6	3	
Task Force Management Floodings	2007	2009	0,2		
1st & 2nd High Water Defense Programmes	2007	2020	2,6	1	
Closure dam upgrades	2012	2016	0,8	2	
Sand engine	2012	2013	0,1	3	5
3d High Water Defense Programme	2014	2028	3,7	1, 2	5?
Delta Programme – flood protection	2014	2028	2,4	Not clear yet	
Delta Programme – not yet allocated	2014	2028	0,9		
Total	*1986*	*2028*	*21,8*		

4.4.13 Indication (based on a sense obtained during the course of the research for this thesis) of the role the landscape quality objective has played for the main Dutch flood risk projects conducted since 1986.

It can well be stated that the rise of the landscape quality objective (intermingled with enhancing aquatic nature) is one of the most characteristic trends for the development of the flood risk system since 1986, in the professional and public discourse, as well as in the final policies and projects. According to van Schaik (2013, based on Schreuders et al. 1987), the Europoort barrier was about 10% more expensive than the alternative of just reinforcing the dikes but was preferred in part for (urban) landscape quality arguments: waiving unattractive urban dike reinforcements and erecting the iconic Maeslant barrier instead. Also the Room for the River projects and the sand nourishments relied heavily on the landscape quality argument.

Nevertheless, landscape quality remains a difficult and elusive topic. Long before the introduction of the term, the rivers were already considered a particularly beautiful part of the Netherlands, even after the river normalisation activities in the 19th century (e.g. Thijsse 1938). ENW (2007) explains why in the past, '(attractive) form followed function': because of technical *limitations* our ancestors adapted the dikes decently to their environment and established regional coherence in dike design, without really being aware of it: 'engineering and beauty were the same'. Today's *technical freedom* has 'separated engineering and beauty'; because there are many forms to follow function, landscape quality is required as a separate additional objective for good dike design.

Apparently the belief is held that a sole focus on engineering nowadays would lead to a horrible landscape. But is this really so? Do engineers have such less feeling for landscape quality than landscape architects, as is always so implicitly assumed? The quality argument for replacing agriculture by nature in the unembanked floodplains can also be argued: was the original river landscape actually indeed perceived as an unattractive landscape? Many appreciate the openness of the agricultural land. Perhaps the landscape quality argument is mainly advanced by a vociferous minority temporarily disadvantaged by dike enforcements, and perhaps landscape architects happily help them for professional pleasure and daily bread. Because of its subjective and elusive character, the landscape quality argument and the rising use of it in water system design is better approached with healthy suspicion.

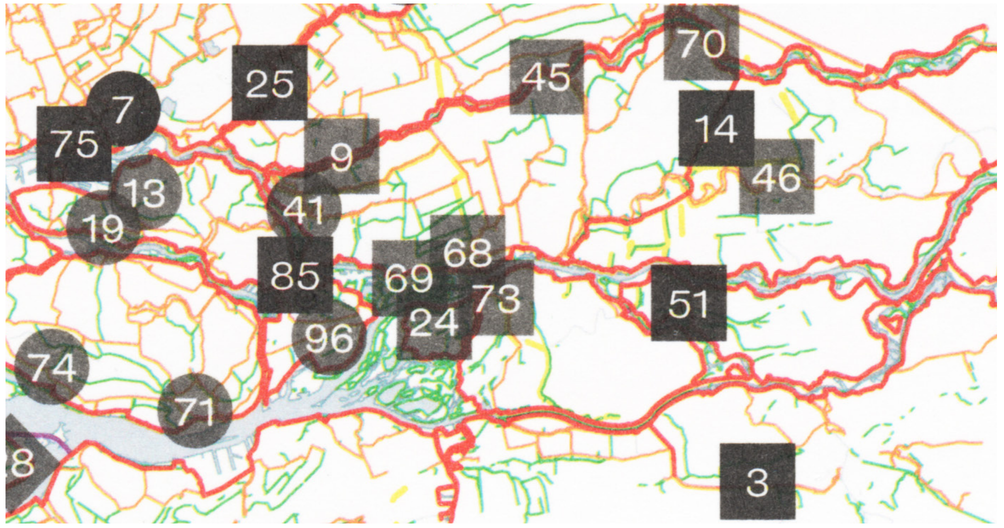
Applying a systems analysis framework to a 'landscape quality system'?

The current Dutch approach to flood risk policy consists of modeling and mapping the *system state* relative to *system requirements* based on *fundamental system objectives* to be followed up by *system modifications*. It is an advanced rational policy framework; one of its advantages is the formal separation between assessments and upgrades. The clearer these are separated, the more objective the problem analysis and the wider the scope of solutions (possibly multiple solutions to possibly multiple problems) can be expected to be (Keeney 1996). Furthermore, with independent landscape quality assessments it should be easier to compare quality gains or losses concerning water infrastructure projects to gains or losses for non-water infrastructure landscape projects.

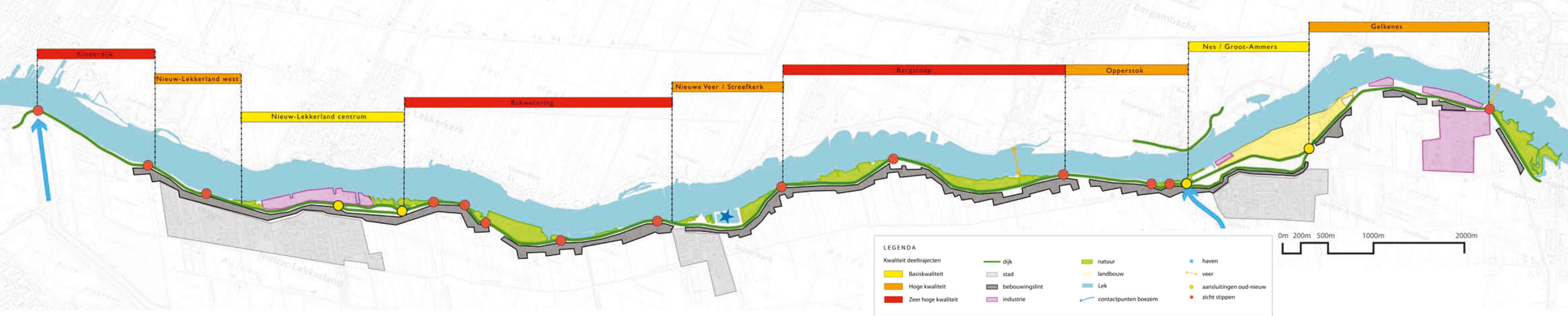
There are however no formal national landscape quality assessments for the Dutch water system separate from system upgrades. Yet, as observed in the previous subsection, landscape quality has been an important objective for the development of Dutch flood risk policy over the last 30 years. This finding might support a plea for independent landscape quality assessments. What would these look like and could it be a serious possibility to bring them to a similar level as the flood risk assessments?

Landscape quality *system components* would be embanked areas, flood defenses, unembanked areas, water bodies and control structures.

Three independent quality assessments for *dikes* were found with results projected on a map (figures 4.4.14, 15 and 16). The three maps all show the southwestern Lek dike

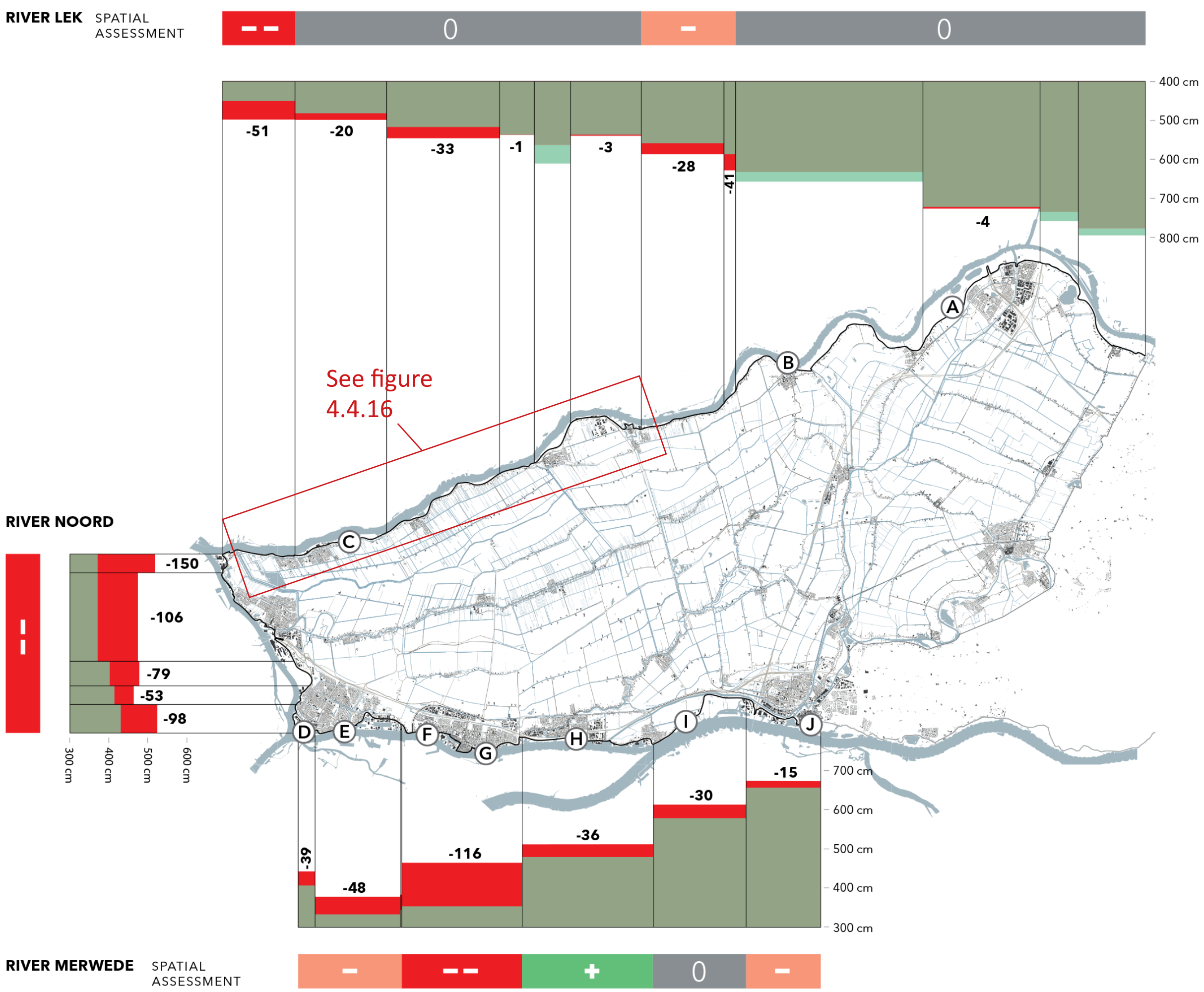


4.4.14 The book *Dikes of the Netherlands* has mapped the 100 most attractive dikes of the Netherlands according to LOLA landscape architects (Pleijster et al. 2015).



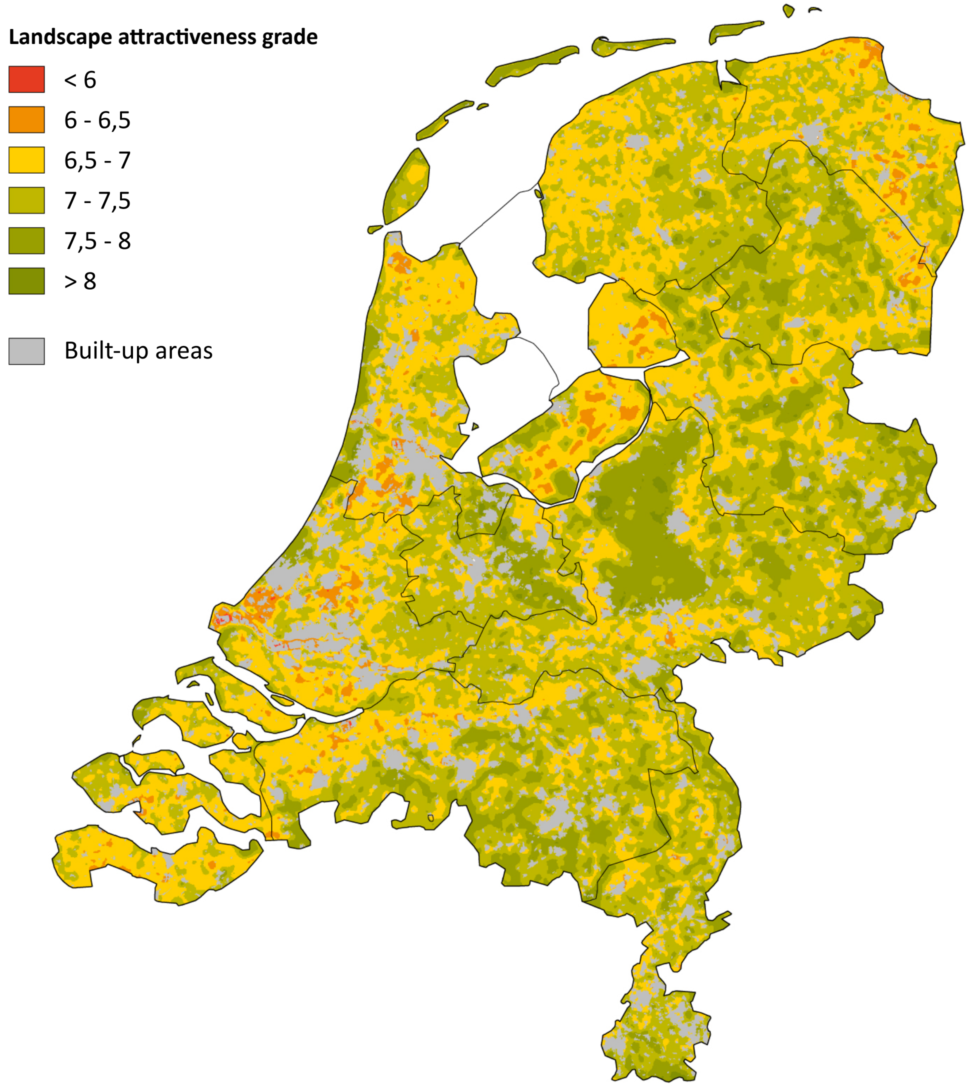
▲ 4.4.16 Dike on the south-west side of the River Lek, assessed by landscape architects H+N+S, from red (very high quality) to yellow (base quality) (H+N+S 2010). Interestingly, the assessment resembles the assessment by Nillesen in figure 4.4.15.

▼ 4.4.15 Assessment of the same dike as in figure 4.4.16, plus the other dikes around the Alblasserwaard dike ring. A positive assessment (green) indicates that a dike upgrade is expected to improve landscape quality; a negative assessment (red) suggests a negative impact (Nillesen 2014).

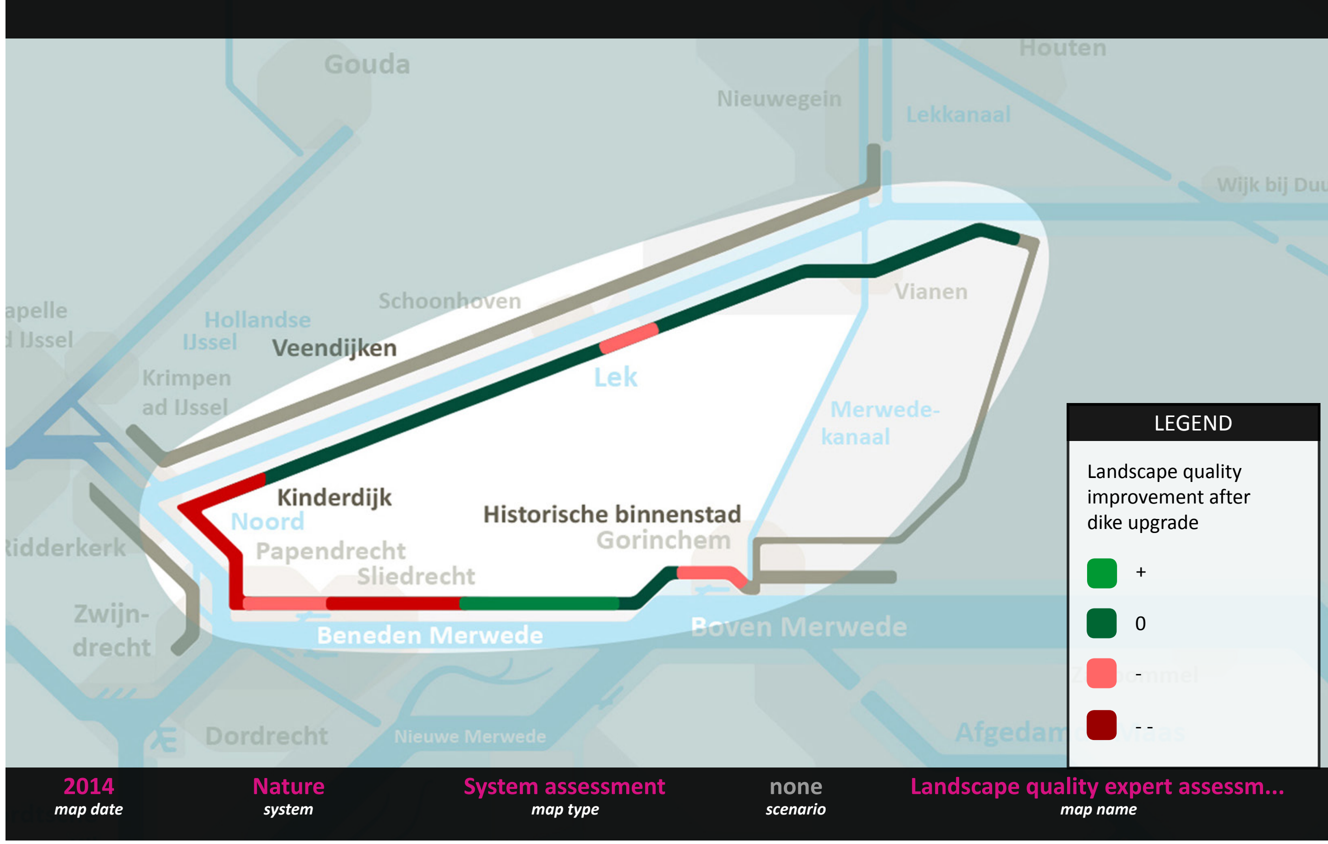


and the observations diverge, as could be expected. Similar landscape quality maps for *unembanked areas* have not been found.

A body of work exists on *general* national independent landscape quality monitoring (Roos Klein-Lankhorst et al. 2005, Farjon & van Hinsberg 2015), based on GIS-operations towards landscape *core qualities*, *experience* and *overall attractiveness* (see figure 4.4.17). The current follow-up of this work, still in a development stage, uses mobile phone apps to crowdsource additional information to advance from *stated preferences* to *revealed preferences* (Farjon & van Hinsberg 2015; SHINE 2015). The grid size of 250x250 should be fine enough to project the gauged attractiveness on dikes, unembanked areas or water bodies. Interestingly, when the Dutch rivers are projected on this map it seems that most of the river landscape already has a positive landscape evaluation, with or without Room for the River projects. What would this mean for the quality argument which played such a large part in Room for the River? Perhaps the supposed landscape quality *loss* by dike upgrades and the landscape quality *gain* by river projects is still substantial even though the initial landscape quality for both is fine. Exactly the *independence* of this assessment brings about these kinds of provocative questions.



