# Improving the Replacement and Renovation Process of Hydraulic Structures

## Creating a decision method for the implementation and assessment of standardisation

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by

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# Preface

The completion of this thesis was the last step to obtain the degree of Master of Science in Hydraulic Engineering at Delft University of Technology. It marks the end of my years as a student, years that have left me with many great memories and resulted in both academic and personal growth. The road to the end of this thesis was filled with many great adventures and learning moments. It has taught me that while we may set out with a predetermined course in mind, unexpected detours can lead to an even better result than initially expected.

To begin with, I would like to thank my thesis committee for their support during my thesis. First, Mark Voorendt for his efforts in keeping my graduation on track with weekly meetings and a positive mindset. While the topic was out of his comfort zone, he provided insight into how I should structure my research while also making it a 'compelling story'. I am happy we stepped out of our comfort zones together.

Next, Erik-Jan Houwing for his enthusiasm, which showed me the real potential of the topic. His experience with asset management helped me find multiple bottlenecks that would otherwise go undetected. At the end of the thesis, Erik-Jan showed me that I had all the puzzle pieces of my report; I just had to put them in the right place to really bring home my message. I will never forget the quote "De bal ligt op de stip, de doelman is naar de wc, je moet alleen de bal er nog in trappen".

Last but not least, Marco Versluis. In my time at Witteveen+Bos, I have learned a lot about engineering companies, tender procedures, used jargon, and the politics of asset management. His practical insight into my topic helped to bridge the gap between standardisation in practice and literature. Moreover, he helped me formulate the thesis to really encourage organisations to take action in improving their replacement and renovation process.

In addition to my thesis committee, I would like to express my gratitude to everyone I spoke to at Waternet and Rijkswaterstaat for sharing their expertise and knowledge on asset management and standardisation. Their perspectives provided a unique glimpse into the operations of an asset management organisation. Furthermore, I want to thank my colleagues at Witteveen+Bos, particularly Alexandra and D'tasha, for welcoming me from the start and providing additional support during the thesis.

To finish, I am grateful for my family and friends' unwavering support throughout my academic career. My family's steadfast presence through the highs and lows of student life has been a source of strength and encouragement. I am most fortunate to have so many amazing friends from the university, my hometown, and the student association. I have had an amazing time in the last few years, and it would not have been the same without these amazing people around me. Finally, I would like to thank Lars for his support and assurance throughout this thesis.

I will look back on my years as a student with many happy memories and I am excited to see what the future will bring.

*Iris Kolk*
*Delft, April 2024*

# Summary

In this thesis, a decision method is created to provide structure to asset management organisations that seek to improve their Replacement and Renovation (R&R) process of hydraulic structures through standardisation.

In the coming decades, asset management organisations face the task of executing R&R for hundreds of assets, including bridges, tunnels, and locks. However, they are constrained by specific demands, time frames, and budgets, making the pursuit of efficiency an ever-present priority (RWS, 2021; AGV, 2022). Asset management organisations have started exploring measures such as standardisation to improve the R&R process and solve the existing difference between the required and available resources. However, despite the potential benefits, limited progress has been made in the Netherlands due to factors such as fragmentation and the current approach to R&R.

The objective of this thesis is:

> ***To develop a decision method for implementing and assessing standardisation in order to improve the Replacement and Renovation process of Hydraulic Structures***.

Possible improvements in the R&R process and the implementation of standardisation were identified by conducting semi-structured interviews at Rijkswaterstaat and water authority Amstel, Gooi, and Vecht. The General Decision Method, shown in Figure 1, results from combining the identified improvement points and the Basic Design Principle (TU Delft, 2020).

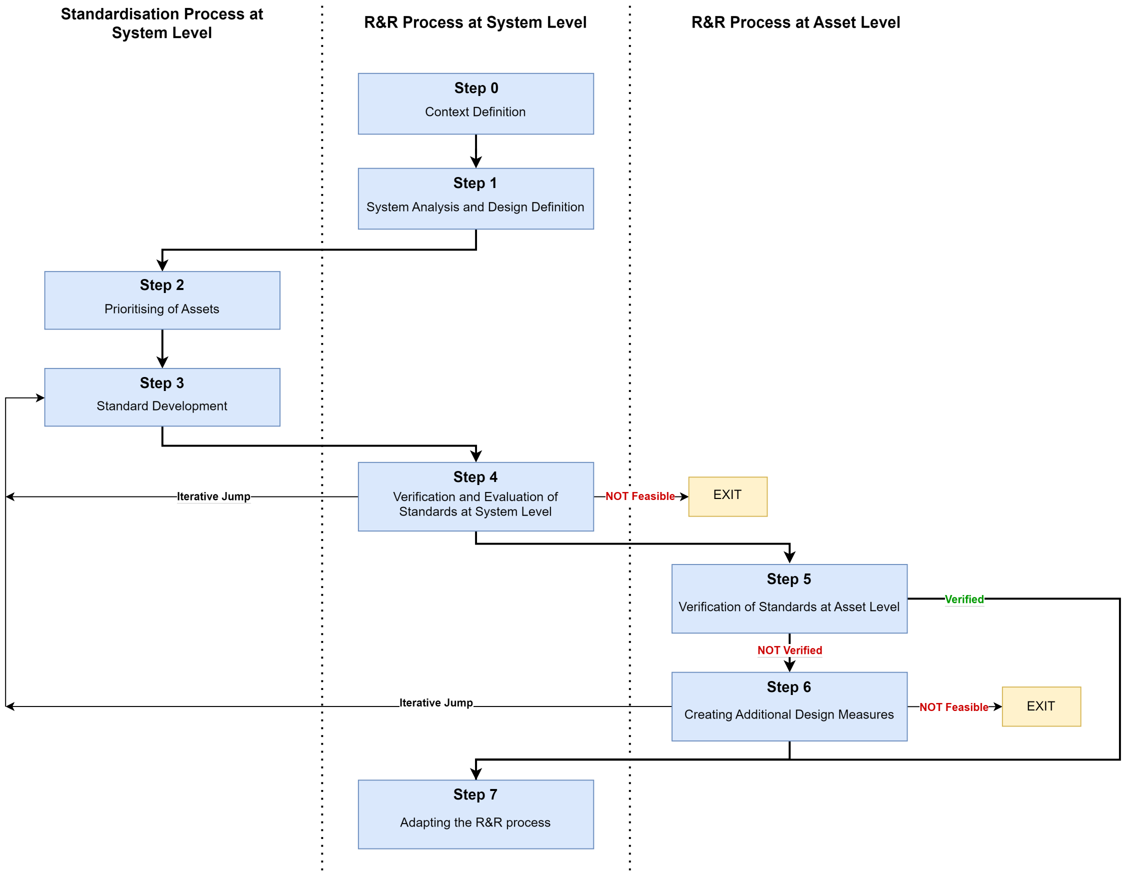



**Figure 1:** General Decision Method

The General Decision Method distinguishes three active processes in the R&R process. First is the R&R Process at a System Level. This process concerns all process steps related to the R&R of the more extensive system of technical assets and the improvement of asset management in general. Second is the Standardisation Process at a System Level. This process encompasses steps related to creating standards and defining which standards should be implemented in which assets. The last active process is the R&R Process at an Asset Level, which concerns steps related to the technical implementation of a standard into individual assets. The General Decision Method is further developed by describing the required steps, decisions, input, and generated output.

A semi-quantitative case study was conducted to verify whether the decision method can be used to implement standardisation in order to improve the R&R process. The considered case was the management area of water authority Amstel, Gooi, and Vecht and its executive organisation, Waternet. Standards were created for fifteen pumping stations, and the effects on the management area were assessed. In addition, a prioritisation order was suggested to execute R&R for the fifteen assets based on the created standards and the current condition level of the assets. The case study showed that the decision method can be used as a first approach to implementing standardisation into the R&R process of an asset management organisation. A generalisation step showed that the decision method is applicable to assets with similar normative boundary conditions.

To identify any discrepancies between this study's decision method and the ideas of asset management organisations, semi-structured interviews were conducted at Waternet. This led to the addition of Step 0 - Context Definition and the two Exit points, shown in Figure 1.

Two conclusions are drawn in this thesis:

1. The decision method enables organisations to implement and assess standardisation of assets and applies to a broad selection of cases.
2. The decision method's transparency, iterative nature with limits, and integration of standardisation into the larger R&R process pushes asset management organisations to break through the bottlenecks (e.g. time or capacity) that normally limit the implementation of standardisation and/or hinder the R&R process.

This decision method is a starting point for asset management organisations that want to start with implementing standardisation into the R&R process. A potential benefit of using the decision method is increased efficiency of the design process, as a learning curve is expected, saving time and money. Furthermore, the results can be used for an in-depth discussion about the feasibility of standardisation in the considered management area.

For future research, additional case studies using a full-quantitative approach should be executed for different asset types in other management areas. The best approach to visualising the cross-correlations between standards should be determined based on multiple case studies. The decision method could be developed further by including process standardisation and making it more user-friendly. Furthermore, using this decision method would require organisational changes for which collaborative contracting is recommended. Finally, asset management organisations that experience the described bottlenecks should start with familiarisation with the decision method before involving other stakeholders and should assign a control team representative of the organisation.

# Contents

# Nomenclature

## Abbreviations

**AGV** Water authority Amstel, Gooi, and Vecht
**ASP** Archimedean Screw Pump
**CEN** European Committee for Standardization
**ISO** International Standardization Organization
**FIN** Ministry of Finance
**I&W** Ministry of Infrastructure and Water Management
**BZK** Ministry of the Interior and Kingdom Relations
**MWW** MultiWaterWerk
**NEN** Nederlandse norm
**PoA** Program of Requirements
**PoR** Program of Requirements
**R&R** Replacement and Renovation
**RWS** Rijkswaterstaat
**VenR** Vervanging en Renovatie
**WLD** Water Level Difference

## Terminology

| Term | Definition |
|---|---|
| (Technical) Asset | A physical object that adds value to the owner, its partners or other stakeholders and contributes to the water system's primary objectives. In this thesis "Asset" is used to refer to technical assets. |
| Asset manager | Function of one person within an asset management organisation |
| Asset management organisation | 'Object beheerder' in Dutch. Refers to entities that control assets and are entrusted with maintaining these assets. |
| Clustering | The task of grouping a set of objects so that objects in the same group (called a cluster) share similar characteristics. |
| Custom project | Project that carries out replacement and renovation using an individual approach. |
| Evaluation | assessment of the effects of standards on the system or an asset based on predefined ambitions. |
| Individual approach | Approach to replacement and renovation, where the optimal solution for a single asset is found. |
| Official Client | 'Ambtelijk opdrachtgever' in Dutch. Function within an asset management organisation. An official client translates administrative assignments to executive assignments for employees within the organisation and acts as a link between the directors and asset managers. |
| Process standardisation | Creating uniform contracts, procedures, and approaches within asset management. |
| Project planner | 'Werkvoorbereider' in Dutch. Function within an asset management organisation. A project planner is responsible for coordinating and planning the various physical tasks and resources necessary for the maintenance of an asset or R&R projects. |

| Term | Definition |
|---|---|
| Replacement and Renovation (R&R) process | The extensive process, including design and construction, of replacing or renovating an asset that is at the end of its service lifetime. |
| Standardisation | The process of adopting standard procedures across multiple assets to create a more uniform system. |
| Standardisation potential | an assessment of whether creating a standard would be beneficial. |
| Standardisation Strategy | Combination of multiple standards that can be implemented simultaneously or in series without obstructing one another. |
| Technical standardisation | Relates to the standardisation of technical assets themselves and the corresponding design choices. |
| Validation | Decision moment whether the result is deemed sufficient. |
| Verification | Check whether the standards meet the requirements. |

# 1. Introduction

## 1.1. Motivation

The significance of hydraulic structures became painfully evident in the Netherlands and abroad during the Great Flood of 1953. The disaster was triggered by a powerful storm, spring tide, and deteriorated dikes due to inadequate maintenance. It led to breached dikes and extensive flooding across substantial portions of the Netherlands, resulting in significant loss of life and considerable financial damages (RWS, 2023a).

Asset management organisations, including entities like Rijkswaterstaat and water authorities, are entrusted with maintaining hydraulic assets to prevent the recurrence of catastrophic events. However, despite centuries of active management, finding optimal strategies remains an ongoing challenge. In the coming decades, asset management organisations face the task of replacing or renovating hundreds of assets, including bridges, tunnels, locks, and viaducts. However, they are constrained by specific demands, time frames, and budgets, making the pursuit of efficiency an ever-present priority (AGV, 2022; RWS, 2021).

This thesis draws inspiration from a project initiated by Rijkswaterstaat known as MultiWaterWerk (MWW). Facing a problem of fragmentation within locks, leading to unique spare parts and knowledge required, standardisation was assumed to be the solution to optimise the Replacement and Renovation process of 52 locks, consequently lowering the life cycle costs and improving the availability and reliability of the assets (Rijkwaterstaat, 2015).

This thesis provides a decision method to support asset management organisations in improving their Replacement and Renovation process, hereafter referred to as R&R (or Vervanging en Renovatie, VenR, in Dutch), through the implementation of standardisation.

This chapter starts with the problem analysis, in which the bottlenecks in the R&R process are examined. Next, possible measures to improve the R&R process are introduced. A focus is placed on standardisation efforts, the corresponding benefits and bottlenecks, and examples from literature and practice. Next, the thesis objective and the approach are given. At last, an outline of this thesis is presented.

## 1.2. Bottlenecks in the R&R process

Any hydraulic structure that has to fulfil a function, whether it be flood protection or regulating the water quantity, goes through the general Asset Life Cycle (ALC) shown in Figure 1.1. The number and name of the life cycle stages are a matter of definition. In reality, the distinction between life cycle stages is not as clear-cut as shown in Figure 1.1, and there will be some overlap or going back and forth between stages (TU Delft, 2020).

When existing assets are nearing the end of their service lifetime, asset management organisations have a decision to make. Whether it be the functional, technical, or economic lifetime ending, there is a choice between replacement, renovation, demolition, or retirement. This thesis focuses on the R&R process of existing assets and the bottlenecks that occur.

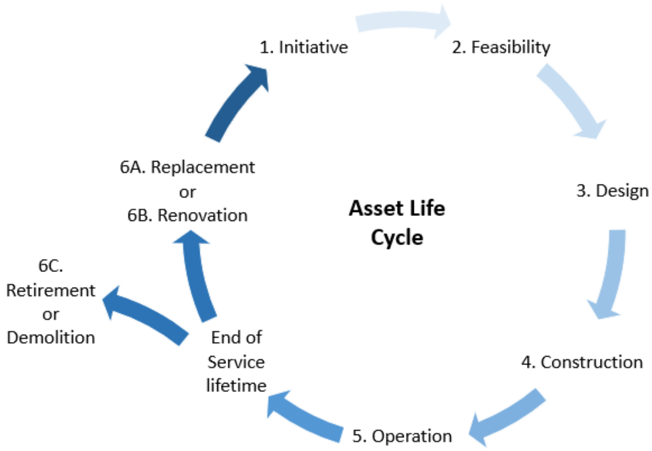



**Figure 1.1:** Asset Life Cycle

Because of the potential major consequences in case of asset failure, asset management organisations must ensure that each asset is up to standard by conducting R&R at or before the end of the service lifetime. However, executing all required R&R on time is obstructed by two bottlenecks. The first is the number of assets that are due for R&R. For example, Rijkswaterstaat has calculated that 250 assets have to be replaced due to the upcoming end of the technical lifetime and an additional 800 structures are expected not to meet the changing functional requirements of the coming decades (RWS, 2021). Together, this is a large number of assets that require R&R around the same time, straining asset management organisations' capacity (budget, time, and personnel).

