

INTEGRATIVE FRAMEWORK FOR LONG TERM REINVESTMENT PLANNING FOR THE REPLACEMENT OF HYDRAULIC STRUCTURES

by

Patrizia Bernardini¹, Saskia van Vuren², Wouter van der Wiel³, Milou Wolters⁴, Geert Roovers⁵, Marcel Tosserams⁶

ABSTRACT

During the last century many structures were built within the main water systems of the Netherlands to facilitate a number of important societal functions. As a result the main water system nowadays provides safety against flooding, sufficient and clean water and a thriving navigational network. The main water system consists of a complex network of waterways with approximately 650 major hydraulic structures, varying from the well-known Delta works in Zeeland to small pumping stations and sluices in navigational channels. These structures were designed to last for 80 or 100 years. In the decades to come, due to ageing, an increasing amount of structures need to be replaced or renovated to meet new and future societal requirements. Rijkswaterstaat is responsible for the management of the main water systems and needs to prepare itself to deal with this major challenge.

Changes in the physical and social environment influence the need and the timing of replacement and the desired functional and performance requirements for the redesign of a structure. The question is how to incorporate sufficient flexibility in time, space and technical design, in order to take the right measures at the right time? This article describes the outline of a framework to support decision-making by the Ministry of Infrastructure and Environment on the replacement and renovation of hydraulic structures in the complex water system of the Netherlands for the long-term. The underlying theory and principles that support the framework will be discussed.

The development of this framework is still in progress and no final version is available yet. However the methods and tools that are being developed as well as the problems that have to be addressed are relevant for a broader audience as ageing of infrastructure becomes an increasingly important issue on a global scale.

Keywords: hydraulic structures, replacement, flexibility, climate change, adaptation.

1. INTRODUCTION

The Netherlands is situated in the delta of the river Rhine and river Meuse. About 60% of the inhabitants live below sea level, 70% of the gross national product is earned in this man-made part of the country and 45% of the transport is waterborne. This is made possible by an elaborate network of waterways equipped with hydraulic structures, such as pumping stations, sluices, weirs, barriers, storm surge barriers, locks and bridges. These networks provide the inhabitants with safety against flooding, clean and sufficient fresh water and a thriving navigational network. Rijkswaterstaat, as part of the Dutch Ministry of Infrastructure and Environment, is responsible for the management of the national highway network, the main waterways network and the main water systems, including canals, rivers and open water. The latter two networks include about 650 large hydraulic structures. Many of

¹ Senior advisor Hydraulic Engineering, Ministry of Infrastructure and Environment, Rijkswaterstaat, The Netherlands, patrizia.bernardini@rws.nl

² Senior advisor Flood risk management, HKV Lijn in Water and researcher at TUDelft, The Netherlands, s.vanvuren@hkv.nl

³ Senior project manager Hydraulic Structures, Iv-Infra, The Netherlands, w.d.vanderwiel@iv-infra.nl

⁴ Senior advisor strategic network development, Ministry of Infrastructure and Environment, Rijkswaterstaat, The Netherlands, milou.wolters@rws.nl

⁵ Senior Consultant, Antea Group, The Netherlands, geert.roovers@anteagroup.com

⁶ Projectmanager, Ministry of Infrastructure and Environment, Rijkswaterstaat, The Netherlands, marcel.tosserams@rws.nl

these structures have been built in the last century and designed to last for a long time, 80 or 100 years depending on the type of structure. Due to aging and increased use, a lot of these structures are nearing the end of their lifetime, making replacement or renovation necessary.

1.1 Multifunctional structures in the waterways networks

Hydraulic structures are of different types, may serve various functions and are designed to meet specific functional and performance requirements, both at network and object level. Besides that they comprehend also different structural components, i.e. the civil structure, steel components (such as lock gates), the operating and control system, electromechanical and electrohydraulic components.

Hydraulic structures may reach their end of lifetime if they are no longer economically maintainable or if they can no longer fulfil their functional requirements. The functions and services delivered by the hydraulic structures must be ensured both for the present situation as well as for the future. The end of lifetime of these structures, often leading to the need for replacement, can be caused by either technical wear and/or malfunctioning or by changing demands, both as resulting from climate change or societal developments.

Rising of sea level, subsiding surface, changes in river discharges, increasing size of ship, changes in laws and regulations but also changes in demand by the different stakeholders are example of these changes. And all these changes have a level of uncertainty. Furthermore, politicians and civilians are less and less willing to accept risks caused by malfunctioning of infrastructure, and economic developments put a stress on the available budgets. As a result efficiency and control are dominant terms in the management of infrastructure.

Changes in the physical and socio-economical environment influence the need and the timing of replacement. At the same time the required functional and performance demands for the new structure may be different from the original one. This insight has important implications for the redesign of existing infrastructure as "one on one" replacement of existing infrastructure may not be the most logical choice.

1.2 The Dutch national Delta programme

The Netherlands are working on the Delta programme. The Delta programme addresses challenges resulting from climate change and socio-economic developments. The aim of the Delta program is to protect the country against flooding and to ensure an adequate freshwater supply, today and in the future. Within the Delta programme so-called Delta strategies are developed. Short and long term (up to the year 2050, 2100) strategies for flood risk management and fresh water supply in the Netherlands are developed based on a scenario approach. A number of hydraulic structures play an important role in these strategies. This leads to a strong connection between the Delta programme and the replacement strategy of the infrastructure:

- a. Insight in the expected life span and replacement of these hydraulic structures forms important information for the development of the Delta strategies.
- b. The Delta strategies can influence both the functional demands for existing infrastructure (e.g. required level of flood protection) and the physical circumstances (e.g. water levels). This can lead to different end of life time, both technical and functional.