4.4.17 Alterra (et al. 2009) generated a single *landscape attractiveness* map for the Environmental Compendium based on four quality assessments weighed according to factors derived from a poll with 4500 people: attractiveness = 5,31 + 0,29 x *naturalness* + 0,23 x *historical distinctiveness* (positive) – 0,09 x *horizon pollution* and – 0,15 x *urbanity* (negative) + 0,03 x age. The grid cell of this analysis is 250x250 meter. The width of a dike zone can be 150 meters and unembanked areas are usually wider; this analysis might thus serve as an independent water infrastructure landscape quality assessment – albeit the authors mention several weaknesses and limitations of their approach, like the limited predictive value (36%) and the way the vicinity of water is embedded in naturalness (de Vries & Gerritsen 2003; Roos Klein-Lankhorst et al. 2005). In the current SHINE project these limitations are being tackled.



4.4.18 The best map to turn into a Flowz landscape quality assessment map is the map of figure 4.4.15. Based on this assessment, the location of the potential high water barrier in the Beneden Merwede may well be chosen at the western side of the one dike trajectory assessed with a positive score on dike upgrade landscape quality.

If landscape quality as a substantive objective is taken seriously enough, it becomes worthwhile to combine a systematic approach as of figure 4.4.17 with expert judgements as elaborated by Sijmons, Nillesen and others. It could be pragmatic to integrate a water infrastructure landscape quality assessment in the periodical national dike (safety) assessments.

Should there even be national *standards* and a *fund* for related upgrades like the Delta Fund? In his farewell address, Sijmons (2015a) warns against national landscape planning as a 'colourless arbitrator for conflicting spatial interests, (…) a bureaucratic planning context' and pleas for a 'cultural and pluralistic, (…) less deterministic' approach. If landscape quality would ever be assessed and mapped like the other water system functions, this should not flatten a colourful topic, but support a debate about perspectives on landscape quality, about reducing subjectivity in this debate, about how to achieve the greatest landscape quality increase against the lowest costs and about how to integrate landscape quality properly with other water system objectives.

4.5 Conclusions

Discussion

The methodological discussion on the four flood risk-related objectives starts with the question why these objectives are considered the main ones, and other objectives are not. In the subsection of chapter 1 on page 26 the objectives selection has been made and compared to systems approaches by others. Let's however consider some additional objectives in this chapter's discussion.

Drinking water could be treated as a separate objective, but in the systems analysis of this thesis, drinking water is *one of* the freshwater users, among other users like agriculture and industrial cooling plants. Relative to the other water systems, drinking water system components have ten to a hundred times lower capacities. Furthermore, the interactions between the Dutch drinking water system with other systems are the same as the freshwater system and beyond that, limited (Moel et al. 2005). It could be interesting however to expand the freshwater conveyance system with the drinking water system and expand the pipeline/aqueduct component in Flowz (see figure 4.1.17 on page 183). In other countries, like semi-arid California, the relative size of the drinking water system to the other systems is often larger than in the Netherlands.

Groundwater is often seen as a separate system, but not in the systems analysis of this thesis: groundwater management is not an objective in itself; it serves the other objectives and should therefore be embedded in the other systems. In other words: when *groundwater salinization* is a problem, this is noticed in a freshwater conveyance assessment. *Groundwater storage* could be a solution to dropping river water tables, serving various objectives, etcetera.

In the past, the Dutch water system has been a crucial part of the nation's *military defense system*. The Pannerdensch Kanaal was dredged in 1701 mainly against armies advancing from the east, the Stelling van Amsterdam protected Amsterdam between 1880 and 1920, the Nieuwe Hollandse Waterlinie was initiated in 1815 and was continuously upgraded until airplanes outdated the concept in World War II. If this objective would be represented in for example a historical Flowz project, it could be considered a special type of (intended) flooding and the inundation areas would be drawn as unembanked floodable areas (light blue).

Particular functions located in the unembanked areas or even in the embanked areas could be uplifted to be represented as an objective in itself. Dredge depots, gravel and sand extraction, logging, parking lots, sports fields, etcetera, could each be considered as single systems. The same for roads and railroads, which interact with water systems in various ways (mainly through bridge foundations and bridge heights). In this thesis' systems analysis however it was chosen to consider only systems which *primarily* revolve around water. Consequently, landscape quality should be read as *the landscape quality of*

the flood risk- freshwater conveyance-, shipping- and aquatic nature/ecotope systems, and not as landscape quality in general.

A similar reasoning was followed for fishing, aquaculture, algae-production, fish and game and aquatic recreation, although these may be considered to revolve primarily around water. Methodologically, however, all considerations for these functions could be placed under the five thesis objectives, since the landscape quality objective serves as a remainder category. The pros and cons of various locations of a dredge depot or camping ground may or may not have relationships to aquatic nature or unembanked flood risk, but it can always be considered a part of landscape quality.

What else can be said about the method followed in this chapter? The goal was to describe the historical and future development of the Dutch national water system from a historical systems analysis perspective, and to do this in the same way for freshwater, shipping and nature/ecotopes.

It was not explained why the particular system components were chosen. For freshwater, freshwater connections may have been divided in natural connectors, open systems and pipelines. Freshwater *inlets* can also be considered control structures. For shipping, ports could be divided in sea ports open ports and inland ports (behind locks). Additional system components could be hard elements in the river bed which may obstruct ships or flows.

The *nature/ecotope* system has been given this double name because the term *nature system* alone feels uncomfortable to many. *Ecotope system* is not a bad term, since ecotopes are physically demarcated and interconnected as in a system. Yet, in the Netherlands, the word nature is used so often for this water system functionality that it was kept, even though the term is interpreted in so many different ways. Nature can be seen as the *occupant* of the ecotopes.

Flows in the nature/ecotope system are hampered by many different passages and gates which in this thesis are all called 'eco-gates'; a more refined subdivision, depending on which natural flows exactly are provided for, would be informative. The role played by the water framework directive in the nature/ecotope system may have been insufficiently investigated: what would be needed to make it an overall nature/ecotope system state assessment similar to the food defense assessments and why did it not work for the large waters in the Southwestern delta?

In the eyes of many, nature and landscape quality are the same or they at least overlap, since the presence of nature is nowadays almost automatically perceived as enhancing quality. Yet, some nature may be hardly experienced by anyone and landscape quality is more than nature alone.

It is interesting to systematically investigate the interconnections between the flood risk-related objectives not only with flood risk but also with each other. The measures to enhance the tidal movement in the tidal rivers for example have a slight negative impact on shipping, widening waterways and new canals (like the Rhine-Danube canal) introduce exotic species in the Dutch waters, etcetera.

Main trend 2: moving up in 'Maslow's hierarchy for water infrastructure development'

Which common theme runs through this chapter? Similarly to the flood risk chapter (page 152), this question starts with a table (figure 3.54) showing the main investments in the flood risk system since 1986, complemented by columns indicating to what extent freshwater conveyance, shipping, nature and landscape quality have played a role in the project. The table shows only projects *primarily for flood risk reduction*, and no projects *primarily for flood risk-related objectives*. Let's paint a general picture for these latter types of projects too and derive a general denominator from both this picture as well as from table 4.5.1.

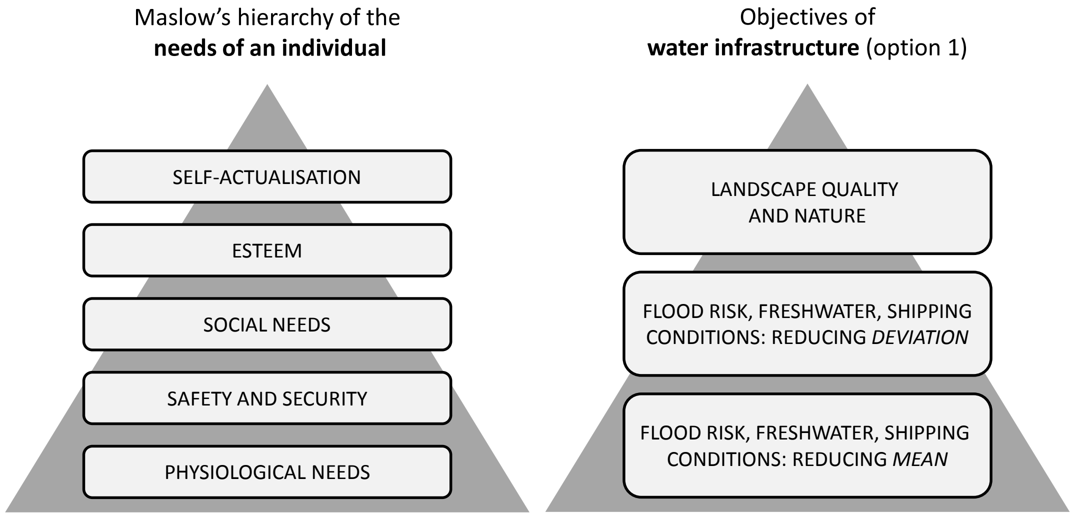
The national investments in flood risk-related water system objectives can be expressed as a percentage of the average annual amount spent and budgeted on national flood protection investments between 1986 and 2028, which are about € 0,5 billion, according to the data collected in table 3.55 in chapter 3. The estimates are based on the main projects described in this chapter, plus an estimate of the size of the combined smaller projects. *National* investments are defined as coordinated and/or (partially) financed by the national government and/or concern large projects with national significance. The numbers exclude costs for maintenance and operations. The idea is to obtain a *general image* of the importance of the objective relative to flood risk.

Over the last 30 years, national investments in the *freshwater conveyance system* (which excludes water quality) have been relatively small, estimated 5 to 10% relative to flood risk investments. For the *shipping system*, port expansions, additional locks and waterway upgrades keep being implemented, for an estimate of 40 to 60% relative to flood risk. National spendings on *water quality* improvements (since 2005 the Water Framework Directive) have been significant: an estimated 40-60% (excluding investments in sewer systems and investments made by local polluters) (van der Molen 2016). Other investments in nature/ecotopes and conservation, mostly in the Southwestern delta have been about 5%. *Landscape quality* has not been treated as a primary objective, except perhaps for small communication projects aimed at education and experience of the existing landscape.

Landscape quality may not have been addressed as a primary objective, table 4.5.1

Project	*From*	*To*	*Size (G€)*	Synergy with flood risk-related objectives: *Freshwater*	*Shipping*	*Nature*	*Landscape quality*: *Lipstick*	*Strategic*
Closure dam	1927	1932		5	5	Negative	1	Hard to say
Delta Works North		1969		5		Negative	1	Negative
Delta Works South	1954	1986		5	5	Negative	1	Hard to say
Remaining dike upgrades Delta Works	1986	2005	0,4				2	4
Europoort barrier	1991	1997	1,4		5			5
Delta Plan large rivers	1995	2000	2,3			1	1	
Maas works	1995	2015	0,6			2	3	5
Ramspol barrier	1995	2002	0,2		3?	3		5
Sand nourishments sandy coast	1995	2015	0,8			1		5
River projects before Room for the River	1998	2006	1,0			2	3	
Kromme Nol barrier	1996	2001	0,1		1	3		5
Weak Links coast	2003	2015	0,9			2	1	
Revetments Scheldts	2004	2007	1,1				1	
Room for the River – spatial projects	2007	2015	1,7		Negative	2	3	5
Room for the River – dike enforcements	2007	2015	0,6				3	
Task Force Management Floodings	2007	2009	0,2					
1st & 2nd High Water Defense Programmes	2007	2020	2,6			1	1	
Closure dam upgrades	2012	2016	0,8	1			2	
Sand engine	2012	2013	0,1			5	3	5
3d High Water Defense Programme	2014	2028	3,7				1, 2	5?
Delta Programme – flood protection	2014	2028	2,4		1	2	Not clear yet	
Delta Programme – not yet allocated	2014	2028	0,9					
Total	*1986*	*2028*	*21,8*					

4.5.1 The main national flood risk reducing projects since 1986, complemented by the most import projects before that date, the Closure Dam and the Delta Works. On the scale from 1 - 5, a 5 means that the flood risk-related objective has played an important part in the decision for the project and/or the execution of the project has been addressed the objective positively, according to the project's proponents and most analysts. "Negative" means that the project has addressed the objective negatively.

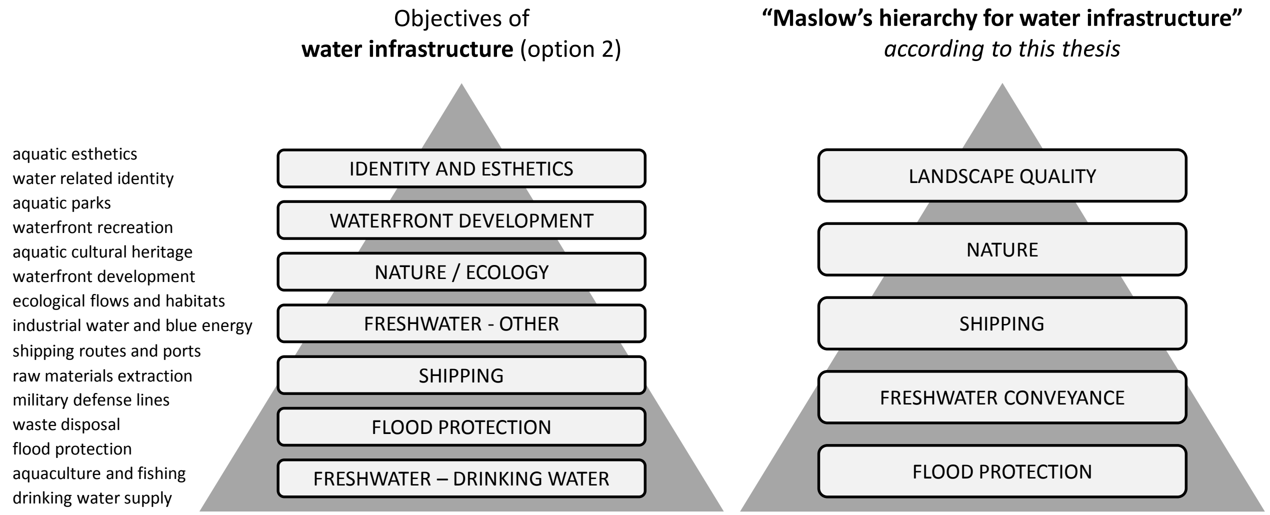


4.5.2 Left: Maslow's hierarchy of the needs of an individual – the pyramid was not invented nor used by Maslow himself but became the widespread representation of the idea (Zimbardo et. al. 2012).

suggests that landscape quality may be considered the most prominent flood risk-*related* objective for flood risk projects during the last 30 years. The table furthermore shows that freshwater conveyance as a relevant related objective has not played a role in flood protection projects since the dams of the 20th century. The same holds for shipping, except for the Europoort barrier (1997) and the decision *not* to place additional dams and barriers in the tidal rivers (2015). The synergy between shipping and Room for the River is slightly *negative*. The objective of improving the nature/ecotope system along with the flood risk system, however, has grown in significance, mostly under Room for the River and the coastal projects.

Characterising the period since 1986 roughly based on which objectives were addressed on a national level, independent from flood risk or in synergy with it, starts with the observation that flood risk itself has been the dominant objective, freshwater has been low in investments and synergy with flood risk, shipping is important in itself and keeps playing a part in flood protection choices, the nature and quality objectives have become more relevant, both as primary (strategic) and secondary ('lipstick' – see page 278) objectives.

Objectives grow or shrink in importance through the ages. Reasoning towards an overarching trend might be helped by the idea that the Dutch water infrastructure motivations continuously try to find a place in some sort of stacking order or *hierarchy* of objectives.



4.5.3 Middle: two ways to place the objectives of water infrastructure in a Maslow-like hierarchy. Right: final suggestion to place the objectives as treated in this thesis in "Maslow's hierarchy for water infrastructure".

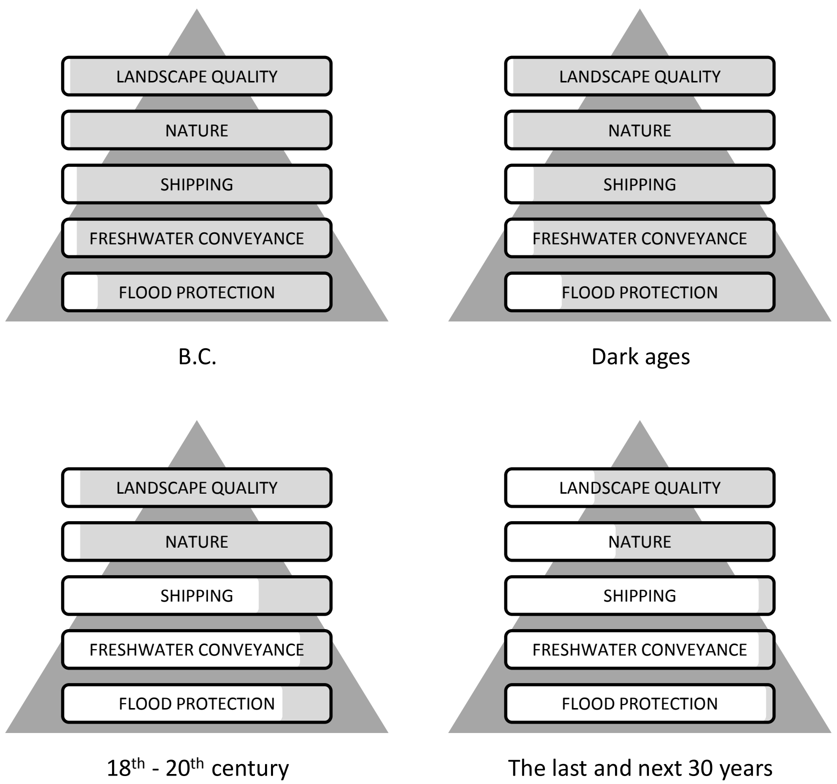
The idea of a hierarchy of objectives in a public domain bears resemblance to the idea of the *hierarchy of an individual's needs* by Abraham Maslow (1943). His name appears occasionally in spatial planning publications (like Hooimeijer et al. 2001; Jonkman 2007; de Roo 2011; Baart 2013); Maslow's main idea was that higher-order objectives (self-actualization and esteem – see figure 4.5.2) are addressed only when lower-order ones (security and physiological needs) are met; not necessarily fully, but to a larger extent lower in the hierarchy (Maslow 1943; Zimbardo et al. 2012).

This hierarchy makes sense to explain the motivations of individuals in their lifetimes and in societies through history and throughout the world. When *objectives* are equaled to *motivations*, Maslow's hierarchy of needs could be applied to create a hierarchy for objectives for water infrastructure development in two ways.

First, stating that water infrastructure *supports* the fulfillment of Maslow's human needs (Vrijling 2013). For example, basic drinking water supply and elementary flood protection support the basic physiological needs of not dehydrating or drowning. Further reducing the probabilities of disasters (in a risk-averse society often against higher costs than the strict risk reduction) addresses the need for security: reducing the *mean* of the hydraulic conditions by which we are surrounded is driven by physiological needs, lowering the *deviation* around the mean (disasters) addresses security and safety needs and provides a necessary (lower-order) foundation for (higher-order) love and belonging. Adding to this approach, half-way the hierarchy large-scale water projects may fulfill the need for esteem and achievement by builders and citizens. In the top, enjoying landscape quality may allow people to fulfill higher-order needs like contemplation and finding creative inspiration.

A second way to apply Maslow's hierarchy is to not put the *needs* in an order, but the *means* to meet needs. From the individual's perspective this is for example (from bottom to top) housing, savings, marriage, job promotion, hobby. These roughly match stages in a lifetime; from the perspective of the water system, a similar order can also be found looking at its development through time.