Efficient R&R of a large number of assets is partially obstructed by the current individual approach to R&R. Design-Build (DB) contracts, also known as Design & Construct (D&C) contracts in Dutch, are the most commonly used integrated contract form within Hydraulic Engineering (PIANOo, 2024a). With DB contracts, the contractor is responsible for the design and implementation of infrastructure. The client draws up a functionally specified request. The contractor is given the space to optimise the design and realisation. The underlying idea is that the market has the most experts to find and apply innovations, and the client does not have all the required expert knowledge (PIANOo, 2024a). Other examples of contracts are Design, Build, (Finance,) and Maintain (DB(F)M) contracts or construction specifications (I&W,2024; PIANOo, 2024b).

The individual approach by using D&C contracts has been standard for centuries and is applied to most assets. Different optimisations and solutions are applied in each project. As a consequence, assets that initially might have been similar or even identical to others become one-of-a-kind assets with unique components and knowledge needed for operation. This fragmentation obstructs efficient maintenance and asset management. Each R&R project magnifies this fragmentation problem, as even more complex and unique solutions are designed for the already unique assets. So, while D&C contracts and the individual approach create room for innovation and optimisation, they lead to unique and complex solutions for every project, which is more time- and budget-consuming.

Besides the demand for R&R being large and fragmentation obstructing efficient R&R, the capacity of asset management organisations fluctuates. For example, for public asset management organisations, budgets depend on the earnings from taxes and the distribution of the funds by the government. Each year, this amount is different, and due to inflation, the budget is even stricter. The same holds for the available personnel at asset management organisations, engineering companies, and contractors.

## 1.3. Possible measures to improve the R&R process

To fix the disconnect between the available capacity and the required capacity, asset management organisations have started to explore possible measures to improve the R&R process: life-prolongation measures, prioritisation, and standardisation.

### 1.3.1. Life-prolongation measures

A starting point to create more time to execute all required R&R is extending the service life of existing assets by applying life-prolongation measures. Instead of executing R&R for entire assets, only specific components close to the end of the service lifetime are replaced to increase the performance of the asset. However, extending the technical lifetime of civil structures requires additional investments. Because of this effect of life-prolongation measures on the resources of an asset management organisation, it is essential to consider the technical requirements and economic (dis)advantages. For example, due to the fragmentation issue, the required components are unique and thus require specific knowledge and engineering to fit the asset, further increasing the investment costs for an asset already reaching its end-of-service lifetime. This consequence reduces the financial feasibility of life-prolonging measures and complicates the choice between partial or complete R&R (Mooibroek, 2015).

### 1.3.2. Prioritisation

A way to be more efficient with the available time is effective prioritisation, the process of determining the order in which the R&R of assets takes place. Creating an order that works efficiently with the available time and budget helps the planning process and gives insight into when to expect certain significant expenses. Each asset management organisation can choose how to approach the prioritisation of the R&R process. For example, the size, importance, risk in case of failure, current condition, or costs of assets can all define the prioritisation strategy.

However, ineffective prioritisation is caused by a lack of information on the state of the assets. For example, if the construction year of an asset is unknown and maintenance records are not up to date, a wrong or even no assessment is made of the overall condition of the asset. Then, the prioritisation of assets is made based on incorrect information. As a result, R&R is executed for assets still in good condition, while necessary R&R for assets in critical condition is deferred.

### 1.3.3. Standardisation

Standardisation is the process of adopting standard procedures across multiple assets to create a more uniform system. First, the benefits of standardisation are described, followed by the bottlenecks in the implementation of it. Next, standardisation efforts in practice and literature are introduced.

#### Benefits of standardisation

Studies have broadly covered the potential of implementing standardisation within processes. Standardising the design process and sub-processes is assumed to result in significant advantages, such as improved process performance (reduced end-to-end time or process costs), enhanced technical interchangeability, or lower probability for process-driven mistakes (Münstermann & Weitzel, 2008).

Besides the internal benefits in an organisation, standards increase interoperability by making products work together more seamlessly (Vennerød et al., 2023). For example, if multiple assets require the same components, manufacturers are able to produce the components in large numbers at once instead of one at a time. Similarly, by making the system more uniform, contractors, engineering companies, and asset management organisations become more efficient in their processes.

Standards facilitate continuous improvement by establishing performance baselines. These baselines make it possible to identify improvements in documented processes that were previously evaluated and tested. Baselines also enable teams to work together to evaluate all variables before determining whether any changes are necessary (SwainSmith, 2019).

As standardisation appears to be the most obvious solution, the question arises as to why it is not implemented more frequently.

### Bottlenecks in the implementation of standardisation

Fragmentation obstructs the creation of a standard fit for the diverse assets. This is because creating a 'one design fits all' uses a normative asset with the strictest requirements, resulting in the overdimensioning of the other assets. Because of this, larger space requirements and increased costs occur even for assets where smaller designs could be used (Hesser & Hoops, 2003).

Another bottleneck is that creating standards requires high investments at the beginning of the implementation (Hesser & Hoops, 2003). Then, if the chosen standard does not fit a project-specific problem or new norms emerge, additional engineering is required to adapt the standard to the project, requiring additional investments. It can be less expensive to use project-specific engineering from the start rather than to start with a standard and have to apply engineering during the implementation.

Cargill (2011) argues that while excellent studies cover standardisation and its potential, most offer limited practical guidance for those actively involved in creating and using standards. In addition, he argues that the success or failure of a standard should be assessed based on whether participants achieved their goals in the standardisation process.

### Standardisation in guidelines

Examples of organisations that bridge the distance between the theoretical aspect of standardisation and practical implementation are the ISO (international level), CEN (European level), and the NEN (Dutch national level). They formulate design and process standards for products, methods, and services and describe them precisely as guidance for users in implementing the standards. Contractors, engineering companies, and other organisations all follow these standards to guarantee safety, as prescribed by law in some cases, e.g. building regulations like the Dutch Bouwbesluit (BZK, 2012; ISO, 2023; NEN, n.d.). While the NEN and the ISO propose design and process standards, they do not give instructions on what a standard design should be. Instead, the standards reflect on quality and assure the structural integrity of assets. Because of this, a standardised approach to R&R is not a focus in these standards, and the fragmentation issue is not addressed by applying them.

### Research on standardisation in practice

An example of a project that aims to implement standardisation into the R&R process to address the issue of fragmentation is the project MultiWaterWerk (MWW) from Rijkswaterstaat. MWW aims to tackle fragmentation within locks, which leads to the need for unique spare parts and specific knowledge. Standardisation was deemed a solution to optimise the R&R process of 52 locks, aiming to reduce life cycle costs while enhancing asset availability and reliability (Rijkwaterstaat, 2015).

Within MWW, several studies have been performed to assess this assumed standardisation potential. For example, Dudink (2018) created a decision model to standardise lock components. A case study was performed on what was assumed to be the lock component with the highest standardisation potential, the gate. The model could be used to decide what gate type is best in certain specific cases based on the required volume of material. It was presumed that a prescription of specific components for all possible cases helps to standardise gate types, as the design freedom would be limited. However, it was stressed that using only one specific, standardised component for every situation would lead to the overdimensioning of the component.

The standardisation possibility of lock gates was further researched by Levinson (2018). Instead of creating one standard for the same gate type, clustering was applied to reduce the variety between locks. Clustering is the task of grouping a set of objects so that objects in the same group (called a cluster) share similar characteristics. Levinson (2018) created the clusters based on two parameters: the gate's height and width. The angle of closure was varied to tackle the problem of standardising locks with different widths. The degree to which the angle of closure could vary was defined by physical boundaries related to stability requirements. Levinson (2018) found that by using five or eight clusters and creating standards for each one, the construction costs decreased significantly compared to applying an individual approach. In addition, spare part management was simplified, the overall stability increased due to overdimensioning, and the availability remained the same.

The studies of Dudink (2018) and Levinson (2018) show positive effects and potential to implement standardisation to improve the R&R process of the locks of RWS. However, both studies focus on the process of standardisation itself. Dudink (2018) prescribes how to find and assess standards, while

Levinson (2018) prescribes how clustering can be used to limit overdimensioning within standards. The practical guidance and defining the goals of implementing standardisation are not considered, as determined as critical by Cargill (2011).

## 1.4. Thesis objective and approach

The objective of this thesis is defined as:

> To develop a decision method for implementing and assessing standardisation in order to improve the Replacement and Renovation process of Hydraulic Structures.

More elaborately, the objective is to support asset management organisations in taking the first steps in implementing standardisation in the R&R process of assets. This includes providing insight into what information is needed and how to obtain it, as well as understanding the effect of adopting standardisation at different levels in asset management. To achieve this, the following steps are taken:

1. **Developing the decision method**:
    - Conducting semi-structured interviews with multiple asset management organisations of different sizes to identify improvement points in current R&R and standardisation approaches;
    - Using the acquired knowledge from literature and practice to create a general decision method that encompasses multiple levels in asset management;
    - Defining the required substeps, information and output based on knowledge obtained from literature and practice;
2. **Performing a case study for the verification of the decision method**
    - Introducing the involved asset management organisation;
    - Executing the created method on the management area of the involved asset management organisation;
3. **Validation of the method**
    - Identifying discrepancies between the created method and the desired method;
    - Altering the method based on the results;
4. **Generalisation of the method**
    - Identifying the (in)dependent variables in the created method;
    - Defining the application limitations of the created method.

## 1.5. Outline of this thesis

The outline of this thesis follows the proposed approach:

- Step 1 of the approach, developing the decision method, is executed in Chapter 2. First, lessons are taken from practice to develop the decision method that supports asset management organisations in the creation, implementation, and evaluation of standards.
- Chapter 3 describes the verification of the decision method through a case study, step 2 of the approach. First, the involved water authority is introduced. Next, the execution of the decision method within the management area of the water authority is described.
- Step 3 of the approach, validation of the created decision method, is described in Chapter 4. The results of the validation are presented and the decision method is adapted based on the result.
- The generalisation of the decision method, step 4 of the approach, is described in Chapter 5.
- In Chapter 6, the discussion of the study can be found, followed by the conclusions and recommendations in Chapter 7.

# 2. Decision Method Development

This chapter covers step 2 of the approach, developing the decision method. First, interviews with two asset management organisations are analysed, resulting in possible improvement points in the R&R process. The knowledge gained is used in combination with a design principle to create the General Decision Method. Next, the General Decision Method is further developed to obtain a precise overview of the required steps to implement standardisation into the R&R process.

## 2.1. Finding improvements points in current R&R approaches

This section considers the current approach to R&R and defines possible improvement points. The improvement points focus on implementing standardisation and avoiding bottlenecks. First, the progress of the project MultiWaterwerk by Rijkswaterstaat (hereafter called MWW and RWS) is discussed. Next, the progress of improving the R&R process at a different asset management organisation is discussed.

### 2.1.1. MultiWaterWerk by Rijkswaterstaat

The studies of Dudink (2018) and Levinson (2018) introduced in Section 1.3.3 show positive effects and potential to implementing standardisation. To compare these findings to the actual progress of MWW, a semi-structured interview at Rijkswaterstaat was conducted with the project manager of MWW, de Graaf. See Appendix A for the full interview.

First, the approach to creating standards is analysed. De Graaf ensured that the project MWW is still ongoing and progress is being made. However, they are not striving towards a 'one-design-fits-all' anymore due to the diverse nature of the locks resulting in insufficient designs. Moreover, it was found that standardising one component independent of the rest of the asset and implementing it in each lock does not result in an approved design without alterations. Therefore, instead of defining the creation of standardisation measures as a separate project, MWW started to integrate standardisation into existing R&R projects: For each project, one component is chosen to research the potential for standardisation. Then, the scope is expanded to make the standardised component applicable in future cases. The advantage of this approach is that part of the design process is predefined and can be skipped. However, adjustments to the standard are required to make it suitable for each new project as different boundary conditions prevail.

While this approach decreases the design time for each asset, it is similar to an individual approach and does not address the core issues of fragmentation, as unique components are still created for each asset. Ideally, standards are created for assets with similar boundary conditions to limit the additional engineering. However, de Graaf mentioned that the RWS management area's diversity complicates finding assets with similar boundary conditions. This is partially due to the assets being located all over the Netherlands. In addition, the assets are mostly primary defence structures with strict regulations to uphold. However, in different management areas where assets are located closer together, this bottleneck could be irrelevant.

Secondly, according to de Graaf, a potential lesson from MWW is that standards should be created for components that benefit more often from standardisation. For assets with a longer service lifetime, e.g. lock gates with a service lifetime of 50 years, the standards will probably be obsolete when the service lifetime ends. Because of this, standards are more beneficial for assets or components with a shorter lifespan, such as mechanical engineering components.

However, different normative boundary conditions prevail for each component of an asset. So, while one standard for one component can be applicable to half of the considered assets, another standard could be applicable to a quarter of the same assets. Because of this, a suitability assessment per asset should be made for each standard. This way, the fragmentation between assets can be reduced as the same standard for components is implemented in several assets. This shows that starting the standardisation process with one asset and generalising to other assets might limit the possibilities instead of assessing the system's potential in general. A possible improvement point is to start with the total management area and define a selection of suitable assets.

Finally, de Graaf stressed that asset management organisations must know their influence in the market. This relates to component production, as manufacturers will only create new standards if the number of objects purchased is substantial. A possible improvement point is using already existing components of manufacturers instead of designing new types.

Besides improvement points addressing the approach to creating standards, de Graaf described two bottlenecks in the organisation of standardisation itself. He stressed that the reason for wanting to implement standardisation should be defined before starting the process. Otherwise, organisations start standardising without aim, and components are standardised without tangible benefits. Moreover, if the objective is not clear beforehand, de Graaf noticed that involved parties will stop supporting standardisation if it is not their preferred standard. Because of this, de Graaf stressed that the benefits of a standard should be demonstrated before potential opponents can object in favour of alternative standards or no standardisation at all.

Proof of these benefits can be partially obtained by creating precise verification and evaluation criteria before standardisation commences. These criteria are used to assess the benefits or disadvantages of the implementation before deciding in favour or against the use of standardisation. Ensuring that standards are created and fully evaluated before the standardisation process ceases, is a key improvement point.

### 2.1.2. Water authorities

Water authorities manage regional water bodies with many assets, mostly smaller non-primary defence structures and systems. These assets are subjected to less strict requirements and are often located closer together than RWS assets. Because of this, the prevailing boundary conditions might be less diverse. This shows potential for standard creation, as de Graaf argued that the diversity of the RWS management area complicates defining standards.