The combination of the replacement task of hydraulic structures with the strategy development within the Delta programme is necessary and can support optimal investment strategies.

1.3 Challenges

In the decades to come the Dutch government is faced with a huge challenge. As a large part of the hydraulic structures were built in the period between 1920 and 1960 all of the existing structures reach the end of their life time in the coming decades and have to be replaced or renewed. Taking into account the substantial replacement value of most of these structures, the replacement of these structures will constitute a substantial part of the available budgets for water management.

Replacement of hydraulic structures has a big societal impact, in terms of functionality and costs. They are measures with a long term effect (a design periode of 80-100 jaar) while policy and society changes at a faster tempo. Therefore, the moment of replacement of these structures is a suitable time to re-evaluate the layout and desired functionality of the networks.

At the same time Rijkswaterstaat developed a professional asset management strategy for the three infrastructural networks, including an altered procurement strategy. Besides that Rijkswaterstaat further increased the focus on public demands and external orientation of the organisation. The above

mentioned changes, including the need for a redesign of the network, stress the absolute importance of an integral maintenance and development strategy at network level.

The described developments pose the following challenges to Rijkswaterstaat:

- the already existing infrastructural network has to be redesigned to meet the challenges of future developments and service demands of future generations.
- Rijkswaterstaat works on an integral maintenance and development strategy at network level.
- The redesign poses new challenges for spatial and financial planning.
- The replacement and redesign lead to a shift in resources from construction of new infrastructure to maintenance and replacement of existing infrastructure for the coming decades.
- The redesign has to be done from the perspective of the integral functions of the waterways network.

1.4 Project “VONK”

To cope with these challenges Rijkswaterstaat is working on a methodology for the long term planning of the replacement and renovation of the major hydraulic structures within a project named “VONK”. The main purpose of this project is to design an integrative framework to support policy makers and politicians with the necessary information for their decision-making process on the long term replacement and renovation of hydraulic structures. At the same time the framework should provide insight in the magnitude of the replacement task to substantiate the necessity for the financial reservations that have been made for the medium term.

The project “VONK” started in 2012 and is still in progress. In this article we describe the outline of this framework.

2. INTEGRATIVE FRAMEWORK: SET OF METHODS AND TOOLS

The replacement of hydraulic structures is a complex and strategic task. To improve the present management of this replacement, Rijkswaterstaat is working on an integrative framework which forms the basis for the forecast of replacements and renovation of hydraulic structures on the long term (strategic, 100 years ahead) and contributes to the decision-making and programming of replacements and renovations of hydraulic structures on the short term (operational).

This framework comprises a new set of methods, tools and agreements:

- a. Technical tools and methods such as an innovative method to estimate the end of the technical and functional lifetime of hydraulic structures, a new approach for stakeholder participation and the application of adaptive pathways.
- b. Agreements with regard to the current workflow within Rijkswaterstaat, decision-making between the involved organisations within the Ministry on replacement and renovation of hydraulic structures.
- c. A presentation tool in order to present the results of the framework to the different stakeholders, interested parties and users.

The use of this toolbox provides insight in the replacement task by:

- assessment of technical and functional end of lifetime of structures, taking into account uncertain developments in future use;
- developing the planning alternatives of the reinvestment activities. This planning takes into account e.g. the function of the structure within the network, regional developments, functionally coherent infrastructure, combination of the replacement of similar constructions, combination of similar solutions for replacement and renovation;
- analysing these planning alternatives from different point of views, i.c. consistency, costs, feasibility;
- designing called adaptive pathways instead of a fixed horizon. Investigate the available policies or planning alternatives, check for moments when you have to and when you have the opportunity to switch to another policy. In this way you can keep options open, with high flexibility to react to uncertain futures.

- assessment of planning alternatives of the (adaptive) re-investment activities based on an assessment framework;
- development of a stakeholder participation strategy..

The toolbox also provides improvements in the decision-making process and the structuring of the activities within Rijkswaterstaat.

In section 3 the method to estimate the end of the technical and functional life service of hydraulic structures is elaborated. Section 4 addresses the stakeholder participation and the adaptive pathways.

3. ASSESSMENT OF FUNCTIONAL AND TECHNICAL END OF LIFETIME FOR HYDRAULIC STRUCTURES

3.1 Hydraulic structures in the Netherlands

An overview of the major hydraulic structures managed by Rijkswaterstaat is presented in Figure 1.