Dutch water history in a nutshell (after van de Ven 1996; Dubbelman 1999; Huisman 2004; Rooijendijk 2009 and others) explains that the Dutch during the ages B.C. mainly used surface water for fishing and local agriculture and erected earthen mounds above flood levels. In the dark ages the first dikes, dams and windmills were built, mostly for flood control. In the 18^{th} and 19^{th} century, national coordination emerged and simultaneously shipping conditions were improved, river water distribution was altered



4.5.4 "Maslow's hierarchy for water infrastructure" through the ages. The grey fills refer to a general rough extent to which the objective has been met relative to the maximum potential.

for military reasons and flood frequencies were further reduced. In the 20^{th} century, the system was heavily upgraded with the Closure Dam and the Delta Works, with flood protection as the main and shipping and freshwater conveyance as secondary objectives, arguably complemented with enhancing 'national identity'. In the 70s and 80s, water quality and ecosystems (nature/ecotopes) entered the scene, and in the 90s and in the 21^{st} century, the word landscape quality appeared in discourses as a relevant objective, not only for rich cities like Amsterdam but throughout the entire country. Figure 4.5.4 puts the five objectives as distinguished in this thesis in hierarchies in these four eras.

Now what does *Maslow's hierarchy of objectives for water infrastructure development* explain or support? The different shapes of the hierarchies presented in figure 4.5.3 illustrate that the idea can be interpreted in multiple ways. The main thing to take away is that climbing the hierarchy can be interpreted as a course of history making perfect sense under economic growth. In the publication on landscape quality by the Royal Academy of Arts and Sciences (KNAW 2008), Sijmons writes that "behind us lies over half a century uninterrupted economic growth and welfare; our image of the world has highly aestheticized. *Otium*, enjoying, has won over *Negotium*, working hard 'facing ones sweat' (in 'het zweets uwes aanschijns')". Philosopher Venmans (2008) suggests that in a utilitarian (lower-order needs/objectives) society or stage, inevitably the question will at some point be asked what the *purpose* is of fulfilling lower-order utilitarian needs. *Why* to be safe from flooding and have optimised freshwater conveyance and shipping systems? Loving nature and landscape quality can well be seen as an answer to this question.

Yet, the water sector seems to be struggling with this. Instead of interpreting the nature and landscape quality-oriented objectives of Room for the River as gradually moving up in a natural order of water infrastructure development, it was seen by many as still addressing lower-order objectives. The ministry of infrastructure for example wrote: "the high waters of 1993 and 1995 made us realise that sustainable protection is more than periodically enforcing the flood defenses. Sustainable flood protection can best be realised by cooperating with natural processes as much as possible." (V&W 1998). A Room for the River evaluation by consultant Berenschot illustrates how means and ends are confused: "levees and other technical measures were experienced as no longer adequate" (ten Heuvelhof et al. 2007). More accurate would have been to state that addressing flood risk alone is no longer adequate, but thanks to levees and technical measures, alternative ends can now be included. If this had been the attitude in the '90s and '00s, a different river project portfolio would surely have resulted.

Climbing the hierarchy of objectives can feel unfamiliar, as will be illustrated in the next chapter.

Chapter 5 in brief

Chapters 3 and 4 presented a systems analysis framework for flood risk as an integrated system, and used the SimDelta/Flowz concept introduced in chapter 2 to visualize the approach and illustrate the historical development of the Dutch national water system. Studying relevant historical flood risk policy documents also revealed several recently emerged ideas about flood risk which have a narrative structure and appear at odds with the systems analysis. Because these *new narratives* were found so frequently, they are considered important enough for a third main historical trend.

The main Dutch policy documents since 1986 and other publications, have been scanned for quotes illustrating fourteen of these new narratives, like 'water should be leading in spatial planning' and 'rivers should not be squeezed in a corset'. The three most popular ones are that 'water should not be our enemy, but our friend', that flood protection entraps us in a dangerous 'spiral of risk' which can be stopped, and that flood risk reducing measures should be 'natural' or 'follow nature along'.

The general critique to the ideas is that they advance certain preferred measures as generally logical without having to systematically compare them to alternatives in particular situations. Behind the new ideas lies increasing interest in objectives like an attractive water landscape (Water as a Friend), fear of large-scale technological solutions (Spiral of Risk) and healthy ecosystems (Following Nature Along). Many quotes reveal a general aversion towards higher dikes.

One explanation for the popularity of the studied new narratives is that especially at times when new objectives (nature and landscape quality) are added to the mix, it is tempting to follow a simple grand idea rather than to do the hard work of unraveling the concept of risk, grasping the interplay between different objectives and systematically comparing alternatives. An additional explanation states that many Dutch water professionals are wary to take a stand for higher-order objectives in 'Maslow's hierarchy for water infrastructure' (chapter 4), and feel comfortable when a certain narrative somehow connects a new objective like nature development to a centuries-old lower-order objective like flood safety.

The third main historical trend identified in this thesis is that since 1986 certain narratives have become popular which address objectives higher up and lower in Maslow's hierarchy *simultaneously*, but which distort well-balanced analyses.

Chapter 5

New narratives about flood risk

Original paper title: a critical approach to some new ideas about the Dutch flood risk system

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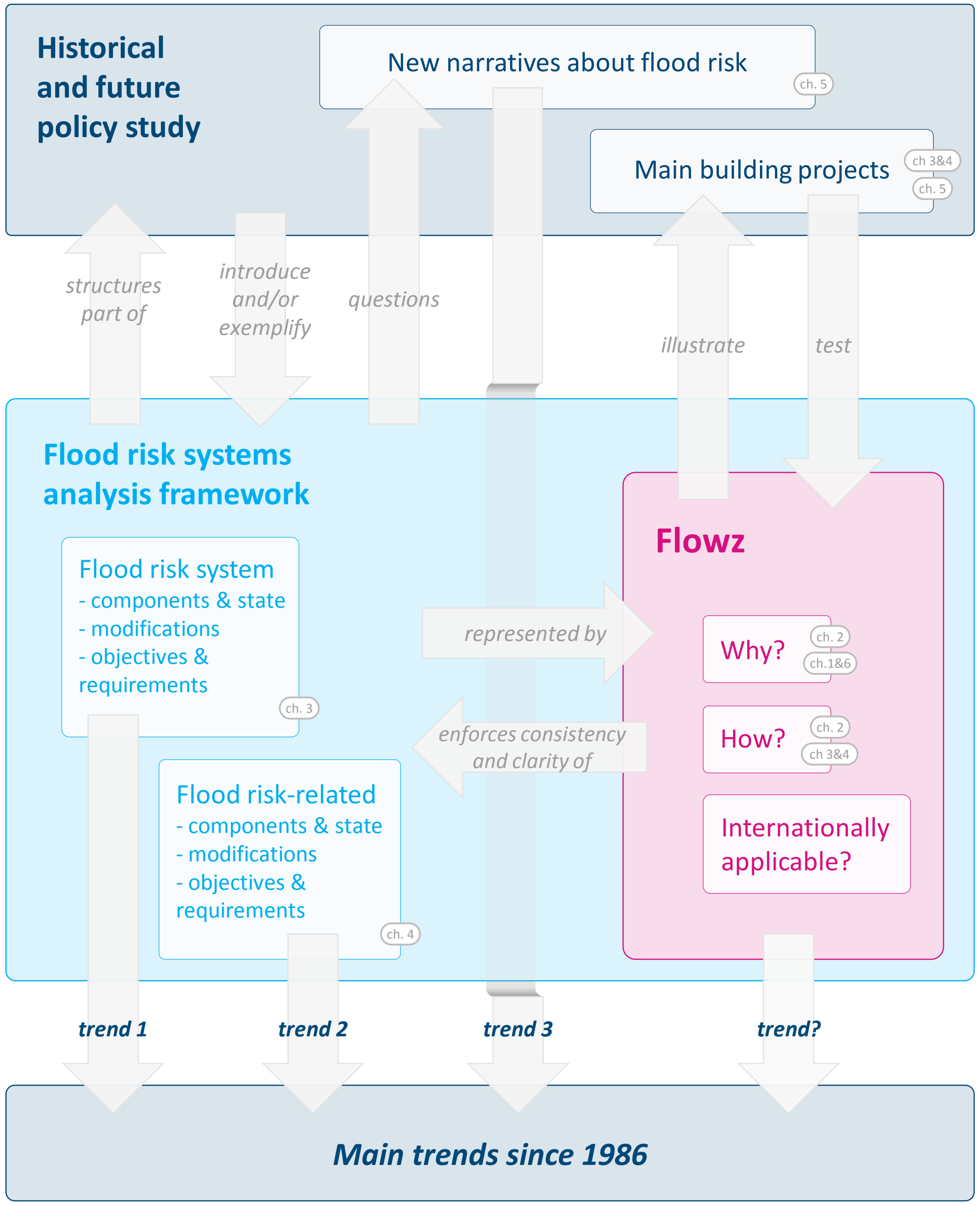
Modifications to the original paper: the general discussion has been slightly modified and the final subsection (on the third main historical trend) was added in 2016. In the new subsections, the term *debatable idea* has been replaced by *new narrative*.



5.0 This chapter completes this part of the thesis as explained in chapter 1 (figure 1.15 on page 40).

5.1 Studying debatable ideas [new narratives]

Introduction

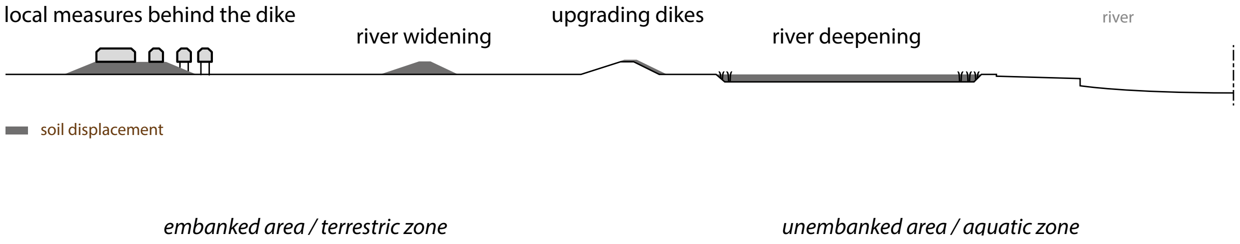
The Dutch landscape may, for a large part, be seen as a gigantic highly man-made water processing machine. A primary objective for this machine is to limit the probability that the seas and main rivers break through its elevations, the dikes, which protect 65% of the country from flooding. Throughout the centuries, the Dutch water machine has continuously been improved and upgraded – the cross-section of a medieval sea dike was at most 50 m^2, reaching two or three meters above mean sea level; nowadays the dike on the same location is easily four times higher and ten times as voluminous.

The water machine is never finished. Under the *Delta Plan* (1953-1997), over a thousand kilometres of dams and dikes along the coast and estuaries were newly built or upgraded. Between 1995 and 2015, about 500 kilometres of rivers were tackled in the projects *Delta Plan Large Rivers* and *Room for the River*. Currently, upgrades are conducted under the *High Water Protection Program* and prepared by the *Delta Programme*. Since 1960, average yearly costs of flood risk system upgrades are estimated 400 million euro (price level 2014); maintenance and operations cost about the same (prices taken from MIRT and other documents).

How are decisions for upgrades made, and which choices do decision-makers have? According to TAW (1998), Vrijling J.K. et al. (1998), Eijgenraam (2007), Kind (2013) and others (elaborated in chapter 4) , upgrades are viable when, in an as broad as possible analysis, the benefits of an investment (primarily risk reduction) outweigh the costs (primarily building costs). The flood protection standards in the Dutch *Water Act* are derived from such a cost-benefit analysis. The system has to match up to the standards, but in practice, decisions for upgrades are often postponed and finally happen only after a flood or near-flood, and/or when times are right for other reasons.

When flood risk reduction is wanted somewhere (in a flood risk system with dikes), there are five types of measures available. 1) Improved disaster management (like evacuation plans), 2) local measures behind the dike (like flood proof buildings and risk zoning), 3) dike upgrades, 4) load reduction by river widening and deepening (spatial measures), 5) load reduction by control structures redirecting flows on a higher scale level (like a storm surge barrier) (after Klijn et al. 2012) – see figure 5.1 for measure types 2, 3 and 4. Each of these measures can impede or support a wide range of accompanying objectives related to shipping, freshwater conveyance, transportation infrastructure, ecosystems, etcetera.

Decisions for measures are made in an elusive process, when ideas, beliefs and preferences among a large group of people converge (Rijcken et al. 2012). There are many theories about political decision-making, like the systems approach, revolving around system models, versus the network approach, revolving around actors and



5.1 Three flood risk reduction types (river widening and river deepening are considered the same type). Other types are disaster management and measures to redirect flows on a higher scale level (like a storm surge barrier or a spillway near a river bifurcation).

processes. Decisions may be rational or emotional, comprise far reaching blueprints or adaptive incremental steps, be pragmatic or appeal to a grand vision. In whatever way they are made, general *ideas* about how the flood risk system works and should work, play a major role. Someone may be in favour of a storm surge barrier because of the outcome of a *specific* cost-benefit analysis, but also because he or she believes in the *general* idea that a river mouth near a major port ought to be protected by a moveable barrier, regardless of the specific analysis.

In science, most time is spent on elaborating good ideas and some time on dismantling bad ideas. Critical publications about flood risk ideas are usually personal opinionated essays (Boorsma 2007; Rijcken 2008; Vrijling 2008; de Wit et al. 2010; Jonkman 2013, etcetera), or comments on specific publications or policy proposals (Rijcken 2007; Jongejan et al. 2008 and 2012; Waterforum 2013, etcetera).

This paper is more extensive and makes an inventory of the major Dutch policy documents, looking for ideas which can, carefully, *new*, or less carefully, *debatable*. Related quotes are collected, dated, grouped and then counted, to be able to make a statement on whether an idea is marginal or more broadly shared. The three most prominent and controversial ideas are analyzed on the used reasoning and the potential harm. The final general discussion considers what the new narratives have in common and suggests what can be learned about related preferences and perceptions in society.

The search starts around 1990, the final years of the Delta Works. In 1986, the famous Eastern Scheldt barrier was completed and a year later parliament voted to build the Maeslant barrier. These feats of engineering marked the end of an, according to many (e.g. van Rooy & Sterrenberg 2000; DG Water 2006; Meyer 2012; Correljé & Broekhans 2014), technocratic mindset, against which the new narratives in this paper appear, at least in part, to rebel.

Method

The research starts with a list of debatable ideas, collected in the years prior to (and leading to) this article (1990-2014). A *debatable idea* is an idea open to discussion because it seems to contain inconsistencies, logical flaws or otherwise present conclusions which do not logically follow from the premises. 'Climate change forces us to improve our evacuation plans', is debatable because improved evacuation plans are not the only possible response to climate change. 'We prefer evacuation plans over other risk-reducing measures', is a preference, not directly formally debatable.

A debatable idea is revealed in *illustrative quotes*. These quotes can similarly be debatable on formal grounds, or otherwise illustrate the debatable idea. 'The main part of our organization believes that climate change forces us to improve our evacuation plans' is not formally debatable, but reveals the presence of the debatable idea.

A debatable idea is *not marginal* when related illustrative quotes are found in more than 10% of the twenty most important national policy reports, and furthermore in multiple scientific publications and other professional documents.

Of the list of debatable ideas, the three most prevailing and most controversial ones are elaborated. For each, the most illustrative quotes are selected and the idea is explained with pictures and drawings. The idea is then explained and criticized on the reasoning and the potential harm. For each idea it is illustrated which types of risk reducing measures are supported by the idea. These are put together to support the final remarks in the general discussion.

> "Until now, space in the Netherlands has primarily been facilitating human activities. Natural forces were tamed. Rivers were embanked, estuaries dammed and inland seas turned into polders. **Human functions lead in spatial planning**. Awareness increases that this approach knows not only advantages, but also yields more and more costs and is finite. The tamed natural forces will, sooner or later, be stronger than man. This can be avoided by no longer working against nature, but with nature, and adjust land use to the possibilities of the water: **water is leading.**"
>
> Derde kustnota (V&W 2000)

> "(...) a policy [is needed], where **water is less seen as an enemy that should be fought, but as an ally** with nature, agriculture and urbanisation."
>
> Rapport Commissie WB21 (2000)

> "Historically we have restrained the water with pumps and levees, but that strategy is changing radically. According to the latest insights we should, in doses, let the water in, rather than **entrench ourselves behind ever higher walls**."
>
> magazine article (Metz 2012)

> "Over the last centuries, a lot of space has been taken away from the river. As a result, **rivers have been sandwiched between dikes** which have, during the recent decades, become ever higher."
>
> PKB Ruimte voor de Rivier (V&W 2006)

> "Large investments (...) ask for more protection and therefore more enforcements of flood defenses. **This makes us go around in a vicious circle.**"
>
> Vierde nota waterhuishouding (V&W 1998)

> "The shift boils down to the Netherlands having to adapt to the water. We have to give space to the water, in stead of take it away (...) Space not in height or depth by deepening channels, but in width. This costs space, but in return we get safety. (...) Only by giving space we can really get our house in order, because if we do not do that, the water will take the space, sooner or later, by force."
>
> Anders omgaan met water (DG Water 2000)

> "Traditionally, flood management practices in Europe have focused on predominantly hazard control, or i.e. flood protection measures such as dykes or drainage systems to reduce the probability of flooding However, in the past two decades **major flood disasters have created the need to shift** from flood protection to a more integrated approach in which flood risk is actively managed to also reduce flood impacts."
>
> scientfic publication (van Herk 2014)

> "(...) do we choose to **connect to natural processes, or will, on the contrary, the opression of natural processes be our starting point?**"
>
> policy vision report (Projectteam NW4 1995)

5.2 Examples of illustrative quotes. The ones related to *Water is our Friend* in blue, the *Spiral of Risk* in orange, *Following Nature Along* in green, other ones in grey. The captions give the document titles (for the major national policy documents) or the type of document (for other types of documents); between brackets () the reference.

5.2 Three debatable ideas [new narratives]

Selection of ideas and search for related quotes

The survey searches for quotes illustrating the following fourteen ideas, well-known to most Dutch water professionals.

1. Water is our friend, not our enemy.
2. A focus on preventing flooding catches us in a spiral of risk, which should and can be reversed.
3. We have to follow nature along and strive for natural solutions.
4. Because of climate change, we have to innovate.
5. Innovative solutions are better than traditional solutions.
6. Spatial solutions are better than technical solutions.
7. Precipitation should first be retained, then stored, and then discharged.
8. Water should be leading in spatial planning.
9. Water problems should not be passed on to adjacent water systems.
10. Rivers should not be sandwiched, laced up, or squeezed in a corset.
11. We can't go on raising the dykes forever.
12. Flood risk reducing measures are like links in a safety chain which should all be equally strong.
13. In a risk system, every layer of risk reduction has to be addressed with measures.
14. Residual risks have to be addressed with measures.

To illustrate these ideas, the twenty major policy documents since 1989 are read or scanned (Ctrl-F in PDF files) for the (Dutch) words *leading, diverge, store, lace up, corset, forever, chain, vicious, residual risk, spiral, friend, enemy, following along,* and *natural*. Figure 5.2 shows examples of illustrative quotes found in the survey.

Of these fourteen debatable ideas, numbers 4 to 14 are not elaborated; ideas 4, 5, 6 and 7 favor particular measures in such an obviously general way that they are hardly controversial. Ideas 8, 9 and 10 are well-known; critique to 8 would be that when land use and water management are intertwined, it is not clear which of the two leads, and why this matters; to 9 that water management is essentially about passing problems on towards the best locations to solve them; to 10 that rivers are not human bodies which can be squeezed in a corset, but volumes discharging precipitation, defined by a surrounding geometry of mostly sand and clay. Ideas 11, 12, 13 and 14 overlap with number 2. Ideas 1, 2, and 3 seem to be the most prominent and controversial.