However, while the management area appears less complex, water authorities still need to overcome challenges similar to those of RWS, such as fragmentation. The fragmentation is partially due to the water authorities' founding history. In 1950, there were 2,600 water authorities; in 1980, the number reduced to 260 and over time, the number further reduced to the current number of 21 water authorities (Waterschappen, 2023). This process, in combination with the traditional individual approach to R&R, results in the described fragmentation and its accompanying bottlenecks. While there is potential for standardisation, it has not yet been implemented on a wider scale within water authorities. This is potentially due to the availability of fewer resources (personnel and budget) compared to Rijkswaterstaat to research the potential of standards while simultaneously executing R&R (FIN, 2022; RWS, 2023b; CBS, 2023; Overheid.nl, n.d.).

To further assess the potential of standardisation for water authorities, semi-structured interviews were conducted at Waternet, the executive organisation of water authority Amstel, Gooi, and Vecht. They are active in different parts of the organisation and encounter R&R in different ways. The first expert, Vogelezang-Havers, is an 'official client', 'ambtelijk opdrachtgever' in Dutch. He translates administrative assignments to executive assignments for employees within the organisation and acts as a link between the directors and asset managers. Vogelezang-Havers focuses on the management of the larger system of assets. The second expert, Rinia van Nauta is an asset manager and is involved in the design process of R&R projects, making plans regarding policy and management of technical assets in the system. The third expert, Tonnon, is a project preparer, 'werkvoorbereider' in Dutch, who is responsible for coordinating and planning the various physical tasks and resources necessary for the maintenance of an asset or R&R projects. See Appendix B for the full interviews.

Because the three experts encounter R&R and standardisation at different stages in the asset management process, they might identify different bottlenecks of standardisation. First, bottlenecks related to the use of standards are analysed. Second, bottlenecks related to the acceptance of standards are analysed.

Considering the use of standards, Rinia van Nauta addressed the lack of clear insight into standards, what they try to convey, and when to implement them. He described that this lack of knowledge results in delays in the design process as well as standards being adjusted to fit new projects. This aligns with the statement of Cargill (2011) that practical guidance is required for all parties involved but is often neglected. In addition, Vogelezang-Havers argued that standards limit innovation potential, resulting in less than the optimal solution being applied in assets. This results in stakeholders rejecting the standard in favour of the individual approach. At last, Tonnon pointed out that while the R&R process heavily depends on the current design, the physical implementation of chosen standards in existing assets is often overlooked in the creation of the standards. If a standard can not be placed in the existing asset, adjustments have to be made, altering the standard and defying the point of standardisation.

These bottlenecks show the need for a streamlined design process in which standardisation is integrated instead of it being a side project. Therefore, standards should be created and described with a selection of assets in mind instead of creating a standard and adjusting it to fit other assets. Moreover, the R&R process should start by defining the aim of implementing standardisation at a larger scope than individual assets. This improvement point aligns with the improvement point described in Section 2.1.1.

Considering bottlenecks related to the acceptance of standards, Rinia van Nauta argued that standards might become obsolete if new (board) guidelines emerge. Vogelezang-Havers confirmed this, stating that created standards often conflict with the board's newly emerging ambitions, resulting in adjustments being required. In addition, Vogelezang-Havers argued that while standardisation holds benefits, it is not without associated drawbacks. He stressed that consideration should be made about how often the standard should be applicable for it to be worth the investment. Put differently, adopting standardisation solely for the purpose of standardising assets is not an acceptable approach. In addition, Tonnon described that sometimes management decisions do not work for individual assets, resulting in the standard being rejected late in the R&R process. Rinia van Nauta emphasised this, stressing that reorganisation would be required to integrate standardisation into the design process to reach real implementation. However, Vogelezang-Havers stressed that the total system is more important than a single asset and that disadvantages for one asset should be accepted if it improves the larger system of assets.

These bottlenecks show a distinction between managing the entire system of assets and managing a single asset. For both levels, system and individual assets, different effects are normative, resulting in the approval or rejection of a standard. Because of this, a possible improvement point is to evaluate the standards and their effects at both levels separately before the final approval of a standard and the continuation to implementation. For this, it is essential that all stakeholders should be involved in the creation of the evaluation criteria.

## 2.2. Developing the General Decision Method

Within standardisation, there is a distinction between process standardisation and technical standardisation. Process standardisation refers to contracts, procedures, and approaches that are part of the R&R process. Technical standardisation relates to the standardisation of technical assets themselves and the corresponding design choices. Both process and technical standardisation can partially address the identified bottlenecks. However, a focus of this thesis is the inefficiency of the R&R process due to fragmentation. Technical standardisation addresses this bottleneck directly. Because of this, this thesis limits the scope of the decision method to technical standardisation.

This section describes the creation of the General Decision Method that will provide the needed practical guidance to integrate standardisation into the R&R process of technical assets. This decision method consists of a systematic series of steps individuals or groups follow to determine the best course of action among various options. In Section 2.2.1, a principle is introduced, used to describe the required design steps to reach an approved design. Next, a distinction between processes active in the general R&R process is described in Section 2.2.2. Finally, the distinguished processes are combined with the principle to develop the General Decision Method in Section 2.2.3.

### 2.2.1. Introducing the Basic Design principle

The objective of the decision method is to outline the steps involved in a R&R process. For this, the Basic Design Principle serves as a foundational reference, depicted in Figure 2.1. This principle illustrates various design activities and their interrelations, providing a comprehensive framework for understanding the design process. The principle encompasses multiple elements that are of importance for the improvement of the R&R process of technical assets:

- Because of its objectivity, the Basic Design Principle is applicable to most design cases without limiting the possible solutions beforehand.

  As each management area is different, other solutions could be defined as optimal. Because of this, the decision method should not be prejudiced towards a certain one.

- The Basic Design Principle starts broad, with each step adding more detail.

  Section 2.1 describes two improvement points at different levels of detail. The first is that the definition of the aim of implementing standardisation should be at a broad scope, considering the larger management area. The second is that standards should be created for components instead of assets as a whole. The Basic Design Principle supports this transition to a higher level of detail.

- The Basic Design Principle is transparent, showing users how results are created and what factors are of influence.

  With this transparency, both advocates and opponents of standardisation can determine what design choices give positive or negative results. This also leaves room for others to check the executed work and evaluate whether the results are biased.

- The Basic Design Principle aims at selecting the optimal solution for the given situation using evaluation, verification and validation.

  As possibly multiple standards are created, it should be determined what standards should be implemented to reach the optimal solution. This should be dependent on the given situation, as otherwise standards that are not applicable for some assets could be chosen.

- The Basic Design Principle has an iterative nature. This leaves room for optimisation in case a solution is deemed insufficient. This can be done independently from previous projects, but gained knowledge can be used to shorten the iterative process.

  If the evaluation or verification shows that the standard is insufficient to improve the R&R process, the iterative nature could improve the result.

- Individuals or groups can use the Basic Design Principle together. Because of this, multiple perspectives, requirements, and ambitions of different stakeholders can be considered.

  As deemed a possible improvement point in Section 2.1, all relevant stakeholders should be considered in the creation of standards. This is supported by the Basic Design Principle.

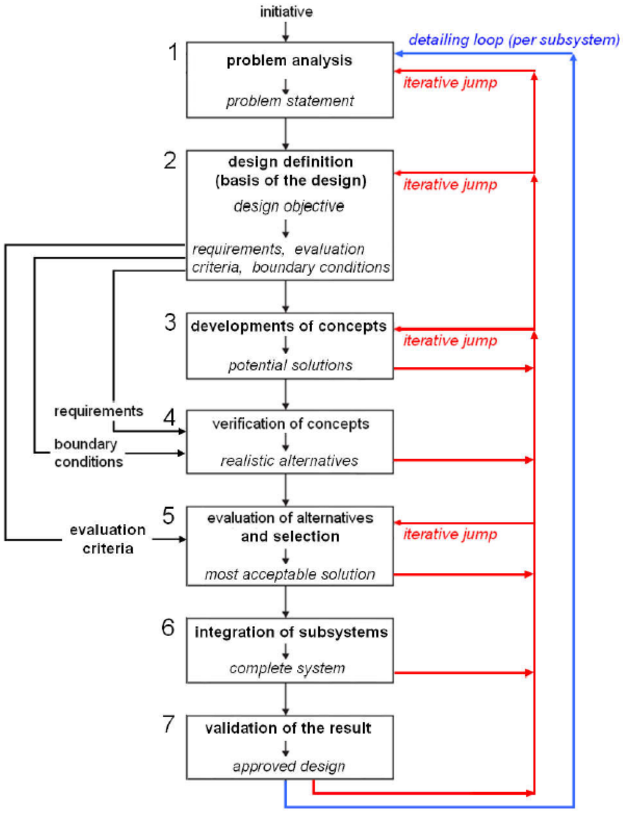



**Figure 2.1:** Basic Design Principle (TU Delft, 2020)

### 2.2.2. Distinction between processes

In Section 2.1, a distinction is described between managing an entire system of assets and managing an individual asset. These levels are both of influence on the R&R process and acceptance of standards. This distinction is included in the General Decision Method as well. In addition, standardisation is a process that should be actively part of the R&R process instead of being a side project. This results in three different processes being active at two levels in the General Decision Method. The processes are described, followed by a description of which steps of the Basic Design Principle are relevant to the specific process. One step of the Basic Design Principle can be relevant to multiple processes. This is because the interpretation of the step is dependent on the context in which it is placed.

- The first is the **R&R Process at a System Level**:

  This process concerns all tasks related to the R&R of the more extensive system of technical assets and the improvement of asset management in general. It aims to ensure effective asset management through standardisation. For this, the aim of implementing standardisation is defined to act as a guide to the verification and evaluation criteria. These can be used to evaluate the effect of implementing standards on the larger management area. This enables the assessment of whether implementing standardisation is worth the initial investment.

  This definition relates to Steps 1 (problem analysis), 2 (design definition), 4 (verification), 5 (evaluation), and 7 (validation) of the Basic Design Principle.

- The second is the **Standardisation Process at a System Level**:

  This process encompasses tasks related to creating standards and defining what standards should be implemented in which assets. The latter task results from the defined improvement point that it is essential to create standards for a selection of assets that share similarities rather than selecting assets based on existing differences in order to address the fragmentation issue. This selection of assets is part of the Standardisation Process as well.

This definition relates to Steps 3 (developments of concepts) and 6 (integration of concepts) of the Basic Design Principle.

- The third is the **R&R Process at an (individual) Asset Level**:

  This process concerns tasks related to the technical implementation of a standard into individual assets. It evaluates whether the standards address all issues found in assets and if a fully approved design is achieved for all considered assets.

  This definition relates to Steps 1 (problem analysis), 2 (design definition), 4 (verification), and 6 (integration of concepts) of the Basic Design Principle.

### 2.2.3. Presenting the General Decision Method

The order of the steps is defined based on the following five considerations:

1. The total system of assets is more important than a single asset. Standards should be verified and evaluated at a System Level before continuing to an individual Asset Level.
2. The aim of standardisation should be determined at a System Level before the process of standardisation commences.
3. The potential of standardisation should be demonstrated before possible opponents can object. There should not be an exit route before standards are verified or evaluated fully.
4. Standards should be created for a selection of assets that share technical similarities to ensure efficient standards.
5. The method should conclude at a System Level, where the focus is placed on adapting the R&R process using the standards.

The General Decision Method based on these considerations is presented in Figure 2.2.

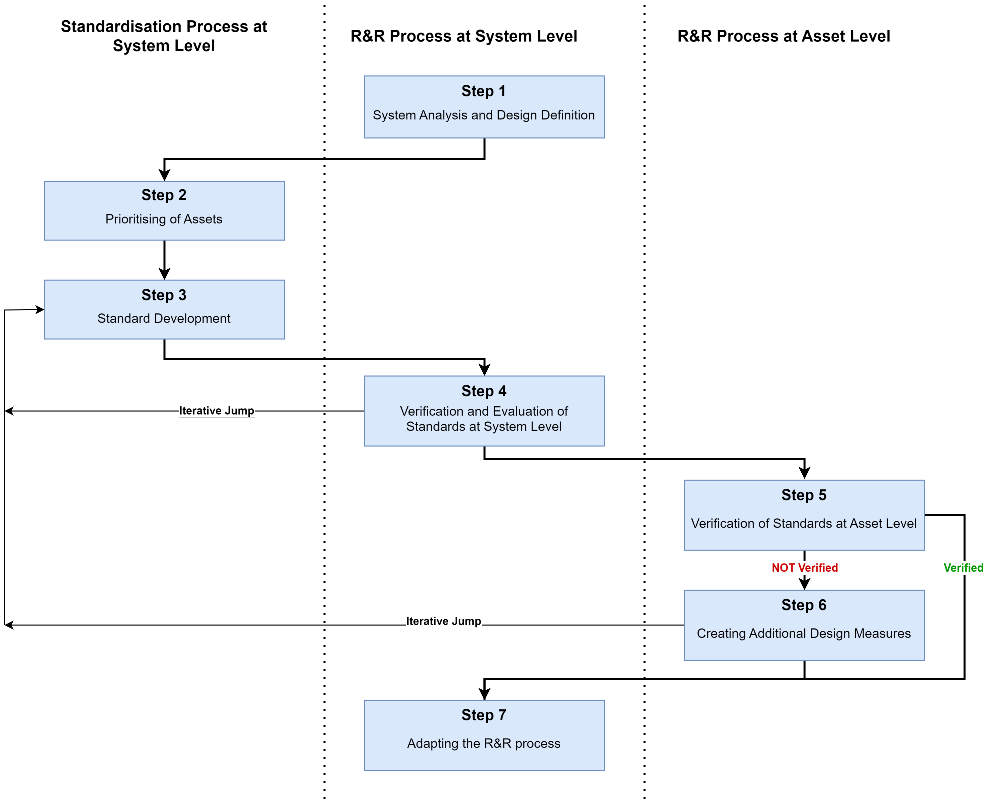



**Figure 2.2:** General Decision Method

Each step is elaborated on shortly with the main objective and reasoning. The General Decision Method is developed further with the required substeps, input, and output in Section 2.3.

1. **System Analysis and Design Definition**

   Step 1 - System Analysis and Design Definition is based on steps one and two from the Basic Design Principle (problem analysis and design definition). The objective is to define the bottlenecks in the considered system, to substantiate the use of standardisation, and to create evaluation and verification criteria.

   Evaluation and verification criteria are formulated as requirements and ambitions. A requirement is a 'must-have', i.e. an essential. The requirements are summarised into a Program of Requirements (PoR). Ambitions are a 'nice-to-have', i.e. desired, but not essential for success. These are summarised into a Program of Ambitions (PoA).