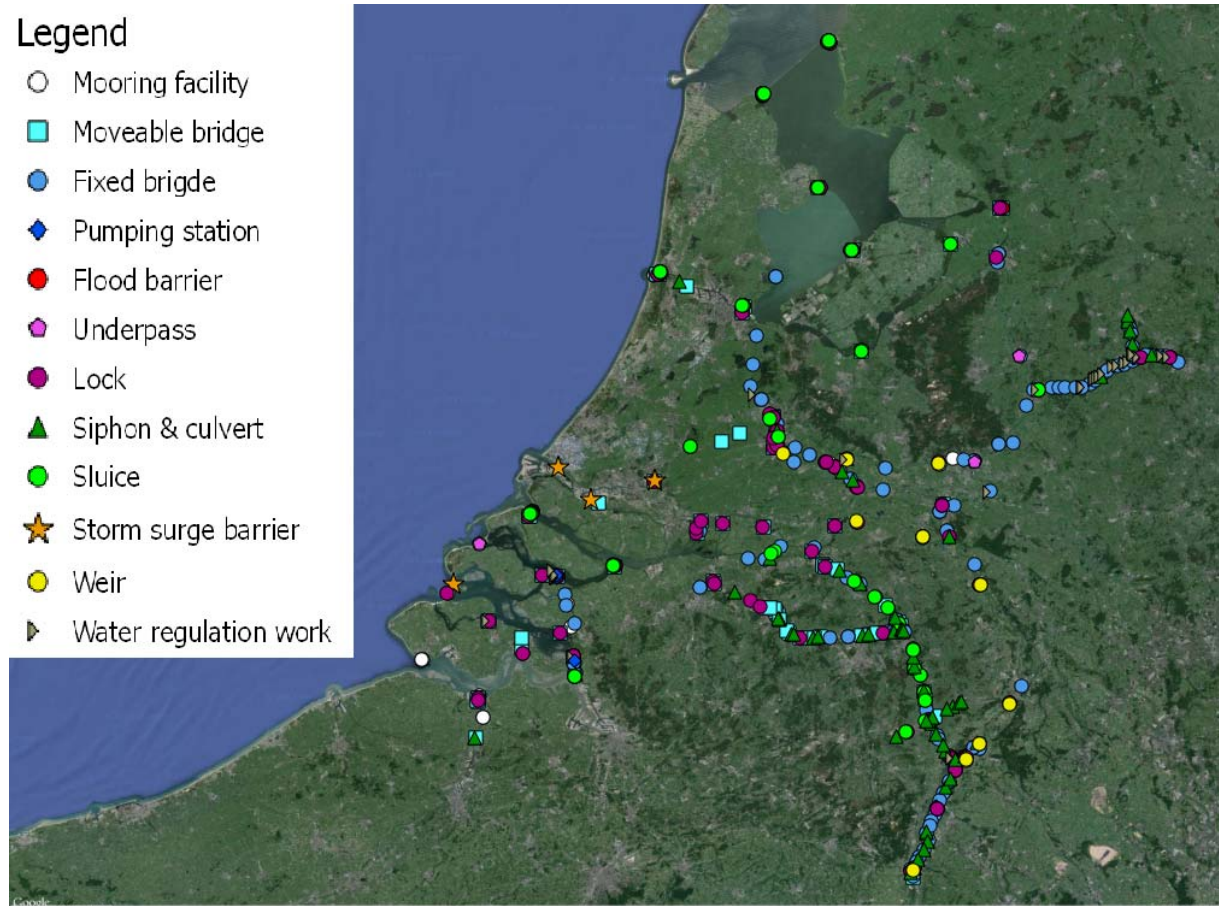


Figure 1: An overview of hydraulic structures in the Netherlands

Figure 2 shows the distribution of the year of construction for these structures in the Netherlands. The oldest hydraulic structure dates from 1853 and many were built in the period 1920-1960. This means that a large number of hydraulic structures may soon be expected to approach their end of lifetime. This will require comprehensive investments for the replacements or lifetime extensions.

Given the relatively old age of the current stock of hydraulic structures in the Netherlands and the high cost of replacing each structure, there is a need for forecasts of remaining service life of the hydraulic structures. These forecasts help the Dutch government to prepare for large investments in the future and to allocate sufficient funds to finance the replacement of infrastructure.

The simplest way to forecast the remaining service life of the hydraulic structures is by simply taking the design lifetime of each structure as the replacement age. Using generic information such as the year of construction and the design lifetime (80 or 100 years) an estimation of the end of lifetime can be given (by adding the design life to the year of construction).

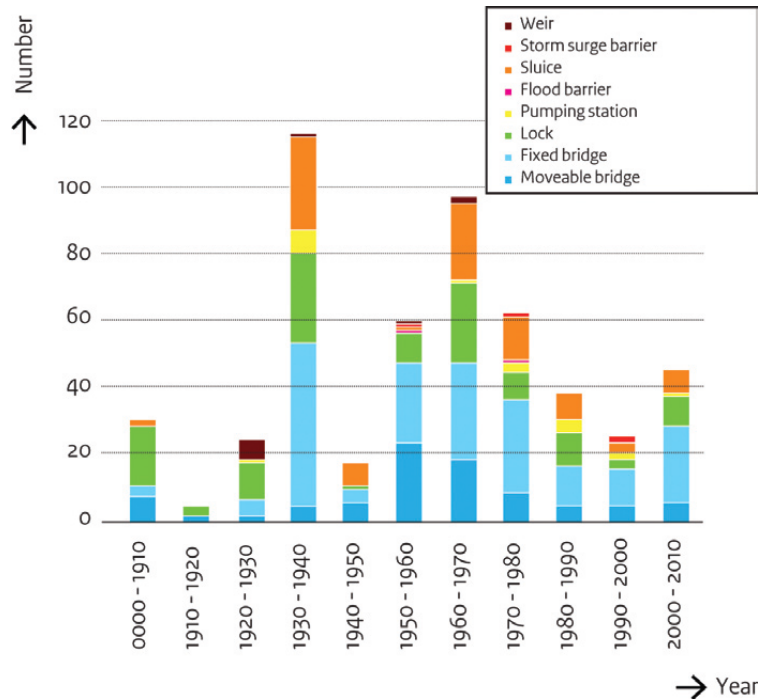


Figure 2. Distribution of the year of construction of hydraulic structures in the Netherlands. (Source: appendix H, Delta Program 2013).