Table 5.3 lists the document types scanned. Table 5.4 shows when the debatable ideas were found. Quotes illustrating a struggle with the concept of nature are the most abundant.

	Documents	Quotes			
		Friend	Spiral	Nature	Other
Major national policy documents	15	2	4	25	8
State commission reports	5	2		3	3
Scientific publications	8	1	4	3	4
Other documents	18	6	7	13	1

5.3 The 20 most important national policy documents on the Dutch flood risk system were read and scanned for quotes like the ones in figure 5.1.

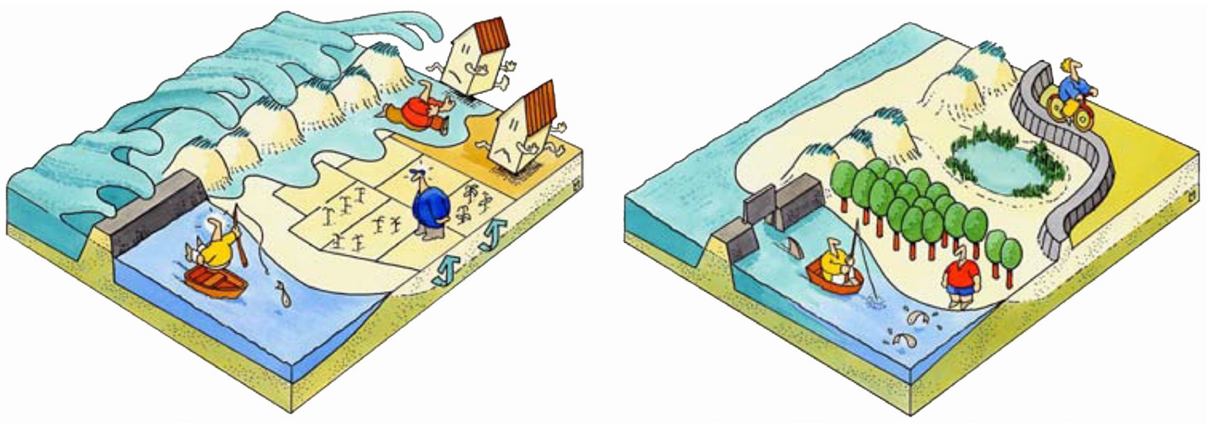
	Documents	Quotes			
		Friend	Spiral	Nature	Other
1990 – 1994	5	1	2	2	
1995 – 1999	4		2	5	1
2000 – 2004	6	3	4	7	6
2005 – 2009	16	5	4	13	3
2010 – 2014	15	2	3	17	6

5.4 Most quotes were found in the 2000s and few before 1995.

1 – Water is our friend, not our enemy

In his foreword to the final report of the (State) *Committee Water Management 21st century*, the chairman writes that “there is no doubt that in the Netherlands, the sink of Europe, a different approach is needed. Too much we still deal with [only] technical management, while time is pressing for a different water policy (…), where water is less seen as an enemy who should be fought, but as an ally with nature, agriculture and urbanisation.” (Commissie WB21 2000). In 2006, the ministry wrote: “There is a growing awareness that living with water contains risks, but also offers opportunities (quality of life, economic profit, roots for national identity) (…) (DG Water 2006). This notion was a central theme in the 45 million euro knowledge program *Living with Water*, whose chairman wrote: “Living close to the river doesn’t only entail flood risks but deeply connects to quality of life. (…) this idea is put to work in the design of river management that includes the local problematic aspects of room for the river but also provide new opportunities for economic and social development. This expresses and supports the paradigm shift from ‘fighting the floods’ to ‘living with water’ ” (Swanenvleugel 2007). *World Wildlife Fund* put it like this: “We don’t stand a chance fighting the far reaching consequences of climate change, when we keep seeing the sea and the whimsical tides as the prime threat against which we have to arm ourselves” (Braakhekke et al. 2008). Figure 5.6 is taken from a Living with Water document.

The quotes were often used in a context of certain popular or preferred measures – see table 5.7 for an indication.



5.6 “From averting the water …… …… to accommodating” (Programmaorganisatie Leven met Water 2006).

Types of measures	Water is our Friend, not our Enemy	
Disaster management	not mentioned	*In the context of the quotes, disaster management measures were not mentioned.*
Local measures and risk zoning	some measures favoured	*Floating housing and water storage treat water as a friend.*
Upgrading dikes	**generally disfavoured**	*Dikes consider water as an enemy. Dike heightening is worse than dike strengthening.*
River widening and deepening	generally favoured	*River measures which reduce water levels treat water as a friend.*
Redirecting flows on a higher scale level	some measures favoured	*Large engineering objects are hostile, but moveable barriers are favoured over dams.*

5.7 Brief indication of the types of measures favored and disfavored in the context of the quotes illustrating the idea that *Water is our Friend, not our Enemy*.

The statement that water should not be our enemy but our friend, makes a pledge for an attractive landscape and other ‘soft’ values on which the flood risk system can have an impact. Yet, the idea opposes two approaches which have always existed, and will always exist, side by side. Under the old paradigm, perhaps, esthetic and emotional values of water were less acknowledged by policymakers (but for sure by others). Still, water has always had functions which can be labelled as treating water as an ally, like shipping, drinking water and agriculture. Under the new paradigm, there will still be storms and heavy rainfall; at rare times the water is able to kill and will surely feel like an enemy to all.

Furthermore, it is not clear why exactly this polarisation is made. It would be a clear

"**The battle has calmed down**. Concerning levee enforcements the crisis in the culture-nature relationship will be heated just once again. Will we literally add another layer or is it time to take a different path? This much is sure: the ruler has won a great victory over the water. It is now time to **care about the exhausted waterwolf and try to become friends with him**."

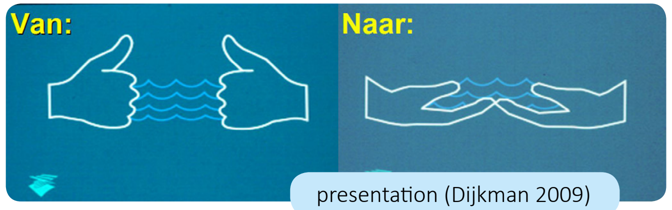
essay (Kockelkoren 1994)

"There is no doubt that in the Netherlands, the sink of Europe, a different approach is needed. Too much we still deal with [only] technical management, while time is pressing for a different water policy. A water policy with a broad orientation, aimed at content, public support and management with a clear target. A policy, where **water is less seen as an enemy that should be fought, but as an ally** with nature, agriculture and urbanisation."

Rapport Commissie WB21 (2000)

"Living close to the river doesn't only entail flood risks but deeply connects to quality of life. In Freude am Fluss this idea is put to work in the design of river management that includes the local problematic aspects of room for the river but also provide new opportunities for economic and social development. This expresses and supports **the paradigm shift from 'fighting the floods' to 'living with water'**."

foreword to a research report (Swanenvleugel 2007)



presentation (Dijkman 2009)

"Building dykes ever taller is not the answer to increasing flood risks. The European project 'Freude am Fluss' proposes a new approach to flood risk management along embanked rivers: **'live with water rather than fight it'** and 'more room for the river'. This new way of thinking includes two main pathways which interact with eachother: The first is technical innovation to adapt housing, land use and activities on the floodplain. In other words: land use has to become flood tolerant. [...] the second pathway focusses on developing a process of joint planning [...] Applying this new concept will fundamentally change the way we manage our river basins."

documentary introduction (Freude am Fluss 2006)

"People choose for attractive and healthy water around them for living, recreation and to enjoy. Direct involvement however, only occurs until they are threatened or experience nuisance and damage. Then the government is called upon, because they expect the government to take care of their safety and protects them from nuisance and damage. **Water as an ally again loses to water as a friend.**"

Rapport Commissie WB21 (2000)

"There is a growing awareness that living with **water contains risks, but also offers opportunities** (quality of life, economic profit, roots for national identity), which, however, can not be cashed, kept or used, without a struggle."

Waterkoers 2 (DG Water 2006)

"In living with water, we see better guarantees for the generations to come, than solely technically restraining water."

newspaper essay (Geldof & van Hilten 2006)

presentation (Adriaanse 2009)

"Slowly, more water appears in neighbourhoods, filled canals are reopened and more and more wet nature appears within our urban structure: water breaks through the hardness of concrete, stone and stress. In this state of mind, **water is not considered an enemy or prey, but rather a partner.** The properties of the water itself and the way it is experienced, should be starting points."

Anders omgaan met water (DG Water 2000)

"For a long time policy has been pledging to accommodate water by 'space for the river' and 'space for water', mostly combined with nature development. [This] policy aims at giving water the place in spatial development issues it deserves, and not always considers it an appendix. **Do not only reduce the probability of flooding, also create, here and there, some space for water.**"

scientific publication (van der Most et al. 2010)

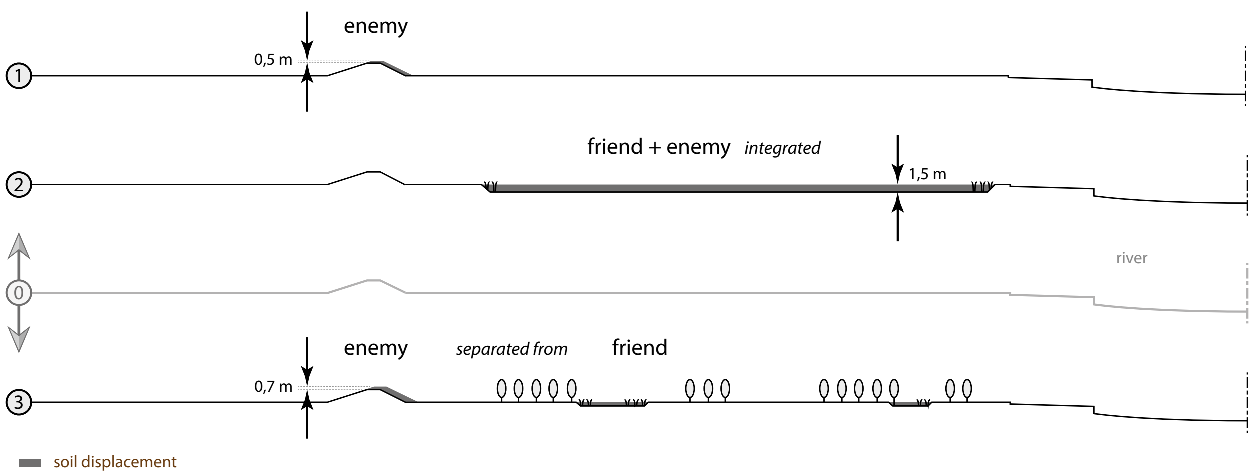
"This long cherished self image of bold conquerers on a swampy subsoil needs a thorough revision for multiple reasons. **We don't stand a chance fighting the far reaching consequences of climate change, when we keep seeing the sea and the whimsical tides as the prime threat against which we have to arm ourselves.** (...) In the 20th century we learned important and expensive lessons about the limits to the ongoing canalisation of rivers, the neglect of the natural dynamics of flood plains; the challenge now is to rebuild our trust in the natural resilience of our own estuary. (...) **We have to work with water, play with it,** rebound with nature and dare to again profit from natural dynamics."

NGO report foreword (Braakhekke et al. 2008)

5.5 Quotes illustrating the idea *Water is our Friend, not our Enemy.* The captions give the document titles (for the major national policy documents) or the type of document (for other types of documents).

standpoint to want to allocate a smaller part of the water management budget to fighting floods and more for increasing quality of life, or to obtain additional budgets to finance particular water-as-a-friend objectives, separate or integrated with flood risk. In stead of taking a clear defensible position like this, it is often claimed that when we treat water as a friend, its hostility will be reduced – a confusing idea that can never be true in general.

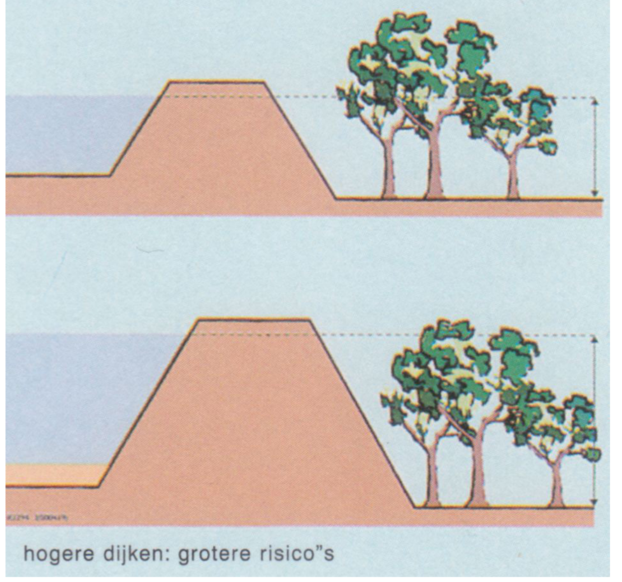
How could this idea be damaging? When it is vague how enemy- and friend-oriented objectives and budgets are connected, it is not clear anymore which parts of the budgets are directed to which issues, making it harder to make and explain decisions. The prerequisite that projects have to address water as an enemy and as a friend simultaneously, excludes packages of measures that meet both objectives separately against lower costs than their integrated alternatives (see figure 5.8). In 2005, the Netherlands Bureau for Economic Policy Analysis (CPB), presented an alternative to Room for the River, with flood risk reduction projects and nature projects partly separated, against lower total costs but with more total nature value (Ebregt et al. 2005). The recommendation was discarded, possibly influenced by the idea that Water as a Friend should not be treated separate from Water as an Enemy.



5.8 The idea that water should become our friend to reduce its hostility, favors certain measures without carefully considering the pros and cons of alternatives. In this figure, the three redesigns of the river profile give the same increase in discharge capacity. Option 1 treats water as an enemy. Option 2 is a typical *Room for the River* floodplain excavation: water as a friend. Dike heightening is avoided, but to achieve the same increase in discharge capacity as option 1, more than ten times as much soil than with option 1 has to be displaced. The resulting nature is high-maintenance; vegetation has to be cut frequently to keep roughness low. Option 3 treats water as friend and enemy separately. Vegetation can grow freely in the floodplains (water as a friend) because the increase in roughness is compensated by the dike (water as an enemy). This option, if mentioned at all, has no support in the Netherlands.

2 – The Spiral of Risk

In the cabinet's decision on the fourth water plan, the ministry of public works and water management wrote: "In the Netherlands we have been building levees and quays for many centuries. The higher and stronger these become, the larger the sense of safety. This makes the embanked land attractive for developers and investors. Large investments in their turn ask for more protection and therefore more enforcements of flood defenses. This makes us go around in a vicious circle. (…) Extreme circumstances like storms at sea and high river discharges ask for extra space, space with which the spiral of land subsidence and raising dikes, of encroaching development and the call for flood protection, can be broken." (V&W 1998). Two years later, a heavy-weight report by multiple governments from the lower rivers region stated that "upgrading levees alone is eventually a dead-end road, and will lead to increasing risks of consequential damages of possible floodings." (de Jong et al. 2000). A scientific publication mentions that in the Netherlands "the height of the dams will have to be increased for centuries to come, (…) the chance of flooding is reduced, but the potential damage after a storm flood is enlarged: seawalls and dykes provide a false sense of safety against flooding." (Smits et al. 2006). Figure 5.10 was published in a national policy vision document.
See table 5.11 for an indication of popular or preferred measures found in the context of the quotes.



5.10 "Higher dikes, larger risks" (DG Water 2000). See also figure 5.12 and 5.14.

"Ongoing embankments and sedimentation of the floodplains forced the high river discharge in **an ever tighter corset**. In stead of dealing with the deeper underlying cause, solutions were sought in clearing natural obstacles in and along the river. Also the levee enforcements, which started around 1820 and are still going on, fits in an agrarian spirit of age, whereby of course also the increased economic importance of the embanked area plays a part. Looking back at 150 years of levee enforcements, we can not withdraw the impression that this is, in part, **a vicious circle, which can not be broken as long as intensive agriculture dominates the floodplains.**"

NGO report (Helmer et al. 1992)

"From a socio-economic point of view, the impression of safety bestowed by the dykes, invites people to invest money behind them. Towns and villages prosper and tend to grow. Although the frequency of a potential disaster has diminished, the potential damage to lives and goods increases: the impression is therefore false. Especially in times of poor maintenance of the dykes (war, recession) this becomes only too obvious.
(...) In the 50 years after 1953, huge investments in trade, industry, and infrastructure were made. The population increased very considerably. Individuals took many decisions to invest behind the dykes. The government not only did nothing to prevent this development but, on the contrary, favoured this development.
(...) Storms that do almost no harm in a natural situation, turn into catastrophes when dykes are breached. This has been the rule for a thousand years.
(...) The huge dams may be technical masterpieces for control of the tidal dynamics of the sea, but they fail to control the socio-economic processes they unleash, and their existence is irreversible. **The chance of flooding is reduced; the potential damage is enlarged, so the net result is zero or worse**."

NGO report (Saeijs et al. 2004)

"The historical traditions of large embankments and similar infrastructure are still being replicated (...). **This reliance and belief in large technological solutions is known as 'technological entrapment'**, and whilst new embankments may be appropriate in certain circumstances, a reliance on these and other 'big' solutions exclusively risks a loss of flexibility, adaptability and ultimately sustainability in flood-risk management."

scientific publication (Zevenbergen et al. 2010)

"In the Netherlands we have been building levees and quays for many centuries. The higher and stronger these become, the larger the sense of safety. This makes the embanked land attractive for developers and investors. Large investments in their turn ask for more protection and therefore more enforcements of flood defenses. **This makes us go around in a vicious circle.**"

Vierde nota waterhuishouding (V&W 1998)

"Costs for room for the river are higher than those for levee upgrades. But it has to be noted that **upgrading levees alone is eventually a dead-end road, and will lead to increasing risks** for consequential damages of possible floodings."

major regional policy document (de Jong et al. 2000)

"Risk was defined as the product of the probability of being flooded and the scale of the consequences. In the Netherlands, it was argued, the reduction of this probability had allowed an ongoing expansion of the economic value and of land use behind the dikes, thus enhancing the vulnerability of the country, in case of another exceptional flood. Ultimately, the risk had not been reduced as much as was widely believed. Thus, the government was confronted with the paradox that **the smaller the probability of flooding, the higher the vulnerability."**

scientific publication (Correljé & Broekhans 2014)

"Ecologic recovery of our entire river system is possible. This recovery simultaneously offers great opportunities to solve other problems. Related to this I would like to mention, considering the political debate, **breaking the vicious circle of the river dike enforcements**."

foreword NGO report (Helmer et al. 1992)

"It is increasingly recognised that engineering responses alone cannot accommodate the future frequencies and impacts of flooding. Moreover, the mere use of **large infrastructure, particularly flood protection, has the risk for 'technological lock-in' or for 'investment trap',** creating a path dependency that reduces the opportunities to take alternative or complementary measures."

scientific publication (van Herk 2014)

"The question is what counts: the safety behind the dike, or the safety of the dike itself. (...) The discussion we have had lately, is about the transition to **a new approach, to the safety behind the dike, the real safety for the people behind the levees**."

parliamentary discussion (van Veldhoven & Sneep 2012)

"Our forefathers would **not for a moment have thought of building in the lowest parts of our country**, but our contemporary planners see no problems at all."

popular-scientific book (van Duijn 2007)

"Municipalities build in areas vulnerable to flooding, today and even more in the future: deep polders, regions with settling soil and groundwater seepage, or areas directly behind high levees. This is not only a consequence of the relatively short planning horizon common in current spatial policy-making. Also the repetitive emphasis on civil engineering measures contributes. Levees are raised step by step, surface water is pumped away ever deeper. This results in a slow increase between ground levels and maximum water levels, and slowly **we reach the limits of the system**."

policy research report (Pols et al. 2007)

"(...) the height of the dams will have to be increased for centuries to come, because the land behind the levees cannot grow in elevation anymore with the rising of the sea. Maintenance of the civil-engineering structures, and mitigating their unpredictable impacts on ecosystems, involve very high recurrent costs. **The chance of flooding is reduced, but the potential damage after a storm flood is enlarged: seawalls and dykes provide a false sense of safety against flooding.**"

scientific publication (Smits et al. 2006)

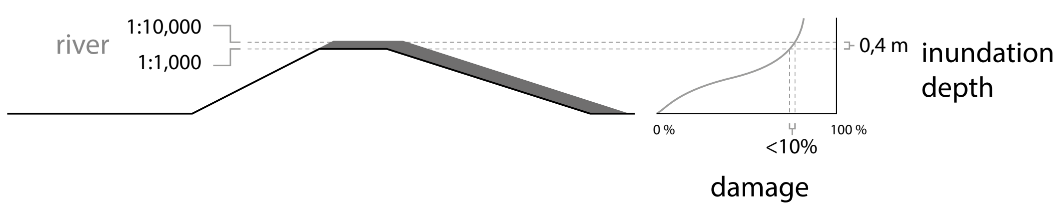
5.9 Illustrative quotes to the idea of *The Spiral of Risk.* The captions give the document titles (for the major national policy documents) or the type of document (for other types of documents).