   A choice has to be made between a full-quantitative, semi-quantitative, or full-qualitative approach. A full-quantitative approach focuses on drawing conclusions based on numerical data. This requires setting specific targets in the PoR, e.g. a 10% decrease in costs, and using numerical methods to analyse the results in Step 4 - Verification and Evaluation at System Level. A full-qualitative approach sets general goals for the PoR, e.g. a decrease in costs and the analysis of the results on the expert judgement of the user. A semi-quantitative approach sets general goals, but the verification relies both on numerical data and expert judgment, depending on the availability of data.

   The bottlenecks and the formulation of requirements and ambitions are at a System Level, focusing on the larger system of assets. This is because of considerations 1 and 2, where it is stated that the entire system is more important than one asset and that the aim of standardisation should be defined at a System Level.

2. **Prioritisation of Assets**

   From MWW (Section 2.1.1) follows that starting with developing a standard for one asset and applying additional engineering to adapt the standard to other assets does not decrease the fragmentation. Moreover, creating one standard fit for assets with largely varying boundary conditions will most likely not result in an efficient standard. Because of this, a selection of assets is chosen as a starting point for the standard development. This selection is based on priority, potential, and technical characteristics of assets. This approach makes it possible to assign created standards to other assets if it is found that they share similar technical characteristics.

   The objective of Step 2 - Prioritisation of Assets is to execute this selection process by considering the similarities between assets, their priority (e.g. urgency), and their standardisation potential. The standardisation potential is an assessment of whether creating a standard for a certain component would be beneficial to the R&R process.

3. **Standard Development**

   With a defined selection of assets, the standard development can commence. This relates to the third step of the Basic Design Principle 'Concept development'. Section 2.1.1 concludes that standards should be developed for components, not entire assets. The objective of Step 3 - Standard Development is to create standards for components within the defined selection of assets for which a standardisation potential is present.

4. **Verification and Evaluation of Standards at System Level**

   Full verification and evaluation are required before a decision regarding the feasibility of standardisation is made, as stated in consideration 3. Moreover, in consideration 1, it is stated that the total system of assets is more important than a single asset consideration. Because of this, verification and evaluation are first executed at a System Level before continuing to the Asset Level.

   The objective of Step 4 - Verification and Evaluation of Standards at System Level is to execute Steps four and five of the Basic Design Principle at a System Level. A verification is the check whether the standards meet the requirements set in the PoR in Step 1 - System Analysis and

Design Definition. If not all requirements are met, the standards are not sufficient in improving the R&R process, and the design process should not continue to the evaluation. Instead, an iterative jump is made to Step 3 - Standard Development, to alter the standards.

The evaluation assesses the standards based on the ambitions set in the Program of Ambitions (Step 1). Based on the results of the evaluation, the optimal solution (standards) can be chosen. The approach to verification and evaluation depends on the approach taken in Step 1. With a quantitative approach, numerical methods are necessary. With a qualitative approach, expert judgment is used. With a hybrid approach, a determination has to take place on what methods and expert knowledge are required to perform both the verification and evaluation.

At last, a validation of the standards is made. In the validation, a decision is made whether the combination of the verification and evaluation together results in standards deemed sufficient to improve the R&R process.

5. **Verification of standards at Asset Level**

   After the standards are approved at a System Level, verification at an Asset Level is essential. Step 1 focuses on the entire system, and as a result, the PoR and PoA are at a System Level. However, for the verification of standards for a single asset, additional location-specific requirements must be included. For example, one asset can be classified as a monument while the other is not. Because of this, Step 5 - Verification of Standards at Asset Level is executed individually for all assets included in standards. Because of consideration 1, the system is more important than one asset, the evaluation is not executed at an Asset Level as it is proven in Step 4 that the implementation will benefit the larger system.

   If the chosen standards leave issues unresolved in assets, additional design measures are required. In this case, the decision method continues to Step 6. In case all requirements are met, the design is approved and the decision method continues to Step 7.

6. **Creating Additional Design Measures**

   Step 6 - Creating Additional Design Measures is based on Step six of the Basic Design Principle, integration of concepts. The objective of this step is to create additional measures that, together with the standards, result in a final approved design. However, if these additional measures interfere with the chosen standards, an iterative jump to Step 3 is needed to resolve this. In case the additional design measures do not interfere with standards and together with the standards result in an approved design, Step 7 can commence.

7. **Adapting the R&R Process**

   In the end, the reason for implementing standardisation is not standardisation itself, it is to improve the R&R process. In the last step of this study's method, Step 7 - Adapting the R&R Process, the standards that are approved at both the System and the Asset Level are used to adapt the R&R process.

At last, while Figure 2.1 shows multiple possible iterative jumps, only two iterative jumps are included into the General Decision Method (Figure 2.2). This is because the opponents to standardisation should not be presented with an exit route at every design step. The iterative points are included at points in the design process where the disadvantages of implementing standardisation are deemed too significant for the process to continue. However, each iterative jump forces the opponent to optimise the standard to create more advantages. In addition, there are internal iterative jumps not shown in either the Basic Design Principle or the General Decision Method. The internal iterative jumps will be presented in the further developed method, in Section 2.3.

## 2.3. Further development of the method

This section describes the further development of the General Decision Method presented in Figure 2.2. For each step, required substeps, information and output are defined based on knowledge obtained from literature and interviews.

### Step 1 - System Analysis and Design Definition

The first part of Step 1 is defining the reason for the implementation of standardisation, which is deemed essential before the standardisation process commences. This can be achieved by performing a system analysis to identify any bottlenecks hindering efficiency in the R&R process or asset management and gain an overview of the organisation's needs.

Besides the defined bottlenecks that determine part of the desired change, acting frameworks, such as legislation, should be considered. Frameworks are external plans that create additional boundary conditions, requirements, or ambitions within the design process. Examples of acting frameworks are legislation and destination plans at different levels. Depending on the considered system, different frameworks are relevant. Each asset management organisation should determine the relevant acting frameworks, as it for example depends on the location of the considered system, its size, involved stakeholders, and the destination plans of the organisation.

The hypothesis is that standardisation can help alleviate bottlenecks in the R&R process. By creating evaluation and verification criteria, this hypothesis can be tested. These criteria are obtained by translating the defined needs into requirements and ambitions. Again, a requirement is a 'must-have', i.e. an essential. If the requirement is not met, standardisation is deemed insufficient to improve the R&R process. The requirements are summarised into a Program of Requirements (PoR). Ambitions are a 'nice-to-have', i.e. desired, but not essential for success. These are summarised into a Program of Ambitions (PoA).

Each asset management organisation has the autonomy to define its approach to establishing the Program of Requirements and Program of Ambitions using either a full-quantitative, semi-quantitative, or full-qualitative approach. This defines the approach for subsequent steps, such as Step 4 - Verification and Evaluation of Standards at System Level. Regardless of the approach, there should be a distinction between the definitions of requirements and ambitions. For example, Vogelezang-Havers (App B.2) states that it is not a given fact that a measure is disregarded if not all requirements are met. If, for one requirement, the results are highly positive but (slightly) negative for another, the end score might still be substantial enough to accept and implement the measure. This example of 'soft requirements' blurs the line between requirements and ambitions.

Thus, if the verification shows that one requirement does not have to be met for a solution to be approved, the PoR is reconsidered as the requirement is not essential to the improvement of the R&R process. The soft requirement is moved to the PoA, possibly with a higher weighting factor than other ambitions. This way, the clear distinction between requirements and ambitions stays in place. This supports the transparency of the method and helps the users to know when the standards are sufficient to improve the R&R process.

The required steps to reach the PoR and PoA through a system analysis are summarised in Figure 2.3 along with a simplified representation of the General Decision Method.

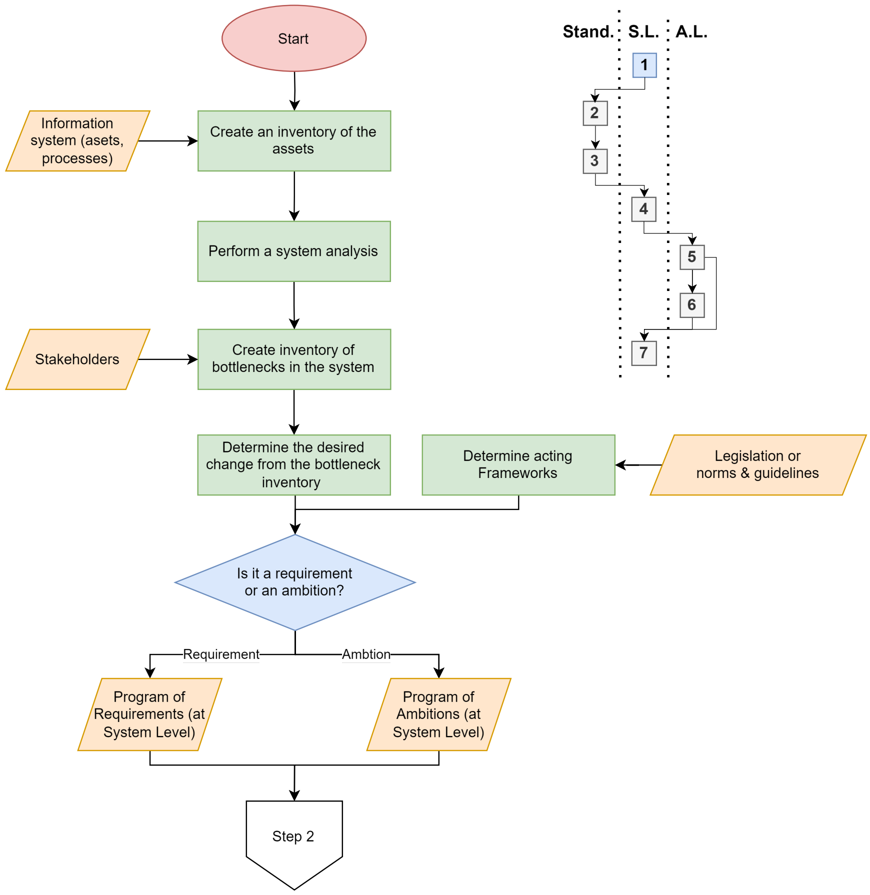



**Figure 2.3:** Step 1 - System Analysis and Design Definition

### Step 2 - Prioritisation of Assets

As described in Section 2.2, the short elaboration of the General Decision Method, Step 2 aims at finding a selection of assets that share similarities. For this, an assessment should be made based on the standardisation potential and priority of assets.

Standardisation potential relates to the possibility of creating efficient standards. Considering assets that share (technical) similarities makes it possible to create standards that are applicable to a larger number of assets without requiring additional engineering. Applying the same standard to multiple assets addresses the issue of fragmentation. In addition, the standardisation potential relates to the number of times the benefits are noticed in the System. In Section 2.1.1 de Graaf argued that the standardisation potential is larger for components present in large numbers with a shorter service lifetime, as with a long service lifetime, the standards become obsolete.

Priority relates to the urgency of R&R. Within a management area, there are assets that are due for R&R, while others still have a longer remaining service lifetime. Creating standards for assets that are still in good condition will not improve the difference between the required condition and the current condition, reducing the urgency of a standard for those assets. However, for assets that are at or reaching their end of service lifetime, the risk of failure is increasing, thus increasing the urgency of R&R and the creation of a standard.

Applying priority and potential as primary filters distinguishes assets into 'System Families' within the management area. However, System Families may consist of too many assets with significant differences between them, obstructing efficient standardisation. By choosing secondary filters based on specific technical characteristics, the assets are further divided into 'Asset Families'. The distinction between System and Asset Families is shown in Figure 2.4. A benefit of secondary filters based on technical characteristics is that new assets entering the system, can be categorised into the right System and Asset Family and be subjected to the correct standards.

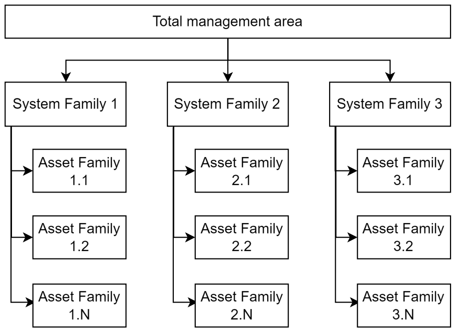



**Figure 2.4:** Distinction between system and Asset Families

The creation of System Families and Asset Families by applying primary and secondary filters is summarised in Figure 2.5 along with a simplified representation of the General Decision Method.

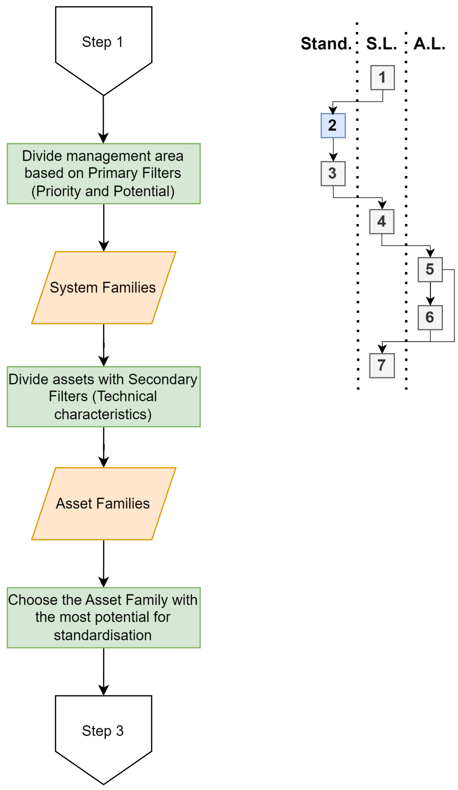



**Figure 2.5:** Step 2 - Prioritisation of Assets

### Step 3 - Standard Development

The objective of Step 3 - Standard Development is to create standards for components within the defined Asset Family for which a standardisation potential is present. Step 2 - Prioritisation of Assets, focuses on assessing the priority and potential of assets as a whole. Step 3 focuses on the standardisation potential of components. The most potential is in components with a shorter service lifetime requiring frequent maintenance. For this, an inventory of the components present is required. After the potential is assessed, standards should be created for each component with potential.

Ideally, one standard fits all assets in the chosen Asset Family. However, as described by both Dudink (2018) and Levinson (2018), as well as Rinia van Nauta in Section 2.1.1, the amount of overdimensioning should be assessed. This assessment should take place based on technical characteristics, such as the volume of material used or efficiency. Levinson (2018) proposed to apply clustering to decrease the level of overdimensioning.

In addition, Vogelezang-Havers emphasised the importance of ensuring that the created standards apply to a sufficient number of assets while avoiding the formation of multiple variants of the same standard to fit more assets. The decision method integrates this by establishing cluster requirements. An example of a cluster requirement is a minimum number of assets within a cluster for it to be recognised as such or a maximum allowance for assets not included within a cluster. Assets that are outside of the clusters are identified as Custom Projects, for which an individual approach is taken. In case the created standard(s) do not meet the cluster requirements, an iterative jump is made to alter the clusters or the standards themselves.