This ‘basic’ approach enables to make a rapid assessment of the end of lifetime of all hydraulic structures. However this approach inevitably brings along a number of simplifications. It does for instance not account for:

- Changing circumstances in operation stage. One of the primary concerns involved is the deterioration of the hydraulic structure, and moreover the uncertainty about this deterioration over time and the remaining lifetime of the structure. Through more (or less) intensive use than was taken into account in the design stage, deterioration can occur faster (or slower) than expected and affects the remaining service life of the hydraulic structure.
- Climate change and social development. This puts new challenges on the water system and its hydraulic structures. Climate change and social development could affect the functional requirements of a hydraulic structure, making the structure no longer meets its requirements.
- Multiple functions. Hydraulic structures may serve various functions. For instance a sea lock usually has not only a shipping function, but also serves as a primary flood defence structure. For one or another function a hydraulic structure could reach their end-of-service sooner or later.
- Uncertainty. Uncertainties inevitably affect the forecast of the remaining service life of hydraulic structures. The age at which a structure needs to be replaced is uncertain. By presenting the end of life time of hydraulic structures as one particular moment in time, an unrealistic picture of certainty is presumed.

This emphasises the importance of getting a more precise indication of when a hydraulic structure will need to be replaced. A unified approach has therefore been developed to determine the remaining lifetime of each structure, acknowledging the fact that this lifetime is uncertain.

3.2 Outline of the unified approach

Estimations of the remaining service life of hydraulic structures are uncertain, as we do not know what future will look like. The age at which a structure needs to be replaced is therefore also uncertain. The objective of the approach is making uncertainty explicit. Estimates will be given in the form of a lower and an upper bound of the replacement age, hereafter referred to as the timeframe for replacement. The goal is to give bounds which correctly represent our uncertain knowledge about the replacement age of each structure. The results attempt to strike a balance between being well calibrated (i.e. the bounds contain the actual replacement age) and informative (i.e. the bounds are as narrow as possible).

The approach is aimed at estimating timeframes for all 650 structures using as much of the generic data as possible. As mentioned, timeframes will be determined for the functional and technical end of lifetime.

For estimating the technical end of lifetime several types of data can be used. First, there is generic information such as the type of construction, the year of construction, the design lifetime (80 or 100 years), the geographical location, etc. Second, each structure is periodically given a quality score based on a visual inspection. Third, some structures have been studied using a fault-tree analysis which gives detailed information on failure modes. Finally, experts may give estimates of the remaining life of individual structures. The several types of data and information will be combined using a probabilistic approach. It results in a probabilistic distribution function of the technical end of lifetime for each of the 650 hydraulic structures.

The functional lifetime of a hydraulic structure will be estimated using a scenario analysis and results in a timeframe with a lower and an upper bound of the replacement age. Several scenarios for climate change and economic development are available for this purpose. The primary source for these scenarios is the Delta program, which is a national research program to safeguard the Netherlands against flooding in the long-term, and its modelling infrastructure.

The estimation of timeframes for replacement due to functional deficiencies is discussed in Section 3.3 and for replacement due to technical deficiencies in Section 3.4.

3.3 Functional lifetime

The 650 hydraulic structures in the country’s primary waterway network could be distinguished in 13 different types of hydraulic structures, such as such as sluices, locks, pumping stations, bridges over waterways and storm-surge barriers. Each hydraulic structure has its function in the Dutch water system and contributes to the well-functioning of society, providing safety against flooding, providing enough and clean water (fresh water management) and enabling safe and efficient navigation.

| Functions network level: societal | Type hydraulic structure | Functions object level: technical | | | | | | | | | | | | |
|--------------------------------------|-------------------------------|-----------------------------------|----------------------|-----------|----------------------|-------------|---------------------------|---------------------|-------------------|-------------------------|-----------------------|---------------|-----------------------|--|
| | | Fixed bridge (188) | Moveable bridge (91) | Weir (10) | Lock (chamber) (123) | Sluice (94) | Waterregulation work (32) | Pumpin station (19) | Flood barrier (2) | Stome surge barrier (4) | Siphon & culvert (63) | Underpass (5) | Mooring facility (15) | |
| Flood protection | high water protection | - | - | - | (x) | (x) | (x) | (x) | x | x | - | - | - | |
| | water discharge | - | - | x | (x) | x | - | - | - | - | x | - | - | |
| Sufficient fresh water supply | water inlet | - | - | - | (x) | - | x | - | - | - | x | - | - | |
| | pumping water | - | - | - | - | - | - | x | - | - | - | - | - | |
| | regulate water level | - | - | x | x | x | x | x | - | - | x | x | - | |
| | separate fresh and salt water | - | - | - | (x) | (x) | - | - | - | - | - | - | - | |
| Enable Safe and efficient navigation | passage navigation | x | x | (x) | x | - | - | - | x | x | - | x | - | |
| | support navigation | - | - | - | - | - | - | - | - | - | - | - | x | |
| Water quality | fish migration | - | - | - | - | (x) | - | - | - | - | - | - | - | |
| | passage road traffic | x | x | - | (x) | - | - | - | - | - | - | - | - | |

x : the function is fulfilled by all objects within the object type; (x): the function is not necessarily fulfilled by all objects within the object type;

Figure 3: Functions hydraulic structures

A hydraulic structure has one or more functions within the network that it’s part of (see figure 3). RWS has functional performance requirements which are used to determine if a structure is capable of performing its function sufficiently well. For example, a ship lock must be able to raise and lower ships between sections of a river or canal with different water levels. Increasing ship sizes or traffic numbers due to economic growth may result in a performance reduction. The lock becomes too small or ships have to wait too long before they can enter the lock. Some structures also have a function to protect against flooding. Rising sea levels due to climate change may result in structures being of insufficient height.