Types of measures	the Spiral of Risk	
Disaster management	generally favoured	*The related concepts 'Safety Chain' and 'Multi-level Safety' emphasise disaster management.*
Local measures and risk zoning	generally favoured	*Measures behind the dike are considered ways to break the Spiral of Risk.*
Upgrading dikes	generally disfavoured	*Higher dikes are core to the Spiral of Risk. Wider dikes are favoured over higher dikes.*
River widening and deepening	generally favoured	*Lower high river levels reduce inundation levels and substitute higher dikes.*
Redirecting flows on a higher scale level	generally disfavoured	*Storm surge- and river discharge distribution control objects are part of the dike system.*

5.11 Brief overview of the types of measures favored and disfavored in the context of the illustrative quotes to the idea of the Spiral of Risk.

The mentioned vicious circle has to do with a fear of relying too heavily on technology. It is sometimes called *technological entrapment* (van Herk 2014), or the *spiral of risk* (Rijcken 2007). The idea has three parts: 1) investments to reduce flood probability and potential flood damage enhance each other until eternity, 2) this should be stopped and 3) this can be stopped.

Flood probabilities often contribute to decisions to settle or invest somewhere, and settlers tend to want to further reduce flood probabilities when they develop. This can come to a halt for some time, for example when flood protection is overdimensioned and growth slows down. There will always be maintenance, however, so when this is taken into account, we may speak of being entrapped in never ending effort. But should this really be avoided? The historic transition from hunting and gathering towards

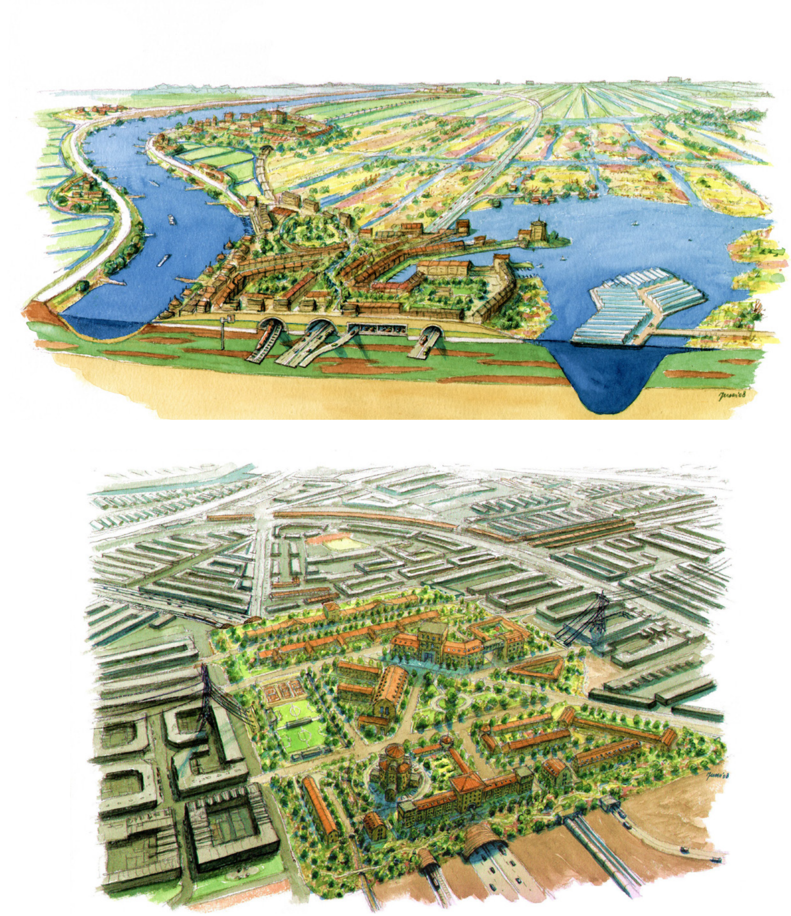


5.12 Part of the Spiral of Risk idea is that dike heightening provides a 'false sense of safety'; risks would increase because higher dikes lead to higher inundation depths. In this reasoning, damage is confused with risk. For Dutch rivers, roughly, a 40 cm higher water level has a 10 times lower probability of occurrence. According to the *stage-damage curve* for an average dike ring, a 40 cm higher inundation depth yields less than 10% more damage. As risk is probability times damage, the new risk is 0,1 x 1,1 = 0,11 as large as the old risk. With dike heightening, risk decreases more than ten times faster than damage increases. Safety is the reciprocate of risk. A sense of *absolute* safety may not be justified, but a sense of *increased* safety when a dike is heightened, surely is.

agriculture and industry is a tremendous entrapment, yet acceptable to most earthlings.

Several options have been presented to break out of the vicious circle of levee enforcements. For example, lowering high water levels – first by excavating the agricultural floodplains, then by relocating the embankments away from the river (Helmer et al. 1992; DG Water 2006; PBR 2013). In the Netherlands, if these types of measures would be implemented to the fullest, there will still remain an average of 7 to 8 meter difference between the design water levels and the embanked land (Silva & van der Linden 2008). Slightly lowered water levels will not stop the spiral of risk from spinning.

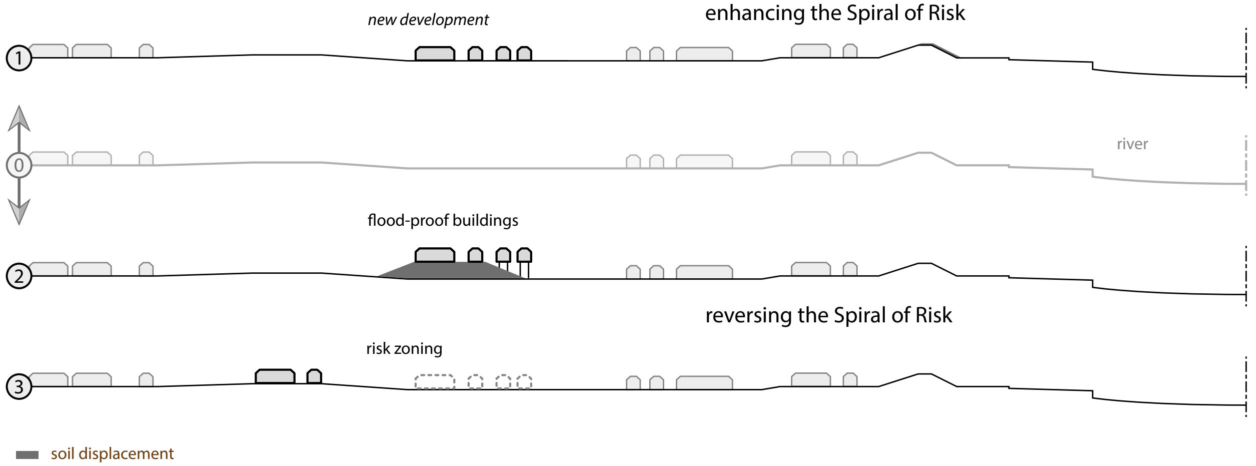
A second way out of the vicious circle would be offered by additional flood risk reducing measures on scale levels lower than dike rings, like risk zoning, abandoning areas, flood-resistant buildings, mounds (figure 5.13) or evacuation plans (eg. Saeijs



5.13 New neighbourhoods on megamounds to avoid an increase in flood damage and thus flood risk (Aerts et al. 2008).

et al. 2004; Pols et al. 2007). This idea influenced two popular concepts: the *Safety Chain* (eg. ten Brinke et al. 2008) and *Multi-Layered Safety* (e.g. DGW 2009; Hoss et al. 2013). Much can be said about which parts of these concepts make sense or not, and which parts are related to values and politics – the essence is that throughout the world a pragmatic approach to flood risk has always been to focus on the most effective measures, instead of spreading measures between scale levels (or layers) as a goal in itself.

In the Netherlands, investments in prevention (the first layer; mainly dikes) cover a small area and protect a large area, and when they work, they work completely. Measures inside the protected area (like flood-proof buildings) however, have to be applied in vast areas, and have limited total effect when the preventive scheme fails (Jongejan et al. 2012;



5.14 The Spiral of Risk idea suggests that the interdependency between flood protection and economic development is dangerous and can be reduced, for example by flood-proof buildings and risk zoning. This idea is often illustrated by exaggerated cross sections like of figure 5.10. Looking at properly scaled typical cross-sections like here above, knowing that a Dutch dike ring is easily 25 kilometres wide (on the scale of this drawing another 10 meters(!) to the left), it appears that *flood-proof buildings* (option 2) protect only new developments and quickly require much more soil displacement (or *effort*) than dike heightening (option 1). The idea of *risk zoning* (option 3) is that higher areas are favoured for development over lower areas. This dike ring floods, say, with a probability of 1:1000, and flood damage as a percentage of building costs may be 40% for option 1, 20% for option 3. Yearly flood risk relative to the building costs now differs between option 1 and option 2 by 0,02%. In practice, the benefits of risk zoning will be crushed by other considerations for development, like land value, proximity to infrastructure, etcetera.

ENW 2012) – figure 5.14 illustrates some principles. When a country has arrived at a point where sufficient prevention requires no more than maintenance and occasional upgrades, this is, from a pragmatic perspective, not an *entrapment*, but a safe haven. The illusion is not *complete safety*, rather that the spiral of risk should and can be broken.

The spiral of risk idea is potentially harmful in many ways: in an attempt to break the vicious circle, tax money earmarked for risk reduction is spent on projects while cheaper alternatives for more risk reduction are neglected; flood-proof building regulation and zoning adds unnecessary red tape to city- and landscape development; public awareness campaigns to change the behaviour of citizens end in vain; hammering on potential flooding deters foreign investors, etcetera. This is a sensitive topic in current Dutch policy-making – it is stressed that these are *potential* pitfalls.

3 – Following Nature Along

“The river fights back”, writes a group of senior consultants in a report for the 4th National Water Plan, referring to the swollen rivers of 1993. They ask: “When we build, operate and manage infrastructure, do we choose to connect to natural processes, or will, on the contrary, the oppression of natural processes be our starting point?” (Projectteam NW4 1995). The cabinet’s position on water management states that “The natural coping capacity of the delta has largely been lost. With technical means like raising dikes and pumping alone we reach the limits of what is possible. (…) The restrained natural forces will sooner or later be stronger than man. This can be avoided by no longer working agaínst nature, but working wíth nature” (DG Water 2000). In an essay published by the ministry of spatial planning and the environment: “Following along with water means: where flows are too strong, we will give, where sediment accumulates, we will take. (…) The Netherlands will thus achieve its natural water order, and will no longer be a giant prosthesis.” (van Schuppen 2007).

The Deltacommittee of 2008 recommends to “follow natural developments induced by climate change and other natural processes along. We build and develop the country as much as possible in harmony with ecological processes.” (Deltacommittee 2008). The recent annual Delta Programme reports mention “following natural processes along” a few times, and use the term “natural flood defenses” more than ten times, especially in the 2013 report (Deltaprogramma 2010; 2011; 2012; 2013). Figure 5.16 shows a typical example of a natural flood defense.

The quotes were often used in a context of certain popular or preferred measures – see table 5.17 for an indication.

"[The Netherlands have to] develop along with climate change. Moving along with-, and making use of natural processes where possible, leads to solutions to which man and nature can gradually adapt. [...] Attempts to control nature will demand ever larger (and more expensive) effort. [...] We [should] **build and develop the country as much as possible in harmony with natural processes**."

Deltacommittee (2008)

"(...) a natural stream is excavated, 60 meters wide and 1,2 meters deep"

web post (Coalitie Klimaatbuffers 2014)

"**The natural coping capacity of the delta has largely been lost**. With technical means like raising dikes and pumping alone we reach the limits of what is possible."

Anders omgaan met water (DG Water 2000)

"We are trying, less than we used to, to curb and restrain the forces of nature, but rather we try to better understand and guide them."

newspaper essay (Geldof & van Hilten 2006)

"The river fights back. (...)
When we build, operate and manage infra-structure, **do we choose to connect to natural processes, or will, on the contrary, the opression of natural processes be our starting point?**"

policy vision report (Projectteam NW4 1995)

"(...) one might say that **Mother Nature**, old and wise, extends her hand to show us how we should and how we shouldn't interact with her.
All we have to do is listen and pay attention and follow her advice.
We must simply 'be her guest'. Let's not forget that she has 3 billion years more experience than we have, and was doing a wonderful job long before Man entered the scene. In fact she produced us!"

popular scientific book (Saeijs 2008)

"The Netherlands thought they had won the battle against the water: the Delta works are done [...] and the rivers have been laced up with dikes and dams. The water is caught in asphalt, steel, basalt and concrete, but maintenance costs increase day by day. At the same time, the Netherlands are sinking, because of the intense pumping and **natural processes like sedimentation and peat growth have been halted**."

web post (Coalitie Klimaatbuffers 2014)

"Everywhere in the world, the reaction of people is the same: if something serious happens, you want to restore the old situation. For the consequences of Superstorm Sandy this is exactly the wrong reaction. **Working against nature is not a solution.**"

web post (Ovink & I&M 2013)

"In the policy concerning flood control and water management, 'hard core' civil engineering approaches are discussed and substituted by approaches which emphasize resilience and working with nature. (...) [This] approach has been applied predominantly in rural areas while in the urbanised western part of the country a more traditional combination of 'hard core' hydraulic engineering and urban planning seems to be the best option. (...) Two serious high-water situations in the river area in the mid-1990s enhanced **the idea that the era of controlling nature was finished**."

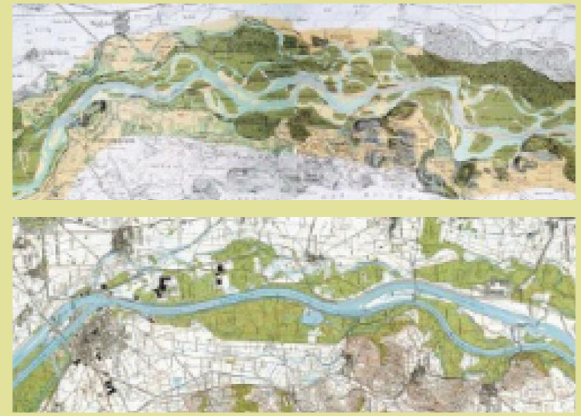
scientific publication (Meyer 2012)

"The system is not capable to handle extreme circumstances (...), and it is therefore required that we give space to water and **restore natural processes**."

Watervisie (DG Water 2007)

"**Connecting to natural processes** by restoring the resilience of water systems will provide important guidance for future water management"

Vierde Nota Waterhuishouding (V&W 1998)



"The natural course of the river has been canalised by man. Now, the river reclaims its original space. Normalisation has, apparently, not been a sustainable solution. The maxim should be: **anticipate and move along with the natural dynamics of the water** and be prepared for the long-term consequences of climate change."

Waterkoers 2 (DG Water 2006)

"A delta without dykes is safer than a delta with dykes, because **natural processes will weaken the effects of extreme storm floods.**"

scientific publication (Smits et al. 2006)

"Water systems need playground to cope with unforeseen develop-ments. For the rivers, this means water conservation in the entire catchment and expanding the flow profile, in stead of the next round of levee enforcements. (...) We have to **remove unnatural obstacles in the river bed. (...) for the coast sustainable safety means space for natural processes.** The less we fixate the coast by hard constructions such as levees, dams and permanent buildings, the less the effort to keep the coast at its place"

Vierde Nota Waterhuishouding (V&W 1998)

"(...) **building with nature offers a much better protection than the technical solutions that go against nature**. We are doing this along the coast, for example; sand nourishments so the coastline expands. I really believe in building with nature. (...) You get more stability when you implement both nature as well as technology. Insights about what works best are changing."

newspaper article (Schultz et al. 2013)

"Moving along with water means: where flows are too strong, we will give, where sediment accumulates, we will take. (...) **The Netherlands will thus achieve its natural water order,** and will no longer be a giant prosthesis. (...) Typical water infrastructure elements are the inlet and outlet for emergency storage areas, broad coastal defenses and room for the river. Housing in areas with 'dynamic water management' are historical typologies such as houses on mounds, on dikes, floating homes and – lest best – the drowning house. (...) It is a mentality of reversal, of paradox: dikes, quays and sluices built to keep the water out, can easily be transformed to function in a system aimed to let the water in."

essay (van Schuppen 2007)

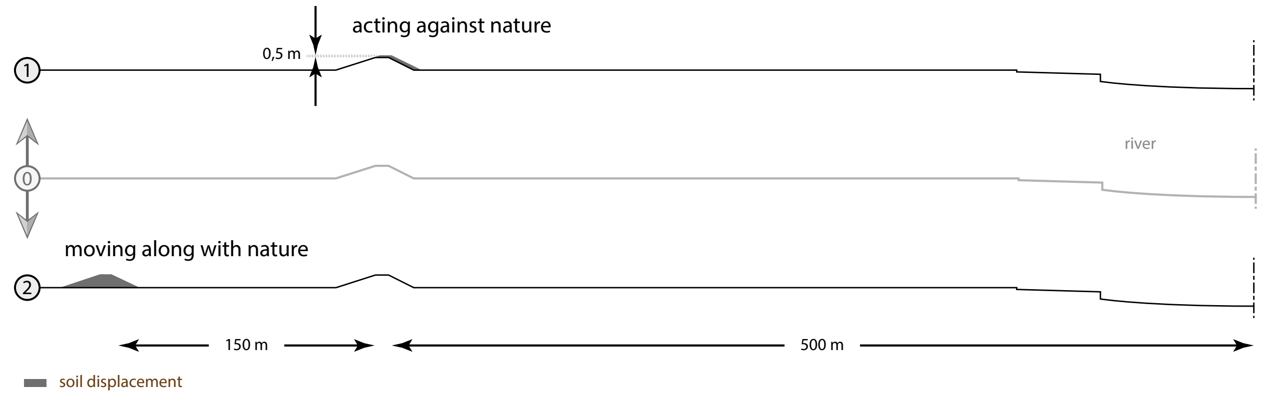
5.15 Illustrative quotes to the idea of *Following Nature Along.* The captions give the document titles (for the major national policy documents) or the type of document (for other types of documents); between brackets () the reference.