After creating standards and defining which assets should have what standards applied to them, the cross-correlation between the created standards should be determined. A cross-correlation identifies whether standards are applicable simultaneously, in series, or would obstruct the implementation of other standards. Based on this determination, 'Standardisation Strategies' can be created. A Standardisation Strategy combines multiple standards that can be implemented without obstructing one another. One or multiple Standardisation Strategies can be defined depending on the number of created assets and the cross-correlations. All Standardisation Strategies will continue to Step 4. If no standard can be implemented with another and no Standardisation Strategies can be defined, the decision should be made to either continue with individual standards or make an iterative jump back to the standardisation measure development to adjust the standards.

The described steps to develop standards, limit overdimensioning, and define Standardisation Strategies are summarised in Figure 2.6 along with a simplified representation of the General Decision Method. The off-page connector labelled as 'A' facilitates an iterative jump from a subsequent step back to Step 3. The initiation of such an iterative jump is described in Step 4 - Verification and Evaluation of Standards at System Level and Step 6 - Creating Additional Design Measures.

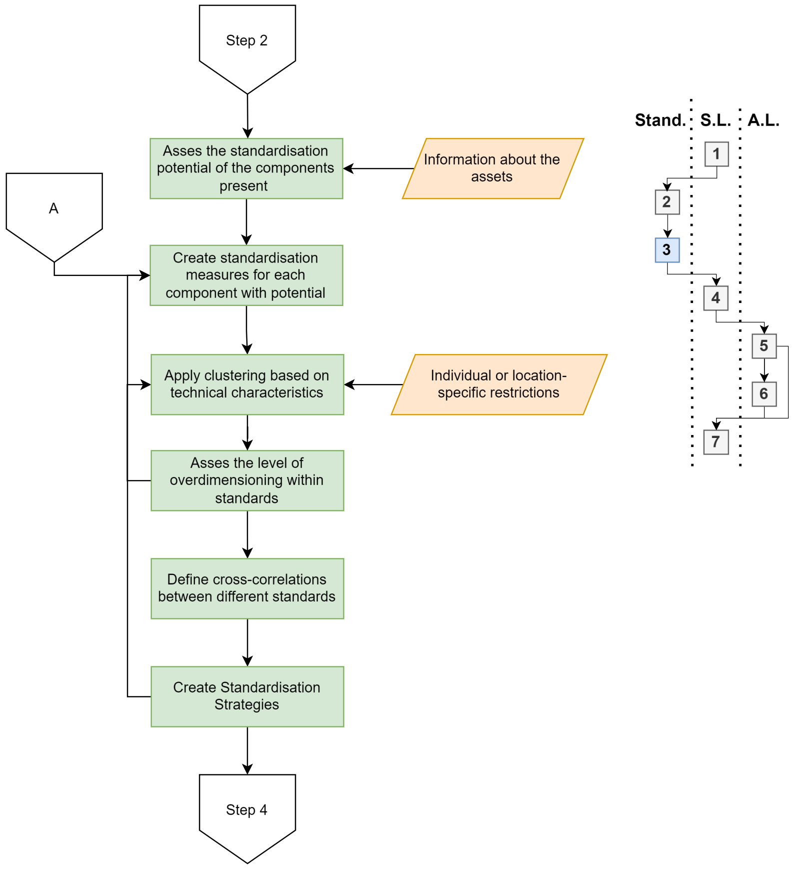



**Figure 2.6:** Step 3 - Standard Development

### Step 4 - Verification and Evaluation of Standards at System Level

Verification and evaluation should be performed at the System Level before continuing to the Asset Level. This approach demonstrates a standard's advantages before potential opponents can object in favour of alternative standards, and a single asset can not sway the verdict on its own.

First, the verification is performed. This is the check whether the Standardisation Strategies meet the requirements set in the PoR (Step 1). If not all requirements are met, the Standardisation Strategy is rejected and will not proceed to the evaluation. There is a possibility to optimise strategies with an iterative jump to Step 3 - Standard Development, following the off-page connector labelled 'A'. The Standardisation Strategies that meet all requirements continue to the evaluation. The evaluation assesses the standards based on the ambitions set in the PoA (Step 1). Based on the results of the evaluation, the optimal Standardisation Strategy can be chosen.

As described in Section 2.2, the approach to verification and evaluation depends on the approach taken in Step 1. With a quantitative approach, numerical methods are necessary. With a qualitative approach, expert judgment is used. With a hybrid approach, a determination has to take place on what methods and expert knowledge are required to perform both the verification and evaluation.

The last step of Step 4 is the validation. In the validation, a decision is made whether the combination of the verification and evaluation together results in standards deemed sufficient to improve the R&R process. If, in this validation, all strategies are deemed insufficient, an iterative jump to Step 3 occurs, following the off-page connector labelled 'A'. In the iteration, the new knowledge obtained in the verification and evaluation should be used to improve standardisation measures.

After Step 4, only the chosen Standardisation Strategy is considered for the rest of the decision method. This is due to time efficiency. The order of verification, evaluation, and validation is summarised in Figure 2.7 along with a simplified representation of the General Decision Method. The off-page connector denoted by 'A' illustrates the iterative jump to Step 3 - Standard Development.

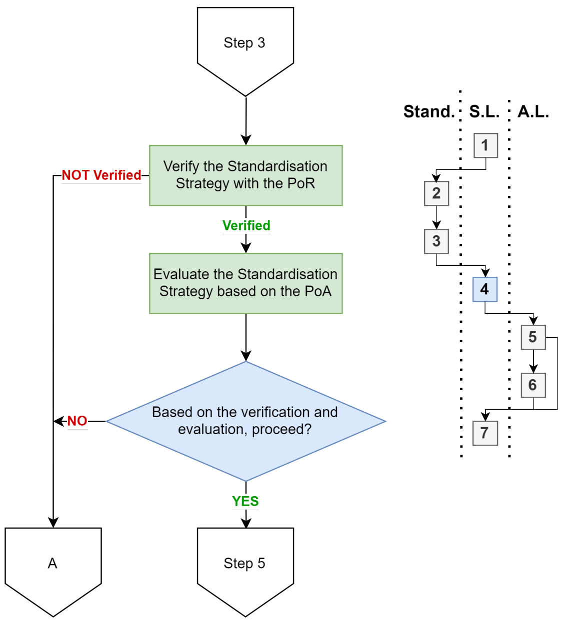



**Figure 2.7:** Step 4 - Verification and Evaluation of Standards at System Level

### Step 5 - Verification of standards at Asset Level

After the standards are approved at the System Level, they are verified at the Asset Level. The PoR and PoA created in Step 1 focus on the entire system. However, additional location-specific requirements must be included for the verification of standards for a single asset. The definition of these requirements requires an assessment of the state of each asset to determine additional issues in the asset that were not found in the system analysis of Step 1. Examples of asset analysis include investigations regarding the soil, surroundings, stakeholders, and current (technical) state of the asset.

Because of the different location-specific requirements, Step 5 - Verification of Standards at Asset Level is executed individually for all assets included in standards. Assets that are not part of a standard are identified as Custom Projects, for which an individual approach is taken. Consideration 1 states that the system is more important than one asset. Step 4 proves that the implementation will benefit the larger system. Because of this, the evaluation is not executed at an Asset Level. If the chosen standards leave issues unresolved in assets, additional design measures are required. In this case, the decision method continues to Step 6. If all requirements are met, the design is approved, and the decision method continues to Step 7.

The described steps for the verification at an Asset Level are summarised in Figure 2.8 along with a simplified representation of the General Decision Method.

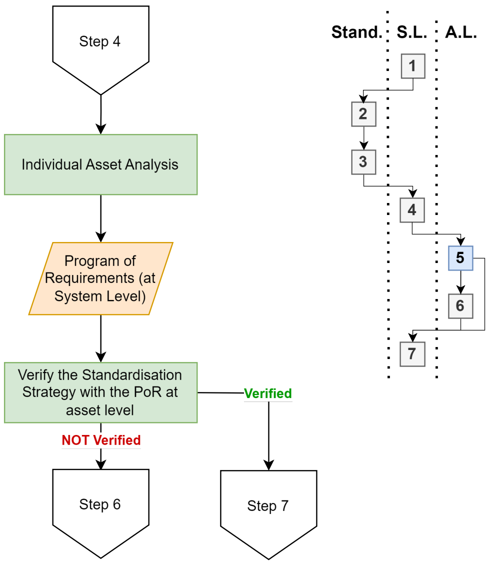



**Figure 2.8:** Step 5 - Verification of Standards at Asset Level

### Step 6 - Creating Additional Design Measures

The objective of Step 6 - Creating Additional Design Measures is to apply additional engineering to find measures that, together with the standards, result in a final approved design. However, the influence of the additional design measures on the standards should be determined. For example, if a standard is created for the gate of a lock, and the additional measure influences the size of the lock chamber, the gate is possibly influenced as well and thus the standard. In case the additional design measures do not interfere with standards and together with the standards result in an approved design, Step 7 can commence. However, if these additional measures interfere with the chosen standards, an iterative jump to Step 3 is needed to resolve this, taking into account the additional information and requirements. This iterative jump follows the off-page connector labelled 'A'. The amount of additional design measures that are needed depends on the type and number of issues that remain after implementing the standard(s). Significant issues often require more extensive adjustments, while minor issues could be solved with less complex solutions.

The described steps for the creation and assessment of additional design measures are summarised in Figure 2.9 along with a simplified representation of the General Decision Method. The off-page connector denoted by 'A' illustrates the iterative jump to Step 3 - Standard Development.

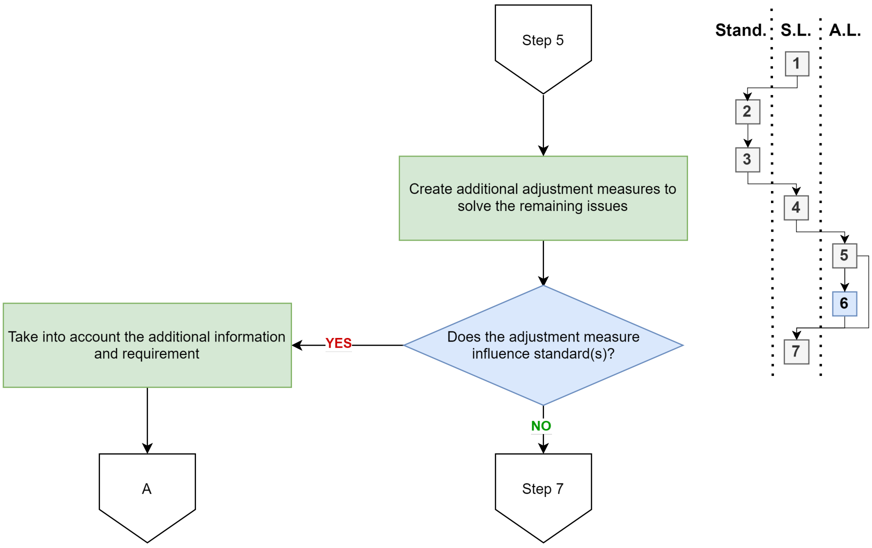



**Figure 2.9:** Step 6 - Creating Additional Design Measures

### Step 7 - Adapting the R&R process

In the end, the reason for implementing standardisation is not standardisation itself, it is to improve the R&R process. In the last step of this study's method, the standards that are approved at both the System and the Asset Level are used to adapt the R&R process.

After the chosen standards are verified at an Asset Level in Step 5 and no additional design measures are required Step 7 - Adapting the R&R process, commences. In this Step, a strategy is created to use the chosen standards to maximise efficiency within the R&R process. In Section 1.3, three possible measures were introduced to improve the R&R process: Life prolongation measures, prioritisation, and standardisation. This decision method combines prioritisation and standardisation to improve the prioritisation of the R&R process. Prioritisation can be defined based on available budget, importance, and remaining service lifetime. This is called a prioritisation strategy. Next, the level for which priority is determined should be defined. The level depends on the level for which standards are created. If standards are created for one cluster, only the assets in that cluster can be prioritised. The different levels are shown in Figure 2.11.

The described steps for the creation and execution of a prioritisation strategy are summarised in Figure 2.10 along with a simplified representation of the General Decision Method. This concludes the method.

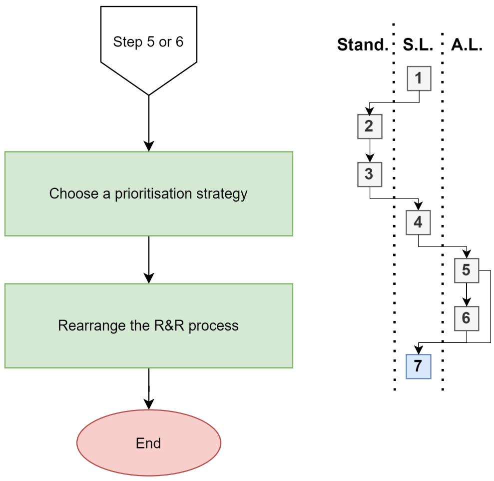



**Figure 2.10:** Step 7 - Adapting the R&R process

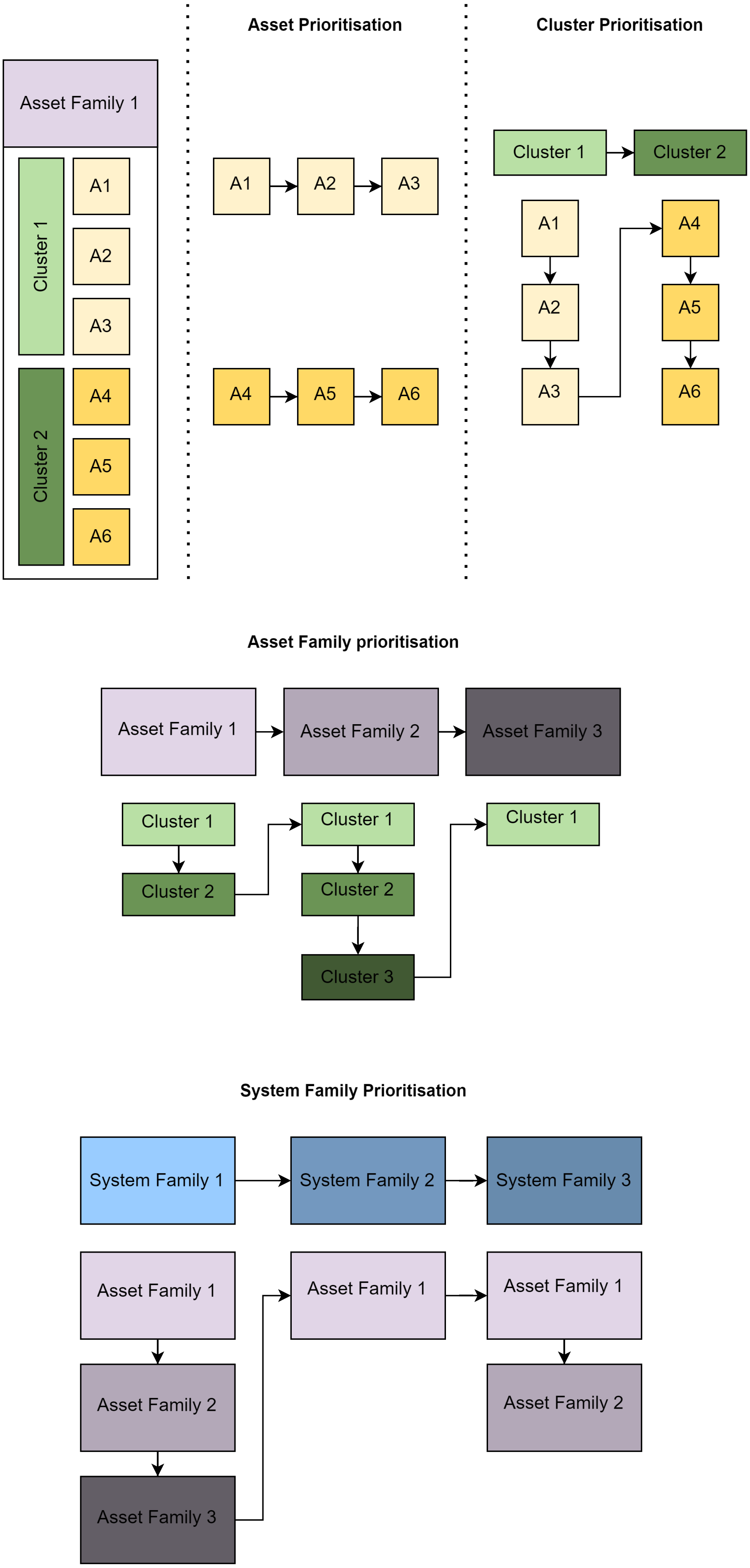



**Figure 2.11:** Visualisation of prioritisation levels

# 3. Verification through a Case Study

This chapter describes the case study used for the verification of the created decision method. In addition, the implementation of this study's method in the R&R process of an asset management organisation is described. First, the case is introduced, next each step of the method is executed. At last, concluding remarks are given.