The timeframes for ‘functional replacements’ are determined for one, maximum two functions, viz. (1) the primary function of the hydraulic structure and (2) additionally the flood protection function in case the hydraulic structure is part of the primary flood defence system. The timeframes for ‘functional replacements’ are estimated using a scenario analysis. The primary source for this scenario analysis emanates from a national research programme in the Netherlands, the so-called Delta program.

The Delta programme addresses challenges resulting from climate change and socio-economic developments. The aim of the Delta program is to protect the country against flooding and to ensure an adequate freshwater supply, today and in the future. A set of tools and instruments has been developed to support the Delta program. The Delta model is available to analyse the impact of climate change and socio-economic developments on the functioning of the main water systems, regional water systems and the navigation network. The impact on flood protection, fresh water supply and navigability could be assessed using the Delta model. The Delta model makes use of four different Delta scenarios (see Figure 4) resembling possible future scenarios for climate change and social development, focussing on the years 2050 and 2100.

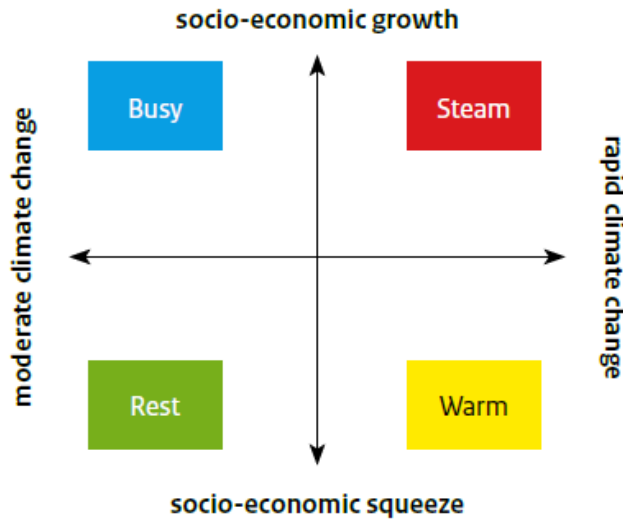


Figure 4: Four Delta scenarios for climate change and socio-economic developments (source: Delta Programme 2012)

The timeframes for 'functional replacements' are estimated using Delta model computations driven by the four Delta scenarios for the reference year (2015) and two years in the future (2050 and 2100). The model results concern for instance water levels and water discharges that can be used to determine the required levels of protection against flooding, the possible shortage of water during summer or the excess infiltration of saline water.

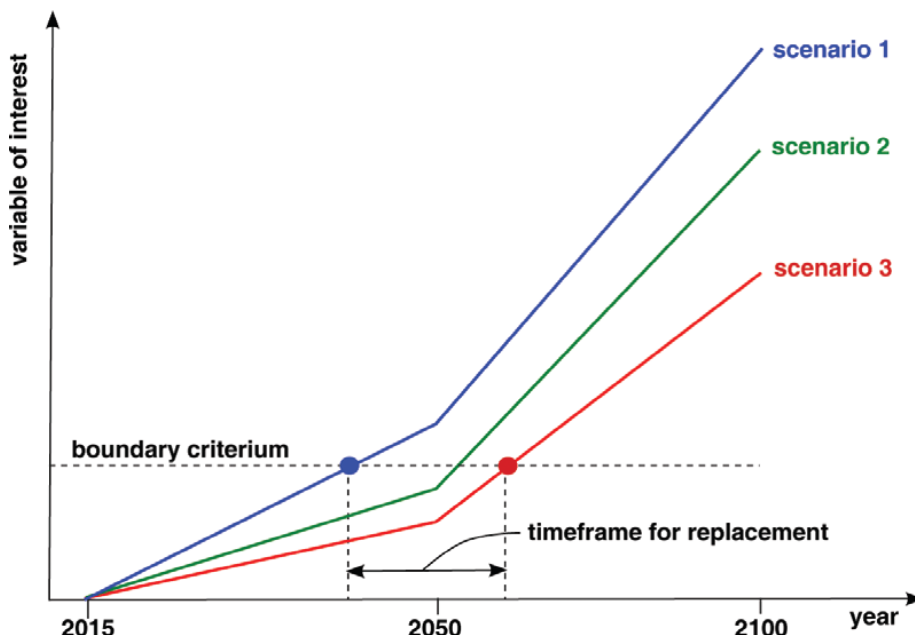


Figure 5: Schematic example of a replacement time frame based on analysis with three scenarios.

Figure 5 shows a schematic example of how a timeframe is obtained from the scenario analysis. The Delta model is used to a prediction of the functioning of the main water system of the navigation network. This provides for example insight in whether normative design flood stages for flood defences are rising, whether a sluice and pumping station should pump more frequent and more water away to maintain water levels, or whether the ship size and the amount of ships that should use a certain a ship lock will increase. For each of the four Delta scenarios these results can be used to determine whether and when a structure functionally deficient (i.e. moment at which a flood defence structure becomes too low, a sluice or pumping station has too less capacity to pump water away or the capacity of ship lock is not sufficient anymore to avoid too large waiting times). Its lower and upper bound are given by the earliest and latest crossing of a boundary condition by the four scenarios.