5.16 Redesign of the Dutch Closure Dam by landscape architect Hosper (Lammers 2009). The green land to the left is currently not there; vegetation is to grow over artificial sand nourishments of several meters high. The concept is promoted by the NGO *Natural Climate Buffers*, in which the major Dutch nature conservation organizations collaborate. The NGO frequently uses the terms *natural safety* and *natural flood defenses* in their communication, for example towards the Delta Programme (SNK 2014a). Also see figure 5.19.

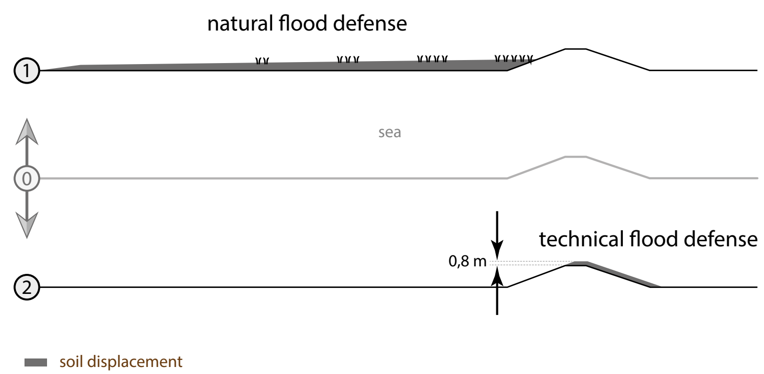
Types of measures	Following Nature Along	
Disaster management	generally favoured	*In the context of the quotes, disaster management measures were not mentioned*
Local measures and risk zoning	some measures favoured	*Prohibiting to build in certain areas (zoning) is sometimes called Moving Along with Nature*
Upgrading dikes	generally disfavoured	*Dikes are considered acting against nature, oppressing natural processes, etcetera.*
River widening and deepening	generally favoured	*Measures in the river bed are called natural and often accompanied by nature restoration.*
Redirecting flows on a higher scale level	some measures favoured	*Open estuaries are natural, dams act against nature, movable barriers are in between.*

5.17 Brief overview of the types of measures favored and disfavored in the context of the illustrative quotes to the idea of Following Nature Along.

The quotes reflect a strong interest in nature conservation and restoration, and in something transcending human interventions and technology, but the terms are not clearly defined. What does it mean to connect to a natural process or to give in when a flow is too strong? In the documents, this is not defined, but exemplified by measures, likes ones which direct water sideways instead of upwards (figure 5.18). Other typical measures are coastal sand nourishments (figure 5.19) and excavated bends to de-



5.18 The idea that the flood risk system should *Follow Nature Along* favours additional horizontal space over extra space in a vertical direction. According to the formula $Q = C \cdot B \cdot H^{3/2}$, roughly 0,5 meter dike heightening (option 1) and 150 meter river widening (option 2) give the same additional discharge capacity. Both result in highly man-made river profiles.



5.19 Artificially elevated foreshores along the coast are often considered *natural flood defenses*, but require more fill than a typical dike reinforcement. How much material is to be displaced by machines apparently does not determine how natural a measure is.

canalise rivers. A term can however not be defined by examples alone. In the Dutch dictionary, the term ‘following along’ does not exist, and in the water literature, a working definition is nowhere found.

The frequent use of ‘natural flood defenses’ might be a serious indication that among water professionals the definition of the word natural is changing. Most commonly, something is considered natural when its shape or place has been caused by a force other than induced by a conscious human decision. The 44 quotes in figure 5.15 are all made in a context of human interventions; no-one advocates to make the flood protection system more natural by doing nothing. So what is meant by a natural measure or a natural system?

Let's consider some contexts in which these terms are used. The concept *building with nature* is clearly defined: wind and currents distribute building materials (mainly sand), and/or building components are designed such that they attract or facilitate flora, fauna and/or entire ecosystems (Waterman 2008; Deltares 2014, etcetera). Nature is a force or a cause.

Most *room for the river* projects are about lowering or widening the river bed by turning agricultural floodplains into natural parks, digging bypasses and lakes for fish and birds, growing wild vegetation on excavated farmland, etcetera (V&W 2006; Q-team 2008 and 2012, etcetera). Nature is an occupant of space.

Along the coast, under the *dynamic coastal management* policy, a yearly 12-20 million m^3 of sand is added to the coastal system to maintain a certain geographical base coast line and allow more sand to blow freely through the dunes. This contrasts to an alternative with less replenishments and more dunes fixed in place by planted grass or revetments, which would create a less diverse and smaller dune landscape (DGW 2009, etcetera).

It seems that a *measure* is called natural when it supports a native, diverse or attractive ecosystem. A *system* is natural by the same definition, or when it resembles the way it was before the interference of man. With this additional definition of *natural*, about half of the quotes in figures 5.3, 5.4 and 5.15 make sense. The other half refers to the poorly defined idea Following Nature Along. Both terms however may instil pleasant emotions in some people but will arouse suspicion in others.

According to epistemologists Collins and Evans the *argument from the natural* is "about as unsophisticated an argument as one can find" (Collins & Evans 2007). People using the term *natural flood defenses* may be suspected to not really know what they are talking about or not to express the real arguments. In the Netherlands, societal interest and political lobby for ecosystem conservation and restoration are strong. To many lobbyists the end justifies the means, and for the nature lobby it is attractive to connect their cause to flood safety – a strategy publicly announced by World Wildlife Fund (Opmeer 2013). Ambiguous and undefined terms can obscure that a budget for an integrated project is primarily justified by providing safety, but is spent mainly on nature development.

5.3 Discussion

Methodological discussion [from the 2015 paper]

After the Dutch Delta Works, new ideas or *narratives* about the flood risk system emerged among Dutch water professionals. New ideas deserve a critical analysis; in this paper, 14 ideas, carefully called *debatable* but yet well-publicized, were quoted and scrutinized. 20 of the most important national policy documents, and 26 other publications, were searched for quotes illustrating the ideas and to find out whether the ideas are broadly shared or marginal. The three most prominent and controversial narratives were selected to elaborate further. 10 quotes were found related to the idea that 'water should not be our enemy, but our friend', 15 on the idea that flood protection entraps us in a dangerous 'spiral of risk' which should and can be stopped, 45 quotes were related to the idea that flood risk reducing measures should be 'natural' and/or 'Follow Nature Along'.

These numbers are enough to suggest that these three ideas have not been marginal but were widely communicated, but more quotes and debatable ideas can be found with deeper searches in the same documents, other documents, or with web searches, possibly extended towards foreign documents. A strict distinction between different types of illustrative quotes could help to reveal when an idea is formed, when it is taken for granted and when it might have disappeared.

A quoted author might say that he or she meant something else than what seems in this paper. It would be interesting to interview the authors of each quote, or to take an entirely different approach and send a questionnaire about the same ideas to water professionals, to generate additional new narratives or different interpretations of the fourteen selected ones. Including the background of the authors, like engineering, geography or law, would reveal interesting correlations between backgrounds and ideas.

Still, many water professionals, engineers and others, will recognise the fourteen ideas, and acknowledge that it is healthy to discuss them. Achieving safety and related objectives require reasonings which are able to withstand critique.

General discussion and conclusion [from the 2015 paper]

From the perspective of the systems analysis of chapters 3 and 4, the general critique to the selected debatable ideas (and perhaps to narratives in general) would be that they support preferred measures as generally logical conclusions without having been systematically compared to alternatives in particular situations. Clearly negative effects like reduction in safety, deliberate deception of the public or squandered tax money cannot be asserted; general beliefs among an unknown part of the decision-makers are not the only factors leading to decisions, and for this paper it was chosen not to delve into all considerations leading to the major decisions since 1990.

Behind the new ideas lies increasing societal interest in objectives like an attractive water landscape (Water as a Friend), reducing our dependence on technology (Spiral of Risk) and nature conservation and restoration (Following Nature Along). Some might argue that these worthy ends justify almost any mean, even weakness in underlying ideas. Others believe that the *content* of ideas is of minor importance, as long as a proper democratic decision *process* has been followed. This thesis is grounded in the belief that content matters and widely shared ideas about the system have, one way or the other, an impact on decisions. Arguments containing questionable ideas or following poor reasoning weaken the outcome of decision-making: the means justify the ends.

The survey leads to a couple of conclusions, presented as hypotheses, open for discussion.

Under almost all debatable ideas lies a general aversion towards dike heightening – see figure 5.20. Throughout history, negative aspects of dike heightening have always been

Type of measures	*Narrative*		
	Friend	Spiral	Nature
Disaster management	not mentioned	generally favoured	generally favoured
Local measures and risk zoning	some measures favoured	generally favoured	some measures favoured
Upgrading dikes	generally disfavoured	generally disfavoured	generally disfavoured
River widening and deepening	generally favoured	generally favoured	generally favoured
Redirecting flows on a higher scale level	some measures favoured	generally disfavoured	some measures favoured

5.20 Favored and disfavored measure types in the contexts of the three debatable ideas (Water is your Friend, not your Enemy, the Spiral of Risk, Following Nature Along). It seems they all favor river widening and deepening, and disfavor dike upgrades.

pointed out (e.g. van der Ham 2004), and dike heightening has met fierce opposition by local habitants during and even before the River Delta Plan (1995-2000) (Van Heezik 2007). Perhaps avoiding dike heightening has become an objective in itself, and people are less critical towards the underpinning of alternatives to dikes.

Studying the narratives Water as a Friend and Following Nature Along created the impression that people, by merging ecosystem restoration and nature development with flood risk objectives, conceal how important nature really is to them. Perhaps

stakeholders are ready for 'natural flood defense', but do not dare to take a stand for nature development as an objective in itself, deserving a large national budget.

An explanation of the attraction to general narratives is that the water system is not easy to comprehend, especially the probabilistic part. Grasping risk and probability is notoriously difficult (Ropeik 2010; Taylor 2011) and the interplay between flood risk and flood risk-related objectives can be complicated. Nowadays more people are involved in the decision-making process than half a century ago, but many stakeholders have little time to learn about the system. It is fast and easy to hitch on to a simple grand idea which appears to have transcended the complexity of the system.

The topical concepts *storytelling* (Hajer et al. 2011) and *framing* (de Bruijn 2011; Vink et al. 2013) explain, and in part support, the power of general ideas. An effective story creates meaning and engages a community; an effective frame wins a political dispute. Narrative persuasion is important to get things done, but the flood risk system heavily relies on a complicated physical reality, well served by craftsmanship, hard science and custom-made solutions; general ideas soon distort a well-balanced overview. The problems and budgets at stake are large enough for a systematic unravelling of objectives and an overview of the spectrum of possible solutions, before any decisions are made.

Main trend 3: new narratives support measures which simultaneously address lower and higher-order objectives [subsection added in 2016]

A historical analysis of Dutch flood risk infrastructure development is not complete without investigating some of the new fundamental ideas or 'narratives' about flood risk which emerged in the 90s and 2000s. How can the investigation be condensed into a single trend, and how does this trend complement the previously identified historical trends?

It seems that in recent Dutch flood risk policymaking people hold a wider variety of fundamental ideas about what a flood risk system should look like, than at the times of the Delta Works. Arguments for measures are often phrased in terms which conflict with the principles and terms of the systems analysis in chapters 3 and 4 of this thesis. Man-made systems can by definition not be natural. Rivers cannot be released from being squeezed between ever higher dikes, because dikes do not squeeze, they do not grow ever higher and even if they would, this cannot be a bad thing in itself. How to interpret statements claiming the opposite?

Before investigating this question, is it here assumed this thesis's systems analysis is 'right' and statements which confront or conflict with it are 'wrong'? Of course, the systems analysis may also be wrong – an intellectual framework should always remain open to admit to flaws or to be incomplete. Conflicting statements might use different terminology (like a different definition of the word natural), and make sense when 'translated' into the language of the systems analysis. It is sometimes suggested that there is no truth but there are only social linguistic constructions in different paradigms each equally valid, but this would go too far in a policy domain which relies so much on physics (for which support is found in for example the famous Sokal (1996) hoax paper).

Still, to be safe, *from the perspective of this thesis's systems analysis*, someone who advocates an idea which conflicts with it may:

1. believe in the idea which makes no sense, wasting energy like Don Quichote was fighting windmills (wanting a natural man-made system is wanting the impossible);
2. not believe in the idea, but use it strategically to confuse and deceive for political purposes (the term 'natural flood defense' creates confusion, but it sounds good, so stakeholders with little time will vote for it and might shift budgets from safety to nature);
3. believe in the idea, but this still has value in itself, similar to how religious ideas seem untrue to some, but respectably valuable for others (the idea that natural flood defenses make the system more natural gives many a good feeling);
4. not believe in the idea, but simplify matters for communication purposes ('natural flood defenses' is more inspiring than 'flood defenses with a desired probability of failure for a small part thanks to the presence of planted and maintained vegetation');
5. believe in the idea but unknowingly pursue more concrete objectives; the idea is like a detour, a slight waste of energy but not too harmful (wanting a natural flood defense is a way to express the worthy desire for new nature).

Which interpretation holds for each illustrative quote in this chapter is left to the reader, but probably the last explanation predominates; as concluded in the previous subsection, the quotes illustrate a growing interest in higher-order objectives from 'Maslow's hierarchy for water infrastructure'. This was already generally concluded in chapter 4, but this chapter adds the tendency to favour particular measures which somehow *simultaneously* address flood risk objectives and higher-order objectives, in a somewhat convulsive way, as if the higher order objective is actually considered more important than the lower order one, but this is not dared to be admitted.

Chapter 6 in brief

The *historical systems analysis framework* of chapters 3 and 4 of this thesis put Dutch flood risk policy-making since the Delta Works in a fresh integrated perspective, to find a sound characterization of the development of the Dutch flood risk system since 1986. In chapters 3, 4 and 5, three trends were identified: 1) continuous investments in flood protection, strongly motivated by more refined risk analyses, 2) moving up in '*Maslow's hierarchy of water infrastructure development'*, 3) new narratives to support measures which simultaneously address lower and higher objectives in Maslow's hierarchy.

Before combining these three trends in a single conclusion, this chapter first takes a step back and places the main events, policy documents and projects treated in the historical systems analysis of the previous chapters into six policy frameworks: Delta Works, River Normalization, Flood Defenses Act, Space for Water, Dynamic Coastal Maintenance and Multi-Level Safety. Subsequently, characterizations of the studied period by other water experts are presented, which shows a discrepancy between *what was said* with *what has been done*. For example, frequently presumed is a shift "from prevention by high dikes and dams to better managing flood risk by a wider spectrum of measures", including "sustainable spatial planning [in the embanked areas] and disaster management". Yet, still 80 to 84% of the projects built and planned between 1986 and 2028 are flood prevention ("high dikes and dams"), 15 to 19% river widening and only 1 to 5% spatial planning and disaster management.

The presumed paradigm shifts are interpreted as a *longing* for the upper regions of a *Maslow's hierarchy for water infrastructure development*, somewhat indirectly stated, similar to how the new narratives of chapter 5 were interpreted. The three main trends of the previous chapters, with this chapter's additional observed discrepancies between what is said and done, lead to the final conclusion that flood risk policymaking since 1986 can best be characterized by a confused and convoluted *struggle to get to grips with higher-order water infrastructure objectives*.

The Flowz platform has been designed throughout this thesis according to the guidelines mentioned in chapter 1. It appears that representing the flood risk, freshwater, shipping, nature and landscape quality systems with a standardised *graphic language* is possible, but higher up in Maslow's hierarchy data are less readily available.

Chapter 6

Conclusions

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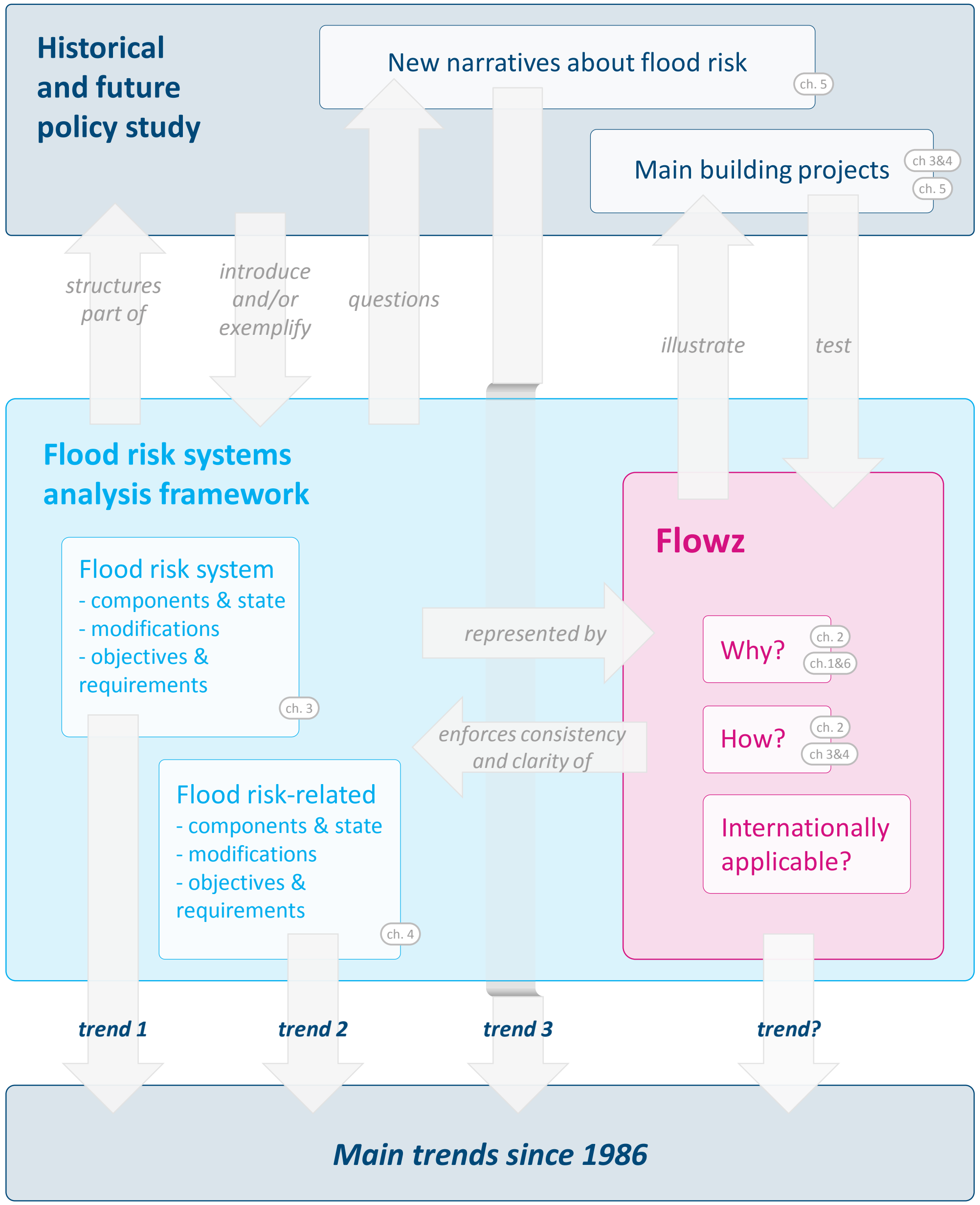


6.1 This chapter completes this part of the thesis as explained in chapter 1 (figure 1.15 on page 40).

What was *done* – thirty years of Dutch flood risk policy

When the Dutch queen closed the Oosterschelde storm surge barrier for the first time on October 4, 1986 (see page 21), she may have declared the province of Zeeland safe from flooding, but the rest of the country was not yet adequately protected.