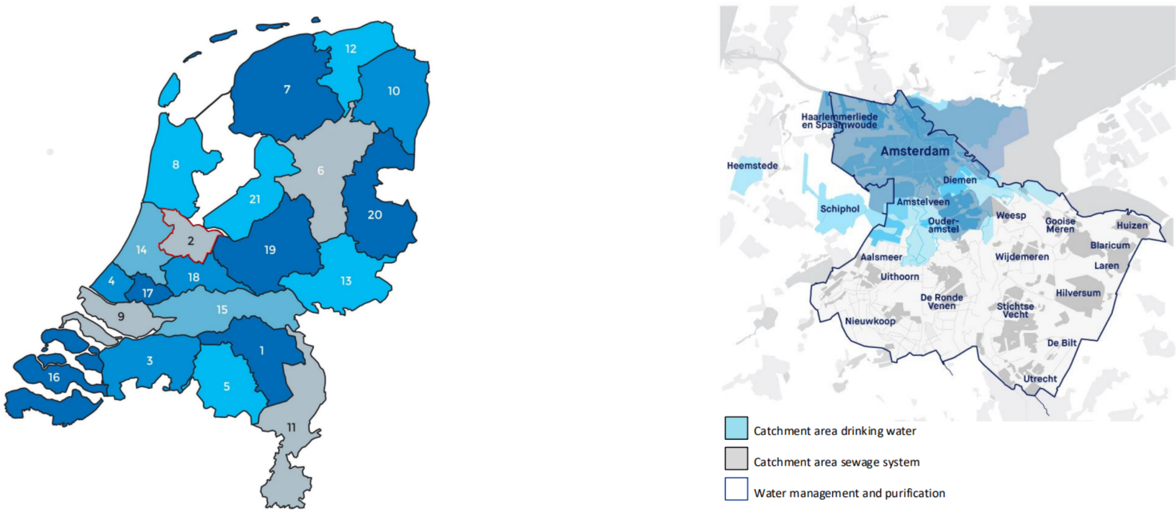
## 3.1. Case introduction

The analysis of current R&R approaches (Section 2.1) shows that despite facing similar challenges to RWS, such as fragmentation, water authorities have not widely adopted standardisation, potentially due to resource limitations. Water authorities are likely better suited for standardisation than RWS as they manage regional water bodies with many, mostly smaller, non-primary defence structures and systems. These structures and systems are subjected to less strict requirements compared to the primary defence structures of RWS. Additionally, the management area of a water authority is smaller. With assets located closer together, such as in the same section of a waterway or the same polder, potentially similar boundary conditions prevail. This increases the potential for a standard suitable for multiple assets.

Currently, there are 21 water authorities active in the Netherlands. Each water authority has unique policy plans with different ambitions, regulations, and guidelines tailored to its management area. Combining these plans into the Program of Requirements and the Program of Ambitions is a political-related task and less related to the bottlenecks in the R&R process. In short, to limit the variation in boundary conditions (technical and organisational), only one water authority is involved.

The involved asset management organisation is the water authority Amstel, Gooi, and Vecht, hereafter called AGV. AGV was established in 1997 and operates in the provinces Noord-Holland, Utrecht, and part of Zuid-Holland, encompassing 19 municipalities, see Figure 3.1a (AGV, n.d.).

AGV governs the management area by creating a water management plan containing all the projects and plans for their board period. This contains plans to ensure all residents' safety, clean and enough water for living, working, and recreation, and plans to manage the water flow in the area. However, the executive organisation is Waternet, established in 2006 through a merger of tasks between the municipality of Amsterdam and AGV, see Figure 3.1b (Kuijpers & Niemantsverdriet, 2023). Their tasks include cleaning water coming from the sewage system before it reenters the natural water system, maintaining the water quality in rivers, canals, and ponds, ensuring the structural integrity of dikes, and at last, maintaining the water level in the regional waterways or polders and regulating the flow of water through assets such as pumping stations. Waternet is regarded as the client for this case study, but information, ambitions and guidelines are gathered from both Waternet and AGV.




**(a)** Water authorities in the Netherlands (Unie van Waterschappen, 2021)

**(b)** Management area of AGV (Waternet, 2023b)

**Figure 3.1:** Overview Water authorities and management area of AGV

## 3.2. Step 1 - System Analysis and Design Definition

This section describes the first step of the method, System Analysis and Design Definition. The detailed method of Step 1 is repeated in Figure 3.2 along with a simplified representation of the General Decision Method.

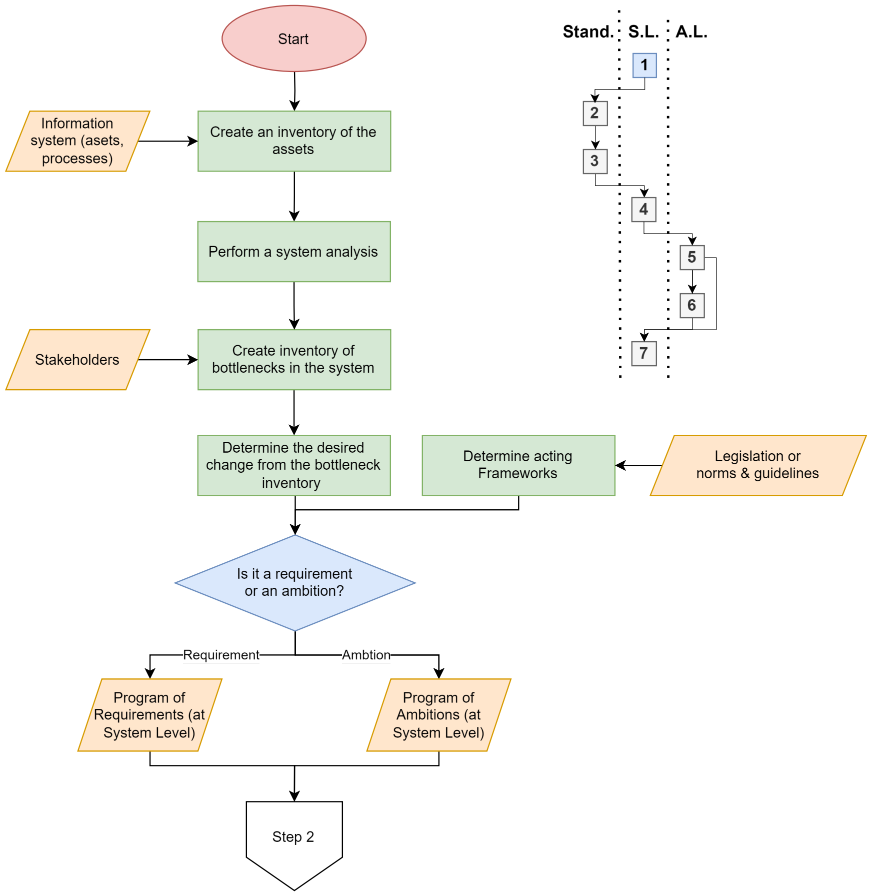



**Figure 3.2:** Step 1 - System Analysis and Design Definition

### Create an inventory of the assets

The inventory of assets encompasses the portfolio of technical assets of Waternet/AGV. A technical asset is a physical object that adds value to the owner, its partners or other stakeholders and contributes to the water system's primary objectives. Technical assets include bridges, pumping stations, locks, and weirs (AGV, 2022). Assets without technical aspects, such as waterways and nautical objects or those of third parties, are not considered. Figure 3.3 shows the 4139 technical assets, each colour representing a different asset type.

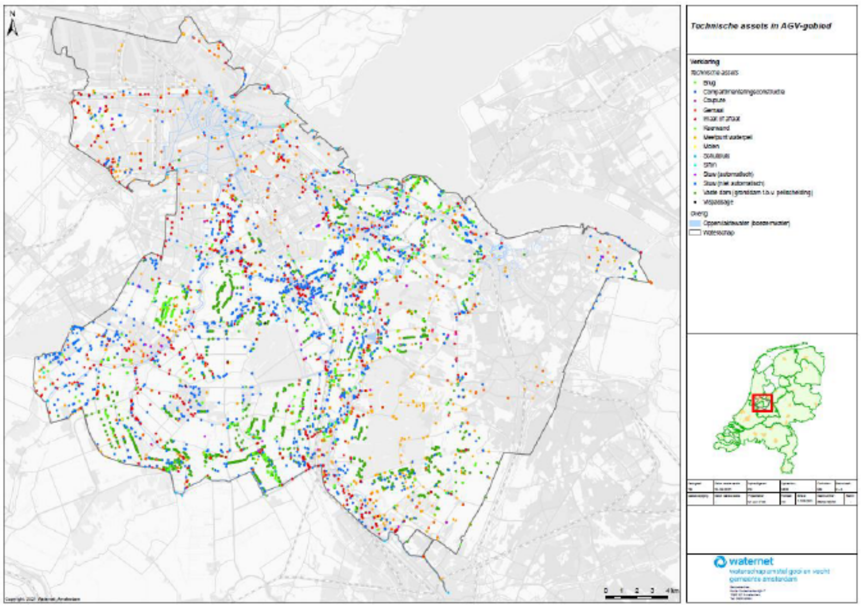



**Figure 3.3:** Overview of locations of 4000 technical assets (Waternet, 2023b)

### Perform a System Analysis

In 2022, Waternet executed a system analysis on all technical assets and the findings were summarised in a Masterplan. AGV charged Waternet with creating this Masterplan to obtain more vision and control over the condition of their technical assets, financing, and planning (AGV, 2022). The Masterplan establishes guidelines that could be converted into an executable program for operational phases using the methodology of Uniform Asset Management. The Masterplan consists of five phases, these are summarised as:

- **Phase 1** describes the legal duties and guidelines, along with external developments that shape the technical asset requirements. It shows that legal and environmental factors play a pivotal role in determining the guidelines.
- **Phase 2** provides an overview of the relevant technical assets, categorised by type and their current condition level (technical state), as well as the extent to which they meet ambitions. Insight into the condition level is derived from available detailed inspections and administrator assessments (visual inspections). If no inspection reports are available, the condition is calculated based on the years in which major maintenance has been performed and compared to the standard technical lifetime. For this, the method described by NEN-2767 is followed, see Appendix C.1 for more information.

  Four categories are distinguished: Civil Engineering (CIV), Mechanical Engineering (ME), Electrical Engineering (EE), and Process Automatisation (PA). CIV is the construction of the object, e.g. the foundation, concrete work, walls and roof. ME includes the pump, hoisting installations, lock doors, moving parts of a bridge or weir, the drive (motor) and transmission, and gears. All installation parts that use or regulate electricity are part of EE. Examples include the cabling and distribution of electricity, transformers or emergency power systems. At last, PA includes all installation parts that deal with control and (automatic) operation. This includes computers, software, routers and (digital) communication lines.

Of the over 4000 assets, 444 larger assets are assessed individually, while the remaining are assessed in groups. This individual assessment found that 60% of the individually assessed technical assets are in good condition, while 40% are in poor condition, with varying conditions across different asset types. In general, CIV is still in the best condition, with more than half in reasonable to good condition. However, the PA condition is in the worst condition, with 80% scoring poor to very poor.

It is found that large differences in condition occur within one asset type. However, taking the mean of each asset type shows that between different asset types, large differences occur; see Table 3.1.

**Table 3.1:** Mean condition level per asset type (AGV, 2022)

| Average condition score | Asset types |
|---|---|
| Poor to very poor: | Emergency bridges, windmill and emergency drainage |
| Fair to poor: | Siphons, cut-offs and navigation locks |
| fair to moderate | Large and medium-sized pumping stations, bridges, and fish passages |
| Good to fair: | Dephosphatisation installation, automatic weirs, small pumping stations, emergency locks, culverts and weirs |
| Excellent to good | Emergency barrier divers |

- In **Phase 3** a risk analysis is performed based on the importance of assets and defining minimum required condition levels for various asset classes. The minimum required condition level for all assets is based on NEN 2767 methodology (AGV, 2022; Waternet, 2022). Highly important assets must maintain a minimum condition level of 2, important assets a level of 3, and less important assets a level of 5.

  After allocating each asset an importance level and minimum required condition level, the difference between the current and required condition level is determined. This results in a larger risk associated with damages. The condition score ranges from 1 (excellent) to 6 (very poor). The component fails if the current score is lower than the minimum score. For example, if the minimum required condition level is 4, and Civil Engineering has a score of 5, the risk of failure is larger than acceptable.

  The current condition level of the 57 very important and 167 important assets is, on average, insufficient. However, the 220 less important assets meet the minimum requirements on average.

  The last step of phase 3 is to determine the costs associated with improving the condition level of an asset to the minimum level while also complying with the ambitions of the Waternet/AGV. Among other budgets, the R&R budget had to be increased from 32 to 40 million over a time period of 40 years.

  Based on Phase 2 and Phase 3, Waternet created a Long Term Asset Planning (LTAP) model to gain further insight into the effect of a gap between the minimum required and current condition level on the budget and planning of AGV. Not all 4000 assets are included in the LTAP; only the 444 more monetary-intensive (i.e. expensive) assets. This model contains all relevant information about the technical water system assets, including asset type, construction year, year of last revision, determined level of importance, and current and minimum required condition scores for several building components (civil engineering, mechanical engineering, electrical engineering, and process automation). It gives insight into the budget and time required to bridge the gap between the current condition level and the minimum condition level required (Waternet, 2022).