In general the method to determine the timeframes for 'functional replacements' boils down in four steps:

- Describing the functional requirements of a hydraulic structure. For each hydraulic structure we make an overview of functional requirements. The timeframes will be estimated for one maximum two functions. The criteria for functional end of life time are described by the functional requirements. For instance the design water levels (i.e. the water level with a probability of exceedance of N times per year) for hydraulic structures that have a flood protection function.
- Determining the required data and information per hydraulic structure. After choosing appropriate functional requirements, data and information should be gathered to assess whether the hydraulic structure full fills the requirements. This means for instance (1) characteristics and information of the hydraulic structures itself, (2) information about the future climate changes and socio-economic developments, and (3) information about how the latter changes and developments affect the water system and the navigation network. With respect to information of the hydraulic structures itself information is for instance required about the flood defence height of hydraulic structure in closed position. The Delta scenarios give possible future scenarios for climate change and social development, focussing on the years 2050 and 2100. The impact of these scenarios on the functioning of the main water systems, regional water systems and the navigation network could be assessed using the Delta model.
- Determining the required data and information per hydraulic structure. After choosing appropriate functional requirements, data and information should be gathered to assess whether the hydraulic structure full fills the requirements. This means for instance (1) characteristics and information of the hydraulic structures itself, (2) information about the future climate changes and socio-economic developments, and (3) information about how the latter changes and developments affect the water system and the navigation network. With respect to information of the hydraulic structures itself information is for instance required about the flood defence height of hydraulic structure in closed position. The Delta scenarios give possible future scenarios for climate change and social development, focussing on the years 2050 and 2100. The impact of these scenarios on the functioning of the main water systems, regional water systems and the navigation network could be assessed using the Delta model.
- Determining the moment when a structure is functionally deficient. For each of the four Delta scenarios the Delta model results can be used to determine whether and when a structure becomes functionally deficient. For instance the moment at which a flood defence structure becomes too low.
- Determining the timeframes for 'functional replacements'. Each of the four Delta scenarios results in a point in time when the hydraulic structure reaches its end of lifetime. The lower and upper bound are given by the earliest and latest crossing of a boundary condition by the four scenarios. The lower and upper bounds give the timeframe for 'functional replacements' of the hydraulic structure.

Figure 6 gives an example of the functional end of lifetime analysis for the ship lock Koninginnesluis that will be tested on two functions: (1) navigation function to enable ships to pass from the Nederrijn to the Merwedekanaal and (2) the flood protection function (to protect against flooding from the Nederrijn side). Figure 6 shows the functional end of life time analysis for the flood protection function. It indicates that for scenario 1 the end of life time is the year 2078, whereas for scenario 2 the end of life time is later than 2100.

Flood defence: Koninginnensluis

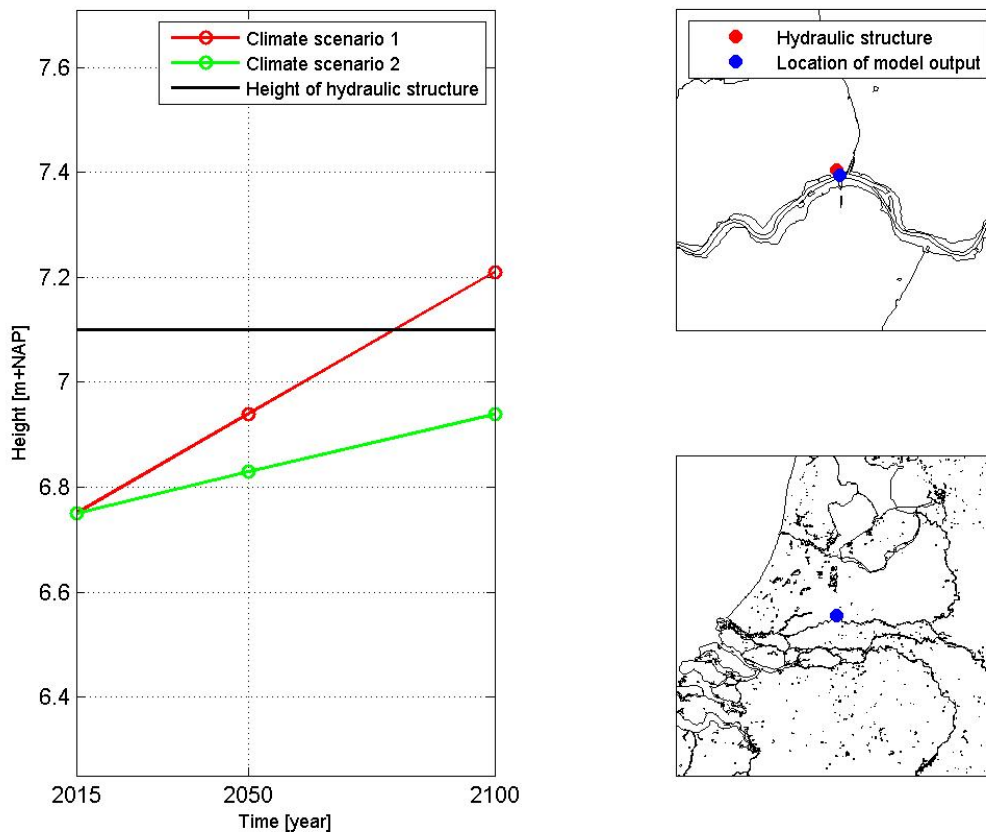


Figure 6: Example of a replacement time frame for the based on analysis with two scenarios

3.4 Technical lifetime

Two approaches to determine timeframes for replacement of structures due to technical deficiencies are presented here: 'DISK Pro' and 'RINK ΔT'. The first approach uses generic data to obtain a rough estimate for all structures. The second approach refines the first estimate using a more thorough technical analysis for a select number of structures.