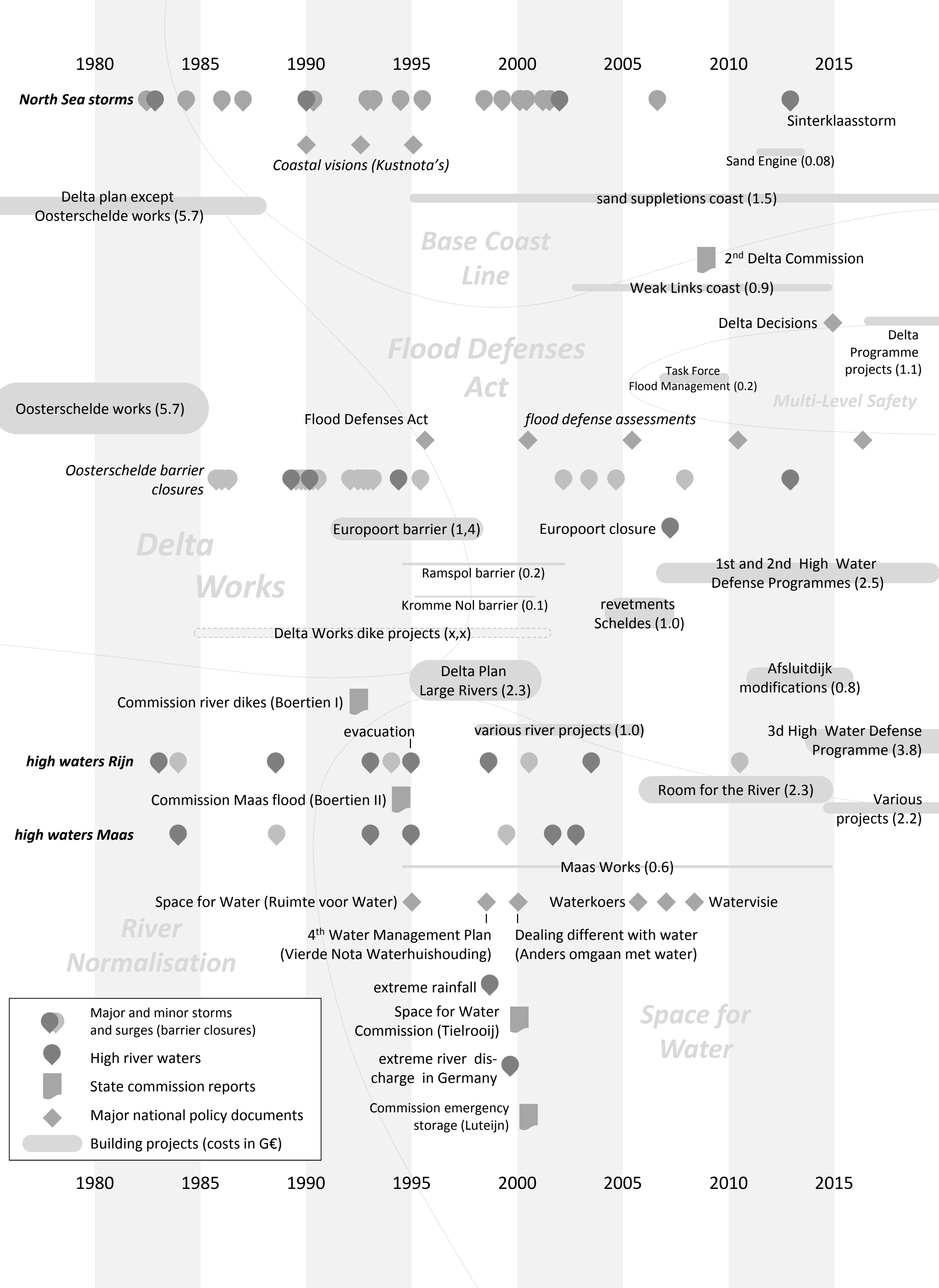
Figures 6.2 and 6.3 show the main flood risk reduction projects, weather events and policy documents of the last 30 years. They can be placed in six *policy frameworks*, ways of thinking which dominate policy-making and projects. *River Normalization* (see page 192) is the aspiration for a normalized and standardized river profile (summer and winter cross-sections). The *Delta Works* (page 129) framework aims at a shortened coast line and at bringing all flood defenses systematically to 'Delta Height'. The *Flood Defenses Act* is the legal manifestation of the idea to nationally coordinate all Dutch flood defense assessments, maintenance and upgrades. *Dynamic Coastal Maintenance* (page 144 and 318) aims to maintain a fixed coast line by sand nourishments. The main idea of the *Space for Water* framework (page 302) is to expand water conveyance systems in the horizontal direction. *Multi-Level Safety* (page 307) suggests to reduce risk not only by improving the national protection system, but also to include measures on regional and local levels.

The story of the last thirty years can be told using these six frameworks. They overlap each other but still help to understand the general ideas behind Dutch water and flood management policies and projects.

Along the main Dutch rivers, the objective of striving for normalised and standardised (engineered) summer and winter streambed cross-sectional profiles prevailed since the 19th century. Despite statements of the contrary (van Heezik 2007), it can be argued that River Normalisation is still influential and even still dominant: most efforts in the river area, including bypasses and floodplain excavations, create highly engineered winter beds, still revolving around standards to prevent flooding; also the summer beds remain highly monitored and maintained to facilitate shipping and high water discharges.

Yet, when in 1995 major projects started along the upper rivers, the spirit of River Normalization gradually merged with the Space for Water policy framework. The Delta Plan Large Rivers conducted landscape-sensitive dike upgrades between 1995 and 2003. River widening projects had already started before 2003 (DGR 1995; V&W 1998; PBR 2013), when the Room for the River projects officially started. Space for Water was the dominant framework in the professional discourse since 1998, but the Flood Defenses Act was the legislative foundation, and 9 out of the 34 Room for the River projects were dike reinforcements.

In the delta, at the end of the '80s the Oosterschelde works were completed but it took until 2005 to finally complete the Delta Works dike enforcements along the tidal rivers and finally abolish the Delta Act of 1958. In 1996, the Europoort barrier was erected, which includes the Maeslant barrier, a feat of engineering often seen as the Delta Works' masterpiece (next to the Oosterschelde barrier). The Maeslant barrier can however also



6.2 Timeline with the major weather events, national building projects and policy documents since the Delta Works. A rough pattern becomes clear, where extreme weather events are first followed by policy documents and then by building projects. Documents and projects are grouped in five conceptual frameworks: River Normalization, Delta Works, Dynamic Coastal Maintenance, Flood Defenses Act, Space for Water and Multi-Level Safety.
Weather events: the North sea storms shown are 10 or 11 Beaufort; the dark ones had an average wind speed of more than 100 km/h during one hour. Barrier closures represent high sea levels caused by storms and tidal surges. For the Oosterschelde barrier, the dark dots represent sea level heights of over 3.4 meter. River discharges for the Rijn in grey are higher than 8.000 m3/s, in dark grey over 9.000 m3/s, for the Maas grey is higher than 1.800 m3/s, dark grey over 2.000 m3/s (daily average, once or more in a year) (Wikipedia 2014; KNMI 2014; helpdesk water 2014).
Building projects: the selected ones are national and substantial. The surface area is proportionate to the total building sum, price levels 2014 (against 3%) (DGR 1995; V&W 1998; HWBP 2011; Deltaprogramma 2013; RWS 2014; MIRT 2014).
Policy documents: shown are: all national state commission reports related to flood risk and policy documents written by the ministry which were issued as important and/or had major policy implications.

be considered one of the first projects in the Flood Defenses Act policy framework, since the barrier was the result of a formal assessment of the completed Delta Works in the tidal rivers (see the Flowz images on pages 92-94).

Along the coast, according to the Dynamic Coastal Maintenance policy framework, effectuated in 1990, a Base Coast Line has been maintained by structural sand nourishments. In 2012 a landmark project was created: the Sand Engine. The nourishments will be continued in the decades to come, funded by the Delta Fund, and more sand engines can be expected.

Between 1986 and 1996, the Flood Defenses Act was written, providing the legislative backbone for the largest investments in the flood risk system since the Delta Works: the High Water Defense Programmes, reinforcing relatively weak dikes throughout the entire country after periodic systematic and nationally coordinated assessments based on convertible standards. The Flood Defenses Act became part of the Water Act and the Delta Act after 2011, and under the Delta Programme the improved probabilistic approach and the new standards presented in section 3.2 were adopted (on a scientific foundation established in two decades by Vrijling, Eijgenraam, Kok, Jonkman and others - see page 132-139). The conceptual policy framework however, the *way of thinking*, can be considered to have largely remained the same.

In 2008 the Second Deltacommittee was appointed, initially to advise on the coast only, but eventually on the entire Dutch water system. The commission produced the Delta Programme, which, as seen in figure 6.2, enabled existing programmes and projects to continue, mainly the High Water Defense Programmes, the sand nourishments and river widening. In the 2000s, enhanced by the Delta Programme, a new policy framework emerged: Multi-Level Safety, which advocates investments not only in the flood protection

Project	From	To	Size (G€)	Main drivi	ing forces	Synergy with flood risk-related objectives					Narratives		
									Landscape quality				
				Policy framework	*Additional force*	*Freshwater*	*Shipping*	*Nature*	*Lipstick*	*Strategic*	*Water is your Friend*	*Spiral of Risk*	*Move with Nature*
Closure dam	1927	1932			Floods 1916	5	5	Negative	1	Hard to say			
Delta Works North		1969		Delta Works	Floods 1953	5		Negative	1	Negative			
Delta Works South	1954	1986		Delta Works	Floods 1953	5	5	Negative	1	Hard to say			
Remaining dike upgrades Delta Works	1986	2005	0,4	Delta Works	Floods 1953				2	4			
Europoort barrier	1991	1997	1,4	Delta Works	Unembanked risk		5			5			
Delta Plan large rivers	1995	2000	2,3	River Normalization/ Flood Defenses Act	Near-floods 1993-'95			1	1				
Maas works	1995	2015	0,6	Flood Defenses Act/ Space for Water	Floods 1993-'95			2	3	5	3	2	5
Ramspol barrier	1995	2002	0,2	Flood Defenses Act	Near-floods 1993-'95		3?	3		5			
Sand nourishments sandy coast	1995	2015	0,8	Dynamic Coastal Maintenance	Available technology			1		5	2		3
River projects before Room for the River	1998	2006	1,0	Space for Water	Environmentalism			2	3		3	2	5
Kromme Nol barrier	1996	2001	0,1	Flood Defenses Act	Near-floods 1993-'95		1	3		5			
Weak Links coast	2003	2015	0,9	Flood Defenses Act	Sea storms 1998-2003			2	1				
Revetments Scheldts	2004	2007	1,1	Flood Defenses Act	Delta Works				1				
Room for the River – spatial projects	2007	2015	1,7	Flood Defenses Act/ Space for Water	Near-floods 1993-'95		Negative	2	3	5	4	2	5
Room for the River – dike enforcements	2007	2015	0,6	Flood Defenses Act	Near-floods 1993-'95				3		1		
Task Force Management Floodings	2007	2009	0,2	Multi-Level Safety	Hurricane Katrina							5	
1st & 2nd High Water Defense Programmes	2007	2020	2,6	Flood Defenses Act	Hurricane Katrina?			1	1				
Closure dam upgrades	2012	2016	0,8	Flood Defenses Act		1			2				
Sand engine	2012	2013	0,1	Dynamic Coastal Maintenance	Building with Nature			5	3	5	3		5
3d High Water Defense Programme	2014	2028	3,7	Flood Defenses Act					1, 2	5?			
Delta Programme – flood protection	2014	2028	2,4	Flood Defenses Act/ Dynamic Coastal Maint.	Climate change		1	2	Not clear yet		1	3	2
Delta Programme – not yet allocated	2014	2028	0,9	Multi-Level Safety?									
Total	*1986*	*2028*	*21,8*										

◀ 6.3 The main Dutch national flood risk system upgrades (excluding maintenance and other recurrent costs) with the main findings collected in the previous chapters. The numbers under the 'synergy' column illustrate the contribution by or to related water system objectives: a *blank* means that the objective played no part at all, 'negative' means that the flood risk reduction project had a negative impact on the objective, positive numbers (1 to 5) mean the impact was positive and/or that the objective played a major part in the design of the project.

system (first layer, in the Netherlands covered by the Flood Defenses Act framework), but also inside the embanked areas (second and third layer) – see pages 150 and 312. Multi-Level Safety however does not seem as influential a policy framework yet as Space for Water, Dynamic Coastal Maintenance and the Flood Defenses Act. So far, the Delta Programme investments planned (2016-2028) in the second and third layer are less than 1% relative to the investments planned in the first layer. When the 0,9 billion euro in the Delta Fund still to be allocated (according to the financial paragraph in Deltaprogramma (2014)) would be spent entirely (which seems unlikely) on the second and third layer, investments planned in the second and third layer relative to the investments planned in the first layer could still grow to not more than 17%.

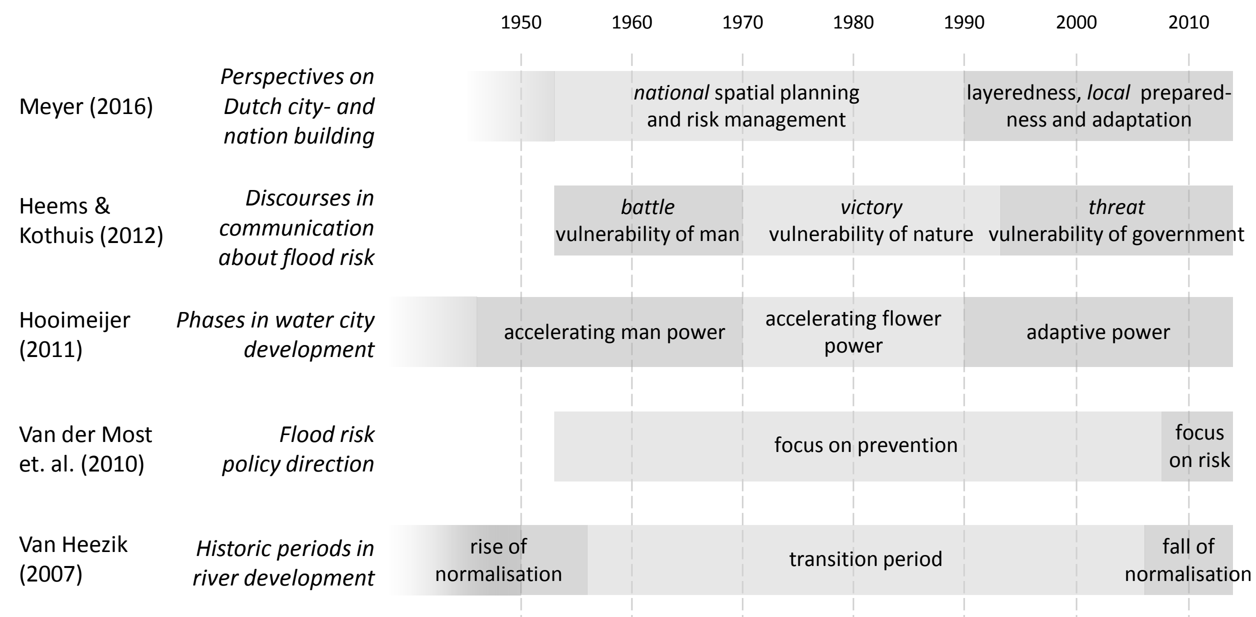
When all investments between 1986 and 2028 are placed under a single policy framework according to figure 6.3, Multi-Level Safety (the second and third layer) could grow to a maximum of 5%, compared to Delta Works 8%, River Normalisation 11%, Flood Defenses Act 57%, Space for Water 15%, and Dynamic Coastal Maintenance 4%.

Next to the projects conducted and planned, relevant for the period between 1986 and 2028 are the *Delta Decisions*, proposed by the Delta Programme to the Dutch Cabinet in 2015 and approved by Parliament in 2016. For flood risk, in essence, these consist of new required *safety levels* for the embanked areas and related new *safety standards* for the flood defenses, as described in chapter 3. The Dutch flood risk system should be upgraded to meet these levels and standards by the year 2050. Every twelve years there will be a national *assessment* as well as a *debate* about the height of the prevailing standards, which offers the possibility to lower the standards when the required safety level can also be reached by Multi-Level Safety measures ('smart combinations'). Furthermore, the Delta Decision for *Lake IJssel* is to add pumping stations to the Afsluitdijk, for the *tidal rivers* to *not* build new dams or barriers and along the *upper rivers* to *not* modify the discharge distribution and to (in addition to the High Water Defense dike projects) implement spatial measures here and there, but fewer than under Room for the River (Deltaprogramma 2014).

What was *said* – presumed paradigm shifts

Before making a general concluding statement on the three trends identified in this thesis and the projects and policy frameworks of figure 6.3, this subsection presents an overview of characterizations of the period since 1986 by a selection of other water professionals.

Figure 6.4 shows *phases* for Dutch water history identified by five Dutch water scientists.

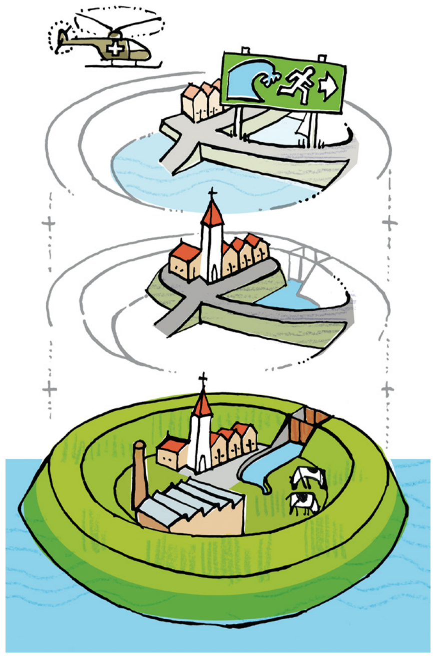


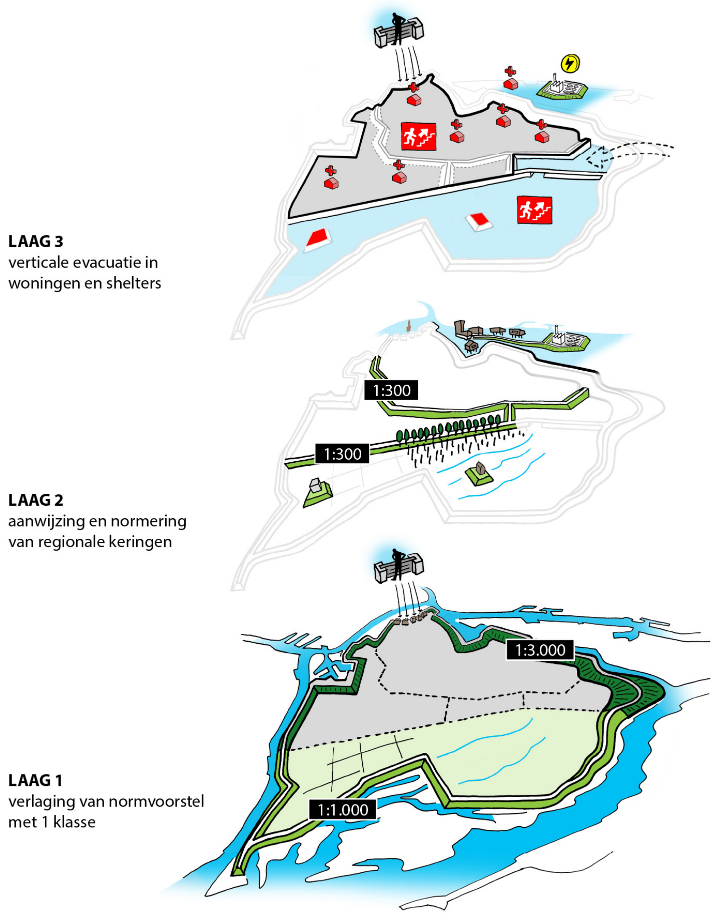
6.4 Phases in Dutch water history according to one book (Meyer 2016), three PhD theses (Heems & Kothuis (2012), Hooimeijer (2011), van Heezik (2007)) and one essay (Correljé et al. 2010).