  **Phase 4** focuses on formulating measures to bridge the gap between current and required condition levels, transitioning to risk-based maintenance, replacement, and renovation.
- **Phase 5** deals with determining execution strategies. The Masterplan emphasises prioritising projects based on their importance level and condition gap, as well as projects that include the board's ambitions.

### Create an inventory of the bottlenecks in the system

In the Masterplan, three bottlenecks in asset management are identified:

- There is no clear view of the current state of the assets, resulting in a lower condition level than expected and an increased risk of failure.
- The number of assets with a lower condition than desired is higher than expected. Because of this, there is a gap between the needed and the required capacity (time, personnel, and budget) of Waternet to R&R all assets due for R&R, resulting in delays and thus an additional risk of failure.
- Effects of climate change, such as large rain showers, result in assets malfunctioning or reaching their end of functional service lifetime before the designed moment.

In addition to bottlenecks related to asset management, bottlenecks specifically related to the process of R&R should be included to understand the total system and the desired change. For this, semi-structured interviews with three employees in various functions at Waternet are conducted, see Appendix B. Two additional bottlenecks related to the R&R process are identified:

- Due to fragmentation, specific knowledge and parts are required, complicating management (operation, planning) and maintenance. In addition, each R&R project is unique, resulting in the total design process being required, using more time than desired.
- New ambitions and norms emerge every few years and should be integrated into designs. However, as the flexibility of a standard is low, they could become obsolete in a few years. Because of this, the investment would not generate the required return.

### Determine the desired change from the bottleneck inventory

The primary objective of an asset management organisation is maintaining assets in order for them to fulfil their function. Assets should not reach their end of service lifetime before R&R can occur. Right now, more assets are due for R&R than initially expected. Due to a gap between the required and available capacity of Waternet, it is not possible to solve execute all the required R&R. As a result, the risk of failure is higher than acceptable for some assets. To decrease the risk of failure to a desired level, the asset management organisation desires to ‘do more with the same’. This desire translates to the need to make R&R projects less expensive or more efficient. Standardisation is assumed to hold the potential to contribute to this optimisation of the R&R process.

### Determine acting frameworks

The acting frameworks are different for each asset management organisation (and each project). They consist of national and regional frameworks and change over time for various reasons. Short descriptions of possible acting frameworks for this case are given:

- **National legislation**

  The first framework is the ‘Water Authority Act’ (Dutch: Waterschapswet), which regulates the abolition and establishment of water boards and provides rules regarding the tasks and organisation of the water boards and the composition of their boards (I&W, 2023c).

  Before 2024, the relevant additional legislation for a water authority was the ‘Water Act’ (Dutch: Waterwet) and the ‘Building decree’ (Dutch: Bouwbesluit). The Water Act mainly regulated the management of water systems, including flood defences, surface water and groundwater bodies. The law is aimed at preventing or limiting flooding, water nuisance and water scarcity, the protection and improvement of the quality of water systems and the fulfilment of social functions by water systems (Rijksoverheid, 2022; RWS, n.d.).

  However, in January 2024, a new Environment and Planning Act was introduced in the Netherlands. This act replaced the ‘Building decree’ with the Environment Building Decree. The Water Act is largely incorporated into the Environmental Act, but few parts remain in the Water Act (RWS, n.d.; BZK,2023).

- **Local legislation**

  Besides national legislation, additional local rules and legislation are implemented by water authorities. These are currently stated in the KEUR and contain the rules (in particular commands and prohibitions) that a water board applies to the protection of flood defences, waterways and associated structures, among other things (I&W, 2023b). However, because of the Environment and Planning Act, each water authority has to replace the KEUR before 2026 with a 'water authority regulation'. This regulation contains all rules regarding the physical environment that the water authority sets within its management area (IPLO, n.d.).

- **Standards and Guidelines**

  In Section 1.3.3, ISO, CEN and NEN were introduced. These organisations and their norms and guidelines are not legislation, but they embody parts of the building decree, which is legislation. Thus, following the norms and guidelines is not required by law, but it does guarantee that you meet the requirements set by the law (NEN, 2024).

- **Local guidelines**

  Each water authority, province, and municipality creates its own policy and destination plans, taking into account management area-specific guidelines and attention points (I&W, 2023a).

For this case study, it is assumed that all guidelines are described in the Masterplan. Because of this, the described legislation is not taken into account individually.

#### Create a Program of Requirements

The desired change and the acting frameworks can be divided into requirements and ambitions. A requirement is a must-have, and in case a requirement is not met, the implementation of standardisation is deemed not sufficient enough to improve the R&R process. It is important to highlight that each asset management organisation has the autonomy to define its own approach to establishing the Program of Requirements (PoR) and Program of Ambitions (PoA), which are subsequently utilised for verification and evaluation.

Section 2.2.3 describes the difference between adopting a full-quantitative, semi-quantitative, or full-qualitative approach. The focus of this case study is verifying whether the developed decision method can be used to implement and assess standardisation to improve Waternet's and AGV's R&R process. Because a full-quantitative approach is time-consuming, a semi-quantitative approach has been chosen for this case study. With this approach, more general requirements are defined, and the verification and evaluation rely on both numerical data and expert judgment depending on the availability of data.

In this step, the PoR is defined at a System Level, meaning the requirements are defined for the total system instead of individual assets. The first requirement is related to the assets themselves, the second to asset management, and the third to the process of R&R:

1. Assets can fulfil their respective function for the predetermined technical lifetime, taking into account future developments such as climate change.

   In the Masterplan, Waternet defined standard technical lifetimes based on knowledge and experience of specialists (AGV, 2022). The values are shown in Table 3.2.

   **Table 3.2:** Standard Technical Lifetime as defined by Waternet (AGV, 2022)

   | Category | Standard Technical Lifetime |
   | --- | --- |
   | Civil Engineering | 50 years |
   | Mechanical Engineering | 25 years |
   | Electrical Engineering | 13 years |
   | Proces Automatisation | 8 years |

2. The R&R process becomes more efficient, decreasing the time it takes to R&R assets compared to the current individual approach.

By making the R&R process of one asset more efficient, less time is needed to execute R&R for a single asset, and thus, more projects can be carried out in the same time span. Waternet typically divides its projects into seven phases: initiation, definition, design, preparation, realisation, operation, and deconstruction (AGV, 2017). The first five phases together define the timeline of the R&R process of an asset.

3. The Total Cost of Ownership decreases compared to the current individual approach.

   The Total Cost of Ownership, hereafter called TCO, encompasses all the expenses related to asset management. A decreased TCO makes more budget available for additional expenditures, such as additional R&R projects.

   The TCO comprises the Capital Expenditures (CapEx) and the Operational Expenditures (OpEx). CapEx is defined as one-time investments related to the design, construction, R&R, or demolition of assets. Examples include engineering costs for design and material costs for the construction. OpEx are all continuous (repeating) costs related to the operation of the asset. In other words, the costs related to personnel and assets performing their tasks. Examples include electricity, rent of offices, salaries of personnel, spare parts for maintenance, and cleaning products.

   Not all costs have to decrease for the TCO to decrease. For example, increasing the investment might decrease the operation costs at another. The requirement is met as long as the sum of all expenses (the TCO) is reduced.

The Program of Requirements at System Level is summarised in Table 3.3.

**Table 3.3:** Program of Requirements at a System Level

| **Program of Requirements (System Level)** | |
|---|---|
| **F - FUNCTION** | |
| Assets can fulfil their respective function for the predetermined functional lifetime, taking into account future developments such as climate change. | |
| | |
| **T - TIME** | |
| The time it takes to replace and renovate (initiation, definition, design, preparation, and realisation) all assets due for R&R decreases after implementation of the standard compared to the current approach. | |
| | |
| **B - BUDGET** | |
| The TCO (CapEx+OpEx) decreases compared to the current approach after implementation of the standard. | |
| *CapEx* | Investments at t=0, costs related to the design, construction, R&R, or demolition of assets. |
| *OpEx* | Continuous costs related to personnel and assets performing their tasks. |

### Create a Program of Ambitions

An ambition is a nice-to-have, meaning it will bring positive value if it is included through standardisation, but it is not essential for the improvement of the R&R process. In this case study, the ambitions are related to asset management for users at various levels.

1. The operation phase of assets is improved by making management (operation, planning) and maintenance of assets more efficient.

   This relates to increasing the uniformity in the management area, thus decreasing the required specific knowledge and components.

2. Standards are adaptable to include norms and guidelines, such as sustainability, that emerge in the following years.

Standards should not become obsolete before the investments are returned and benefits are noticed in the R&R process. Because of this, the standards should be adaptable to fit new norms and guidelines without drastically changing the standard.

The Program of Ambitions at System Level is summarised in Table 3.4.

**Table 3.4:** Program of Ambitions at a System Level

| **Program of Ambitions (System Level)** |
|---|
| **O - OPERATION** |
| The operation phase is improved by making management (operation, planning) and maintenance more efficient. |
| |
| **A - ADAPTIBILITY** |
| Standards can be adapted to fit new norms and guidelines that emerge in the following years. |

## 3.3. Step 2 - Prioritisation of Assets

The hypothesis is that standardisation can contribute to the improvement of the R&R process. However, Waternet has a management area of over 4000 technical assets, as shown in Figure 3.3. As described in Section 2.2.3, a selection of assets is chosen as a starting point for the standard development. This selection is based on priority, potential, and technical characteristics of assets. This will most likely result in more efficient standards and, in addition, will make it possible to assign created standards to other assets if it is found that they share similar technical characteristics. For this, the priority and the standardisation potential of the assets is considered. The detailed method of Step 2 is repeated in Figure 3.4 along with a simplified representation of the General Decision Method.

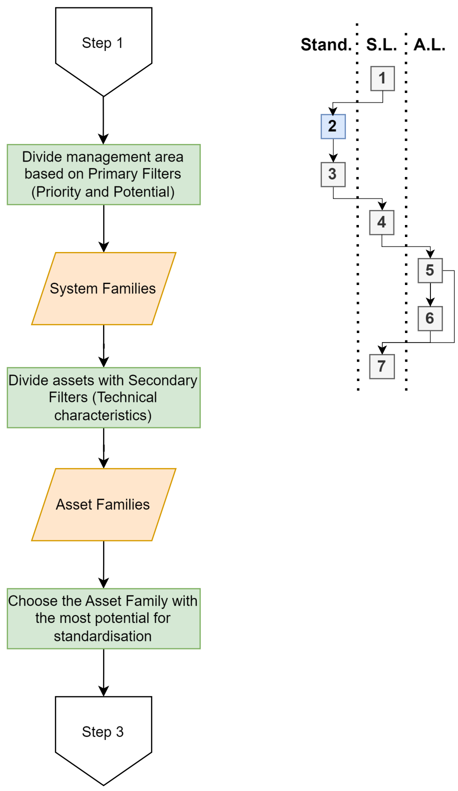



**Figure 3.4:** Step 2 - Prioritisation of Assets

#### Filter the management based on Priority and Potential

Based on priority and potential, the management area can be divided into groups called 'System Families'. Priority relates to the current condition of assets, while potential relates to the similarities of components in different assets.

- **Priority**: Within the management area, there are assets that are due for R&R, while others still have a longer remaining service lifetime. Creating standards for assets that are still in good condition will not solve the issue of the gap between the required condition and the current condition. However, for some assets the risk in case of failure is larger than for others, creating a priority difference. In the Masterplan, this assessment was based on the asset type, as shown in Table 3.1.

  In the Masterplan, the first step in assigning priority was creating a distinction between more and less monetary-intensive assets. The more monetary-intensive assets were assessed individually, while the less monetary-intensive assets were assessed as groups. In addition, for the individually assessed assets, an LTAP was created to gain further insight into the effect of the gap between required and current conditions. This distinction will be applied for the priority of System Families as well.

- **Potential**: Similarity between assets helps to create efficient standards. However, creating standards for almost identical assets will not address the issue of fragmentation. So, some similarity is required, but the assets should not be identical.

  The fragmentation issue is also present between assets of the same type, such as shown with the locks of MWW (Rijkwaterstaat, 2015). This leads to unique components and specific knowledge for many assets while they fundamentally perform the same function, possibly under similar conditions. Because of the possibility of similar boundary conditions, asset type is applied as a filter.

  Finally, it is assumed that implementing a standard into a larger number of assets will accumulate more benefits than for a small number of assets. The reason is that involved parties (e.g. contractors, design team) will become familiar with the standard and will optimize their process to implement it, saving time and budget. If the process is optimised for a group of 100 assets, ten times more, the same steps have to be taken than for a group of 10 assets. So, as a starting point, the largest group of assets is taken.

Applying these first two filters, monetary value and asset type, results in the 17 System Families presented in Figure 3.5. Taking into account only the more monetary-intensive assets and defining the priority based on Table 3.1 showed that emergency bridges and windmills were in poor to very poor condition, resulting in high priority. However, these System Families consist of only 6 and 3 assets, respectively. This creates little standardisation potential, and an individual approach is more fitting. The same holds for siphons (13 assets), cut-offs (14 assets), and navigation locks (17 assets). However, for System Families with a fair to moderate condition score, the pumping stations show standardisation potential with 217 assets present. Because of this combination of both potential and priority, System Family 1 is chosen to consider further.