The goal of DISK Pro is to define a probabilistic model which represents our uncertainty in the replacement age of a hydraulic structure and which can be updated with different types of data by means of Bayesian Statistics. For this purpose, a simple univariate Bayesian model is used. The model presented here has three distinct advantages:

1. the hyperparameters of the prior distribution can be easily determined using the design lifetime or by expert opinion,
2. the prior is conjugate to the likelihood such that updating the parameters is straightforward, and
3. the updating procedure handles both censored and uncensored data.

The RINK ΔT approach offers a more refined estimate for the end of technical lifetimes of a select number of hydraulic structures. This approach is based on a structural assessment of the 'civil' (or concrete) parts of the structures, assessing the stability of these parts (e.g. Lock Heads and Lock Chamber Walls) under changing hydraulic conditions. Life Cycle Cost Analysis show, that 'end of life' of the concrete parts mainly determine the 'end of life' of the total structure. Replacement of other subsystems (e.g. the mechanical parts, the steel doors, the electro technical installation) is still cost effective up to just a couple of years (maximum 5) before 'end of life' of the civil parts. The bounds of the 'end of lifetime' interval is given by the moment that the hydraulic conditions cross a critical threshold. This moment depends of course on the 'Delta scenario'.

The model for obtaining a timeframe for the technical 'lifetime' of a structure uses a simple univariate Bayesian model to make full use of the little information that is available about the remaining life of the

structures. By using an informative prior distribution, the infrastructure manager can start his analysis with default information (such as the design life) or an expert's opinion on the lifetime of a structure. The actual combination of the results of these two approaches is the subject of current research.

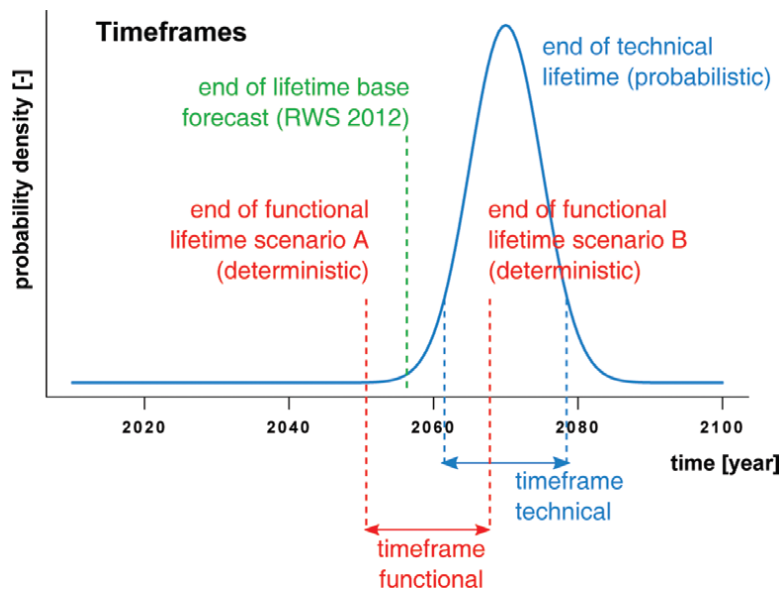


Figure 7: Fictitious example of replacement timeframes

Figure 7 shows the nature of the results (this is a fictitious example) of the described method for a structure and for a certain function. As a reference the outcome of the first basic prediction of 'end of life' of RWS in 2012 (2056, no distinction between end of technical and functional lifetime) is depicted (green).

4. DEVELOPMENTS IN PROGRESS

4.1 Stakeholder strategies for VONK

VONK deals with replacement and renovation of infrastructural assets on the long term, dealing with large uncertainties in a more and more complex world. As we have seen, traditional stakeholder participation methods are problematic, because of the long term uncertainties (substance, strategic and institutional) and the lack of urgency. From theory two promising directions for stakeholder strategies emerge:

1. An accommodation strategy, in which existing values and interests are accommodated within VONK. But, as VONK aims at exploring new options, this might lead to problems. Only if VONK sticks to existing goals and policies, this might be successful;
2. A learning strategy: a strategy in which continuous learning between stakeholders should take place. We call that an invitational stakeholder strategy, in which the asset manager, based on firm insight in its own network, its restraints and the uncertainties involved, invites other stakeholders to join a continuously (periodically) joint planning process.

Within the development of the VONK framework, both options for stakeholder-participation will be lined out. But following the ambitions of VONK, a learning, inviting, strategy will be best suited for a long term development of the infrastructure network and its environment.

4.2 Adaptive pathways

The changes that the Netherlands and Rijkswaterstaat are facing, with regard to climate change and socio-economic changes over the next 100 years contain a large uncertainty. The changes demand large investments and a significant redesign of the infrastructure. In this situation a smart technical and policy approach is needed.