None of these observe a transition between 1970 and 1990, which supports the introductory statement on page 21 that the era of the Delta Works has largely been a solid period with a clear focus. After 1990 things change – one common denominator from figure 6.4 is a shifting focus from the national system level to lower scale levels. According to van Rooy & Sterrenberg (2000), Metze (2010), Meyer (2012) and Correljé & Broekhans (2014), the 90s marked the *end of a technocratic mindset.* In 2006, the ministry of Public Works and Water Management found the water sector to be in the middle of a number of *paradigm shifts*, among which 'from space determines water, to water leads in spatial development', 'from government protects against floods, to clear choices about living with water risks', and the overall shift 'from protection and management, to anticipating and following along' (DG Water 2006).

The introductory essay in the book A Perspective on Water Safety (Kijk op Waterveiligheid - van der Most et al. 2010) paints a picture of the previous 50 years of Dutch

6.5 The legendary *Multi-Layered Safety* image (left) made by Christa Jesse in 2008: the image which has probably been used by today's Dutch water professionals the most, but has been effectuated the least. The drawing can be seen as a narrative which distorts reality: in the image the ratio between the horizontal surface area of the dikes versus the embanked area is about 3:1; in reality this ratio is 1:50 or smaller. In the image, one helicopter serves about ten people in three houses; in reality one helicopter will be available for more than a thousand inhabitants on average. In the drawing a reliable compartment dike seems an easy job, in reality it is a megaproject.



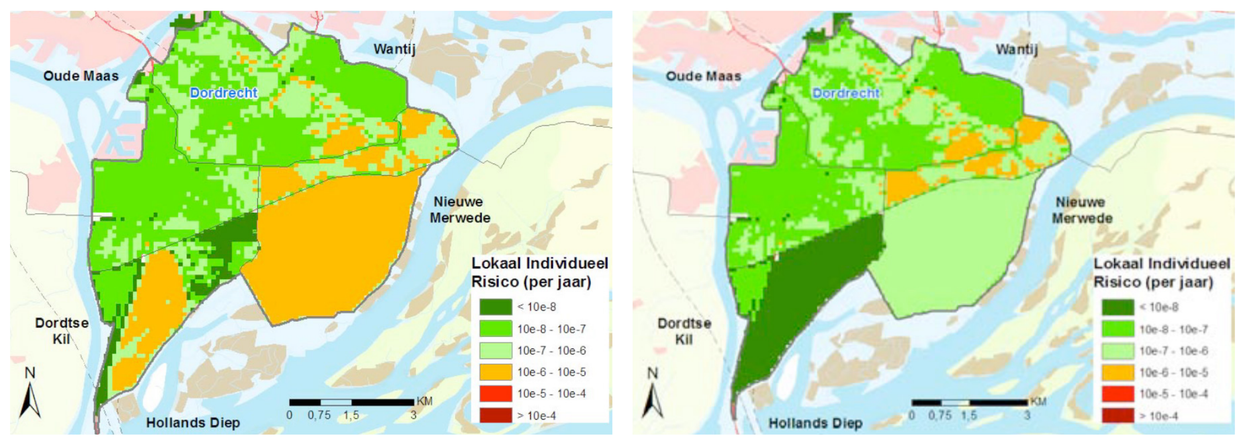


6.6 Possibly inspired by the image in figure 6.5 and despite the low current and future risk illustrated in figure 6.7, the city of Dordrecht considers measures in the Multi-Layered Safety's second and third layers. In this image (right, by the Urbanisten), the ratio between the horizontal surface area of the dikes versus the embanked area is about 1:2, which is 25 times larger than in reality.

flood risk policy-making. We have been shifting "from prevention by high dikes and dams to better managing flood risk by a wider spectrum of measures", including "sustainable spatial planning" and disaster management (Correljé et al. 2010). The authors also observe that nowadays the approach to water infrastructure is "less technical" and "more integrated" than before, a statement which has also been made by various high-level professionals interviewed for this thesis (e.g. Verwolf 2014; de Haan 2016). Recently, Rijkswaterstaat briefed that since the 2015 Delta Decisions we "no longer only look at the probability, but also at the consequences of flooding" (Helpdesk Water 2016)); this is sometimes described as *from a prevention- to a risk-centred approach*.

This overview is not complete and concentrates on professionals who claim major shifts. Yet, the mentioned characterizations will sound familiar to most water professionals today. According to the historical systems analysis of this thesis and the facts in table 6.3, can it be confirmed that the claimed shifts are indeed happening?

From the data under table 6.3 it appears that investments in "prevention by high dikes and dams" still constitute more than 80% of the total (counted between 1986 and 2028). Disaster management (third layer of Multi-Level Safety) is good for about 1% of spendings (The Task Force Flood Management of 2009). Investments in the second and third layer of Multi-Level Safety could potentially rise to a maximum of 5% in 2028, but probably will not: after a decade of talking about it (see page 308), flood proof buildings and zoning will now only be *tested* in three of the smallest dike rings (Deltaprogramma 2013a en 2013b) like Dordrecht, where the current risks are already extremely low and



6.7 Local Individual Risks for Dordrecht before and after three dike segment reinforcements suggested in the VNK project. Currently the total risks are € 120.000 and 0,02 casualties per year for an annual flood probability of 1:700. This probability can be reduced to less than 1:5.000 by the three measures and additional soil surveys (VNK2 & Veenstra-Huisman 2014).

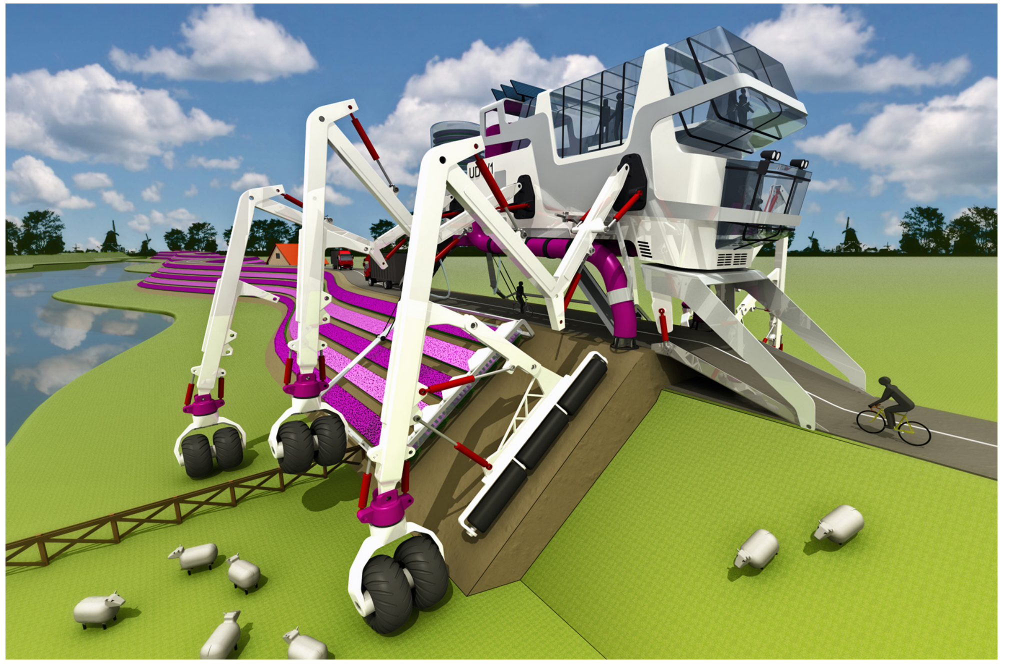
can easily be lowered more (see figure 6.7). The concept is far from actionable legislation; the *European Floods Directive* (2007) and the local *Water Assessment (Watertoets)* prescribe local flood consequence *analyses*, but no mandatory local *measures* (Jong & van den Brink 2013).

Furthermore, Dutch flood risk policy has been risk-centered since the work of Van Dantzig in the 60s (see section 3.2). Decisions to loosen flood defense standards in the 80s (upper rivers, by more than half, see page 94) and the 90s (eastern lower rivers, by exactly half, see page 131) were the result of a careful weighing of costs and benefits, and estimations of consequences were surely made. The 2017 modification of the Water/Delta (former Flood Defenses) Act, from exceedance frequency standards towards flood probability standards, is quite a task, but conceptually still rather a *refinement* of the existing risk approach than a fundamental broadening of the horizon.

Lastly, table 6.3 shows that all flood risk projects except the Task Force Management Floodings address multiple objectives. Since the 90s, in the context of water infrastructure, the word *integrated* usually means *also addressing nature and landscape quality*; the word *technical* means the opposite, (even though many contemporary nature projects are highly engineered).

Conclusion

The previous sections reveal a general discrepancy between what has been *done* since 1986 and what has been *said* about this period. The perspectives by the other water professionals show similarities to the quotes illustrating the narratives in chapter 5. Well formulated or not, particular *feelings* shine through: an almost *romantic* desire for individual responsibility, naturalness, progress, novelty – values higher up in a Maslow's hierarchy (see figure 6.8 for a caricature addressing the desire for novelty, omnipresent



6.8 The *Ultimate Dike Operator* was the result of a bet between this thesis's author and his promotor. The hypothesis was that a 'traditional' solution like raising dikes can still make headlines, when it would be dressed in an innovative jacket (the image and message indeed made it into a national renowned newspaper (Rijcken 2008)). Cruising 20 meters per hour the *UDO* raises the 3000 km of Dutch dikes in six rounds to keep up with a sea level rise of 1,20 meter per century. As a bonus, all dikes are covered in tulips after 17 years (design Rijcken and Sendra).

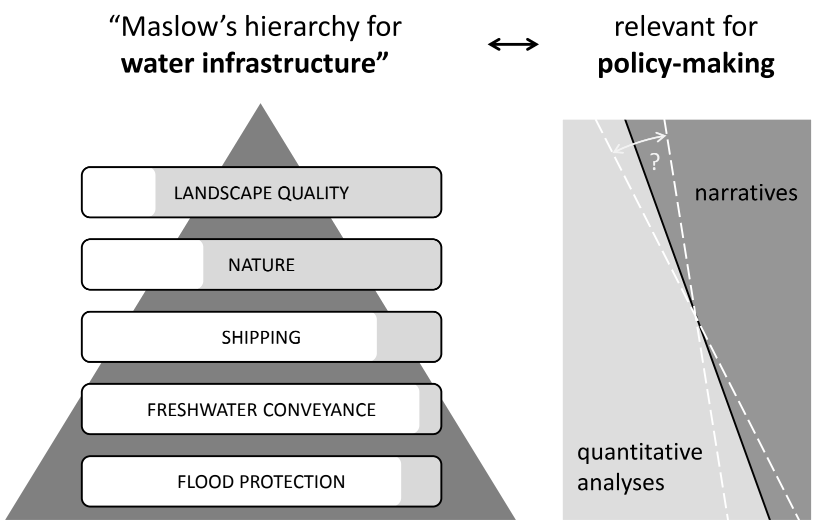
around the year 2007). The presumed changes are seen by many as radical *paradigm shifts*, but according to this thesis as modest *gradual developments:* diligently improving risk frameworks and slowly moving up in Maslow's hierarchy.

The fundamental characterization of flood risk policy-making since 1986 (the research question), obtained using the historical systems analysis framework as developed in this thesis (the research objective), is an addition to the conclusion of chapter 4, *climbing Maslow's hierarchy for water infrastructure development*.

Compared to the frameworks for flood risk (chapter 3), the quantitative frameworks to support objectives higher in the hierarchy are less far developed, coherent and influential in policy-making (chapter 4). New grand ideas about flood risk favor measures which indistinctly address the lower and higher parts of Maslow's hierarchy simultaneously (chapter 5). Acclaimed general paradigm shifts presume that we find ourselves higher up in the hierarchy than we actually are (this chapter). These observations make sense in a broader philosophical context of a shift from clear *modernism* to elusive *postmodernism* (Kamphuis 2006 and 2015).

We are not climbing Maslow's hierarchy in an organized, well-structured and fully conscious way, but rather in a *struggle*, muddling through, indistinctly – just like how human beings generally move about in politics, policy-making and in life.

A way to obtain a stronger foothold in the upper regions of *Maslow's hierarchy for water infrastructure development* would be to embrace the higher-order objectives concerning nature and landscape quality not only when combined with lower-order objectives but also *in themselves*, for example in the Dutch Delta Fund. A proper balance between lower and higher-order objectives is achieved by proper decision support. Figure 6.9



6.9 Roughly, objectives lower in *Maslow's hierarchy for water infrastructure development* are more often supported by quantitative models and objectives higher up with narratives. This scheme suggests that narrative decision support grows when a society climbs the hierarchy. In the future, the balance between narrative and quantitative decision support (the white dotted line) will change; in what direction remains to be seen.

illustrates the observation in this thesis that support to improve landscape quality and enrich nature is expressed more in stories and art than in hard numbers. But what makes a good story? This is a question for further professional endeavours, but a starting point would be to state that even though a good story addresses more values than the ones which can be quantified, the connection with quantifiable science has to be sound, to ensure some amount of coherence, assessability and economic effectiveness.

In figure 6.9, a possible shift from the black line to the white dotted one illustrates that in the future, on the one hand quantitative support for higher-order objectives may improve (as discussed in this thesis for example on page 279) and on the other hand, lower-order objectives also benefit from good narratives, for example to explain certain technical complexities to a broader audience. A fine balance and connection between narratives and quantitative support is aided by an integrated way to present both data and stories: in such a way that data analysts and storytellers understand the data and are moved by stories on the same 'wavelength'.

The Flowz platform as announced by the *design objective* in chapter 1 and initiated in chapter 2, aims to contribute to this balance. The platform has been designed largely according to the guidelines by the Royal Netherlands Academy of Arts and Sciences (2011 - see page 39): all relevant chapters have been reviewed by scientific peers; the platform discloses knowledge and generates new knowledge, for example by improving comparisons between historical assessments (pages 90-94 and 138-141); the predecessor of Flowz, the TU Delft WaterViewer, has been visited regularly by over 2000 loyal professionals since 2015.

The many maps presented throughout chapters 3 and 4 show how most data in the water sector are presented rather poorly and with no graphic coherence between the different studies. It has been shown on pages 90-94, 103, 138-141, 145, 180, 209, 246 and 283 that coherence is possible. The next step is to test whether graphic coherence enhances the understanding of integrated water system issues. Whether the platform will make its envisioned long term contribution, only time will tell.

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About the author - a Curriculum Vitae in words and numbers

At Delft University of Technology, the *T-shaped engineer* is a popular profile to represent an ideal combination of depth and breadth. I like this image. My main expertise is the Dutch flood risk water system; my breadth lies in other water systems (since 2008), in floating neighbourhoods (until 2008), in design and entrepreneurship, landscape photography and contemporary history. I like to hike, bike and dance, I believe in active personal development, I build Lego outer space constructions for my nephew and as a member of our local council I am conducting a participatory redesign for my neighbourhood. With *Flowz* (see pages 72-75) I want to contribute to the work and lives of aquatically engaged professionals and citizens around the world. A newspaper article once described me as a "21st century renaissance man", but I think I can best be called a *Ties-shaped engineer*.

Ties-shape index

Faculties studied at: ***7*** (Geosciences, Physics and Humanities at Utrecht University; Industrial Design Engineering, Policy&Management and Civil Engineering at Delft University of Technology, Joint Program in Design at Stanford University).

Average grade (on a scale of 1 to 10): ***7,8***.

Graduation (in 2003) grade at Industrial Design Engineering: ***10***.

Jobs as a designer, teacher and researcher: ***5*** (at ABC Arkenbouw floating home manufacturing, the Steering Committee for Experimental Housing and the faculties of Industrial Design Engineering, Architecture and Civil Engineering).

Publications - book: ***1***; book part: ***1***; scientific publications: ***10***; professional publications: ***16***; essays: ***13***; columns/blogs: ***24***.

Talks given in the Netherlands: ***102***; abroad: ***15***.

Awards - local Lego award: ***1***; national travel bourse: ***1***; national awards on landscape and infrastructure: ***4***; local entrepreneurship award: ***1***; national photography award: ***1***; local photography awards: ***2***.

Students mentored individually or in small groups: ***63***.
Of whom won an award: ***13*** (***12*** of these in the DeltaSync project).

Research spin-off companies: ***2*** (DeltaSync and Flowz).

Product brought to market: ***1*** (a balancing system for floating homes).

Patent: ***1*** (a floating foundation system - patent number 1025707).

Concept adopted by the 2008 Dutch Deltacommittee: ***1***
(Rhine Estuary Closeable but Open)

Board game invented: ***1*** (Settlers of Catan Delta Dwellers).

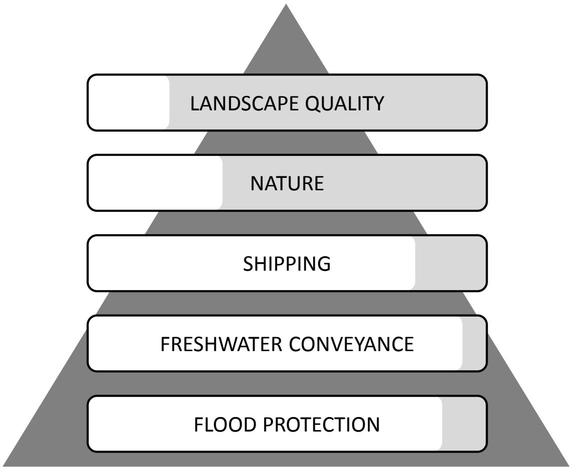
Languages - rather well: ***2*** (Dutch and English);
pretty good: ***2*** (German and French),
a little bit: ***2*** (Spanish and Italian).

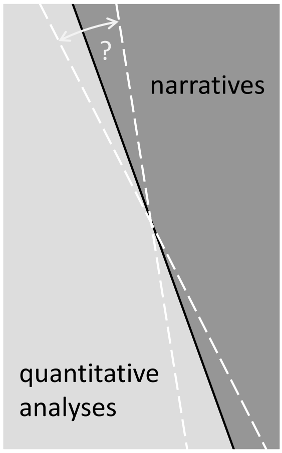
Good friends - in the Netherlands: ***18***; in California: ***6***; in Senegal: ***1***; in Israel: ***1***.

Total amount donated to human rights, refugees, orphans, poverty and wildlife: ***12.523*** euro; to street musicians: ***318*** euro and ***10*** cents.

EMERGO: the Dutch *flood risk system* since 1986

In 1986, the completion of the Eastern Scheldt barrier made Dutch flood risk policymaking world famous. What has happened since then? The comprehensive **historical policy analysis** in this thesis identifies three trends. National investments in flood protection have continued and were strongly supported by refined risk and acceptable risk analyses. The interplay between flood risk reduction and other water system objectives played a major strategic role and can be described by an upward movement in **'Maslow's hierarchy for water infrastructure development'**, a concept introduced in this thesis. Nature development and landscape quality have become increasingly important, but a policy discourse analysis reveals a struggle to get to grips with these objectives and to find a balance between quantitative and narrative decision support.





Ties Rijcken studied Geophysics and Industrial Design Engineering. He is currently editor-in-chief of TU Delft DeltaLinks and founder of **Flowz**, an internet platform to support water infrastructure development, for which he designed the foundations in this thesis.