To avoid unnecessary expenses and to maintain or increase political and societal support Adaptive Delta management is introduced (van Ree, 2012).

Adaptive Deltamanagement is a method that helps to deal transparently with future uncertainties in decision making. Key elements are:

- connect present time decision making with future developments;
- work with so called adaptive pathways instead of a fixed horizon. Investigate the available windows of opportunity and calculate the cost and benefits and risks of different pathways.
- Investigate where flexibility can be created and find a way to value this flexibility. Flexibility can be of value e.g. if it can prevent us from making the wrong decisions, or if it creates opportunities to execute projects or strategies at the right time.
- Combine investments programs of different public or private parties and thus create synergy (societal added value, financing, cost savings, societal support) .

For the VONK project a case study will be done applying the method of adaptive pathways that is further developed by Haasnoot et al (Haasnoot, 2012).

Figure 8 shows an example of adaptive pathways (Haasnoot, 2012).

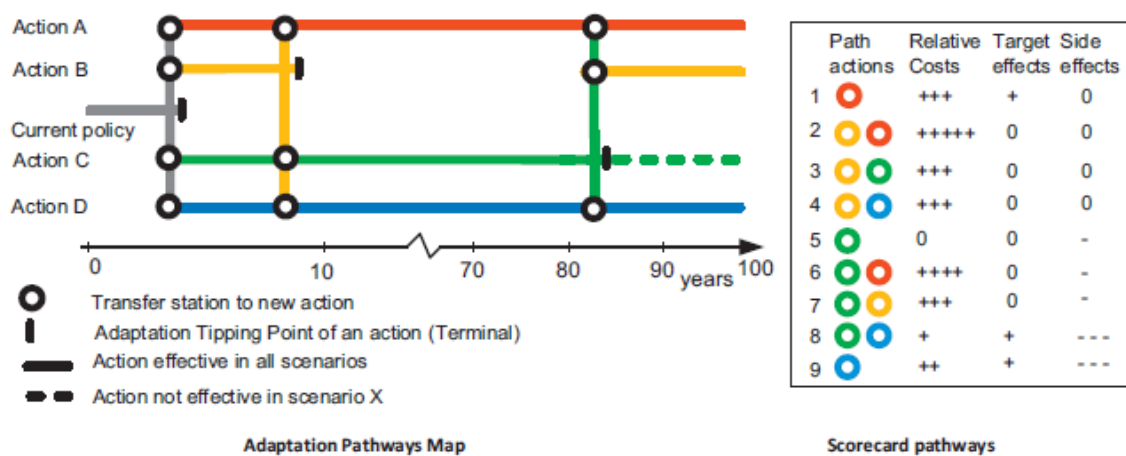


Figure 8: Example of adaptive pathways

The key elements of this approach are that first the present policy is shown with the grey line. Until a certain moment in time the present policy will lead to the desired goals. But later in time the external changes will cause the present policy to fail. Alternative policies ('actions') are developed and shown in the colored lines. Before the present policy fails, a change should be made to another policy. For all policies it is analysed for how long they will be valid and what the costs and benefits are.

It is also shown whether it is possible to switch from one policy to another. Some choices will exclude another action path. With an uncertain future it can be useful to keep options open. Flexibility has a value.

5 CONCLUDING REMARKS AND CONSIDERATIONS

The Dutch government is facing the upcoming replacement investments of hydraulic structures (ship locks, weirs, etc.). Hydraulic structures form an important precondition for sustainable economic development.

In this paper we discussed the complexity and strategic character of this replacement task. Ageing of many hydraulic structures, uncertainty in future developments, budget limitations dictate the need for a substitution strategy. We outlined an integrative framework for long term reinvestment planning for the replacement of hydraulic structures, which forms the basis for the forecast of replacements and renovation of hydraulic structures in the long term (strategic, 100 years ahead) and contributes to the decision-making and programming of replacements and renovations of hydraulic structures in the short term (operational). We focussed on the description of a new method to estimate the end of the technical and functional life time of hydraulic structures. The functional end of lifetime is estimated using a scenario analysis and results in a timeframe with a lower and an upper boundary of the replacement age. Information about a structure, such as generic information, quality score and failure modes, are combined using a probabilistic approach, which results in a probabilistic distribution function of the technical end of life time. We shortly presented two developments in progress, the approach for stakeholder participation and the application of adaptive pathways. A learning, inviting,

strategy for stakeholder participation seems to be the best approach for a long term development of the infrastructure network and its environment. Thinking in adaptive pathways and creating options in solutions is used to shape a more flexible approach to long term reinvestment planning for the replacement of hydraulic structures.

This long term reinvestment approach will result in a better understanding of the replacement task, which will facilitate and improve decision making. This improvement concerns taking into account the long term issues, being aware of the uncertainties, in view of the internal policy objectives of the Ministry and Rijkswaterstaat and the needs of the other governments, commercial parties and stakeholders.

The framework will contribute to:

- giving an overview of the type and scale of the replacement of the hydraulic structures;
- collecting as much as possible insights in future developments and analyze them (taking into account scenarios, functional and performance requirements and quality score of a structure);
- demonstrating how complex and strategic tasks can be dealt with;
- delivering information that will provide time and space to act and to make cost-effective investments at the right time;
- developing a learning strategy in which continuous learning between stakeholders should take place;
- linking expected long term developments and short term replacement investments;
- supporting strategic policy choices.

The framework is not intended to provide one fixed and clear picture of the future but aims to deal with uncertainty.

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