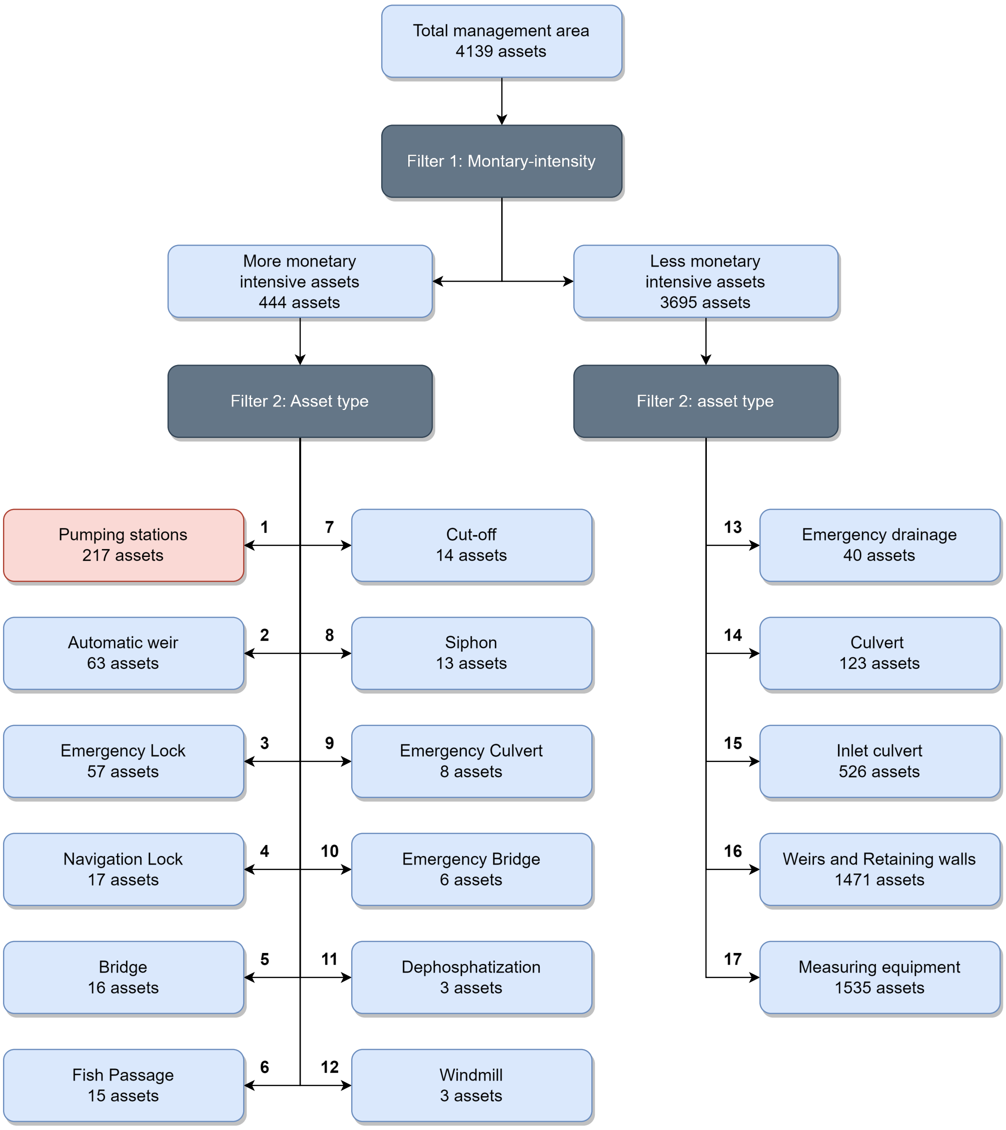



**Figure 3.5:** Distribution of assets into System Families

### Filter the chosen System Family based on Technical characteristics

System Family 1, pumping stations, contains 217 assets. This shows standardisation potential, and the current condition score shows priority. However, a further selection should be based on the technical characteristics of assets. This creates the possibility of applying the standards to other assets outside of the selection in case they share similar technical characteristics.

More monetary-intensive assets typically require more engineering, which is a large cost factor within R&R. The amount of engineering is partially determined by the size of the asset. Waternet distinguishes between pumping stations based on their capacity: Small ($Q < 167$ l/s), Medium (167 l/s $< Q <$ 1250 l/s), and Large ($Q >$ 1250 l/s). Of the 217 pumping stations, 134 are small, 56 medium, and 27 large (Waternet, 2022). Small assets require less engineering than large assets. This decreases the potential for standardisation. In addition, Table 3.1 showed that the condition level of small pumping stations is higher than that of medium or large pumping stations. Because of this, while the small pumping stations have the largest presence, they are not considered further.

Double the number of medium-sized pumping stations are present compared to large pumping stations, increasing the standardisation potential. Large pumping stations typically require more engineering than medium pumping stations. However, this is due to typically more unique and more strict boundary conditions prevailing, limiting standardisation possibilities. Because of this, medium-sized pumping stations are considered.

Besides size, pumping stations are typically characterised by their location. The location of a pumping station defines boundary conditions for the design, such as ground type. Choosing assets located at the same polder or waterway could decrease the number of diverse boundary conditions. However, it also limits the number of assets, decreasing the potential. Selecting one boundary condition, such as the water level difference, defines one of the most important boundary conditions for a pumping station while still taking into account a large number of assets for standardisation.

For the medium-sized pumping stations, the water level difference (WLD) for 44 out of 56 assets has been determined, see Figure 3.6 and Appendix C.4. These values are based on the prescribed established water levels by AGV (Waternet, 2023a).

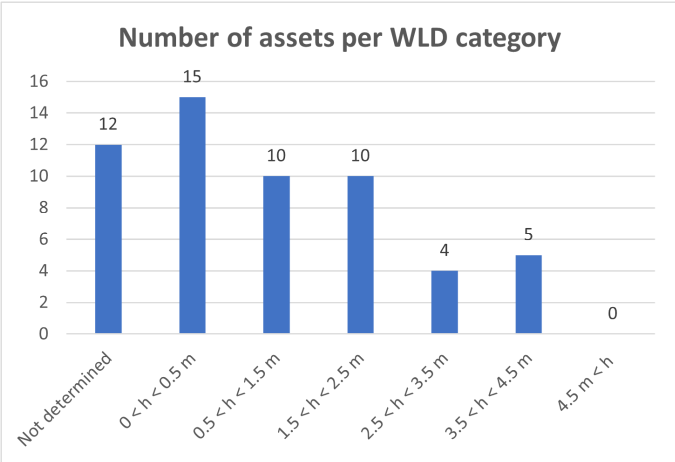



**Figure 3.6:** Water Level Difference (Waternet, 2023a)

Typically, the amount of engineering required increases with the WLD. To limit the amount of engineering while retaining the standardisation potential, a range within the WLD is chosen. For this, the WLD's divided into four categories: not determined, lower than 0.5 m, between 0.5 m and 2.5 m, and higher than 2.5 m. These also define the boundaries of the Asset Families, see Figure 3.7. Asset Family number 3 is selected, consisting of 20 assets. The location of the assets is shown in Figure 3.8.

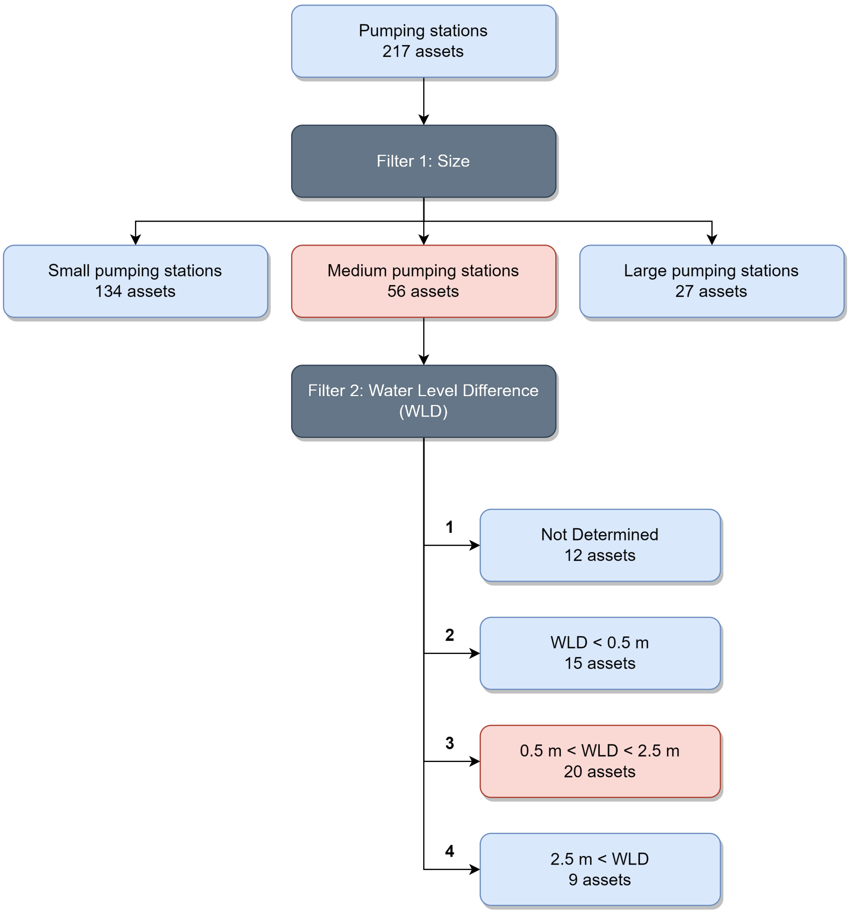



**Figure 3.7:** Distribution of assets into Asset Families

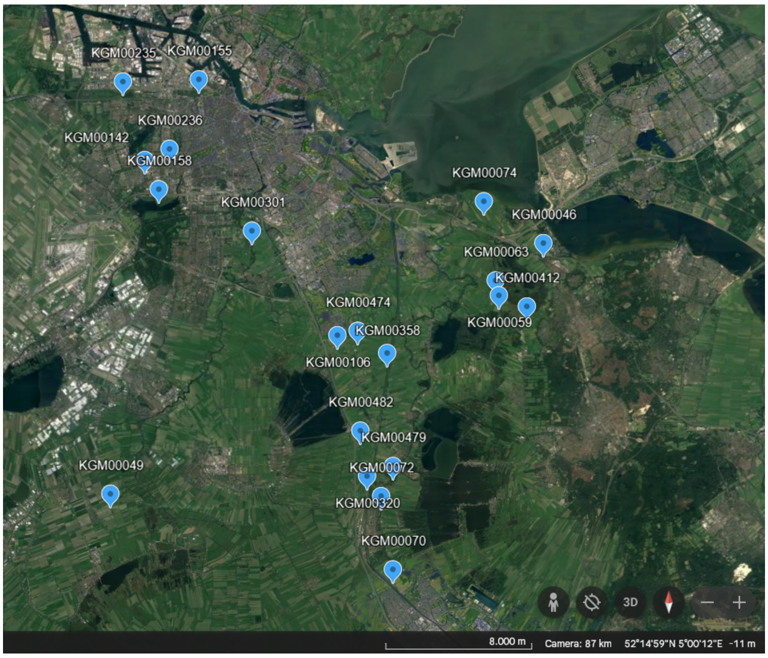



**Figure 3.8:** Locations of the assets in the chosen Asset Family (Google, 2016-2023)

## 3.4. Step 3 - Standard Development

This section covers the standard development for the chosen Asset Family of 20 assets. The detailed method of Step 3 is repeated in Figure 3.9 along with a simplified representation of the General Decision Method.

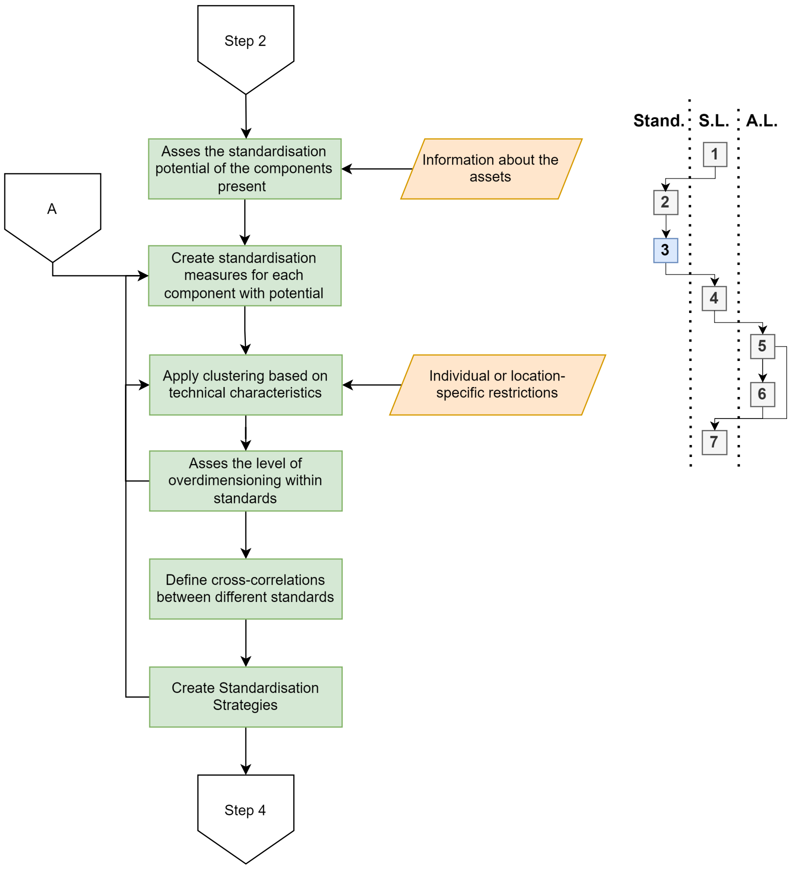



**Figure 3.9:** Step 3 - Standard Development

### Assess the potential of the components present

The function of a pumping station is to regulate the water levels in two bodies of water by pumping water from one to another. Each component of a pumping station can be categorised into one of the four categories introduced in the System analysis: Civil Engineering (CIV), Mechanical Engineering (ME), Electrical Engineering (EE), and Process Automatisation (PA).

This thesis focuses on the R&R process and considers an asset due for R&R if components in the CIV or the ME category are at their end of service lifetime. It is assumed that components related to EE and PA can be replaced without R&R being required for the entire asset.

For each component, an assessment should be made to determine whether there is standardisation potential. As argued in Step 3 of Section 2.3, the most potential is in components with a shorter service lifetime requiring frequent maintenance. For this case study, first, the categories are regarded before moving on to individual components.

Civil Engineering components are designed for a service lifetime of 50 years. In case the civil structure reaches its end of service lifetime, the entire structure is replaced. This is a significant investment that does not occur very often. In addition, the boundary conditions of the Civil Structure are highly location-specific. For example, the soil is different for each location, which influences the type of foundation. This results in few similarities between locations. The combination of a longer service lifetime and few similarities between assets results in low standardisation potential for CIV components.

Components related to EE or PA have a shorter service lifetime, 8-13 years, and require maintenance more often, creating a considerable potential for standardisation. However, Waternet has already started creating standards for PA, called the 'Upgrade modems legacy' project (AGV, 2022). In addition, assets are not identical, EE components are largely standardised and easily replaced in case of failure. This reduces the need for standard creation (AGV, 2022).

ME components have a service lifetime of up to 25 years. This case study regards an asset due for R&R if the CIV or ME components are at their end of service lifetime. As the service lifetime of ME components is half that of CIV components, creating standards for the ME components is desired. This way, the components can be replaced one-on-one to avoid having to R&R the entire asset. In addition, the boundary conditions that define ME components are more similar, as they are related to the hydraulic conditions. The Asset Family is chosen based on the similar water level difference, creating the potential for standardising ME components.

Moreover, within ME, the heart of the pumping station is the pump. The pump influences many other design decisions, such as the required foundation or dimensions of the pumping station. There are many types of pumps, with multiple configurations to implement them. Within the Asset Family of 20 assets, there are five types of pumps present, see Table 3.5. However, the same type of pump does not mean the same identical pump, see Appendix C.3. There are still differences in execution due to different manufacturers being used, thus requiring unique components and maintenance strategies. This results in specific knowledge being required, as described within the fragmentation issue. Because of the large variations in pump type resulting in the fragmentation issue and the pump influencing other design parameters, this case study focuses solely on the standardisation of the pump.

For three pumping stations, no information is available on the current type of pump. Because of this, no estimations can be made about the boundary conditions, and thus, they are not considered further in the case study.

**Table 3.5:** Pumptype per pumping station

| KIN-number | Pump category | Number of pumps |
|---|---|---|
| KGM00106 | Archimedean Screw pump | 1 |
| KGM00358 | Archimedean Screw pump | 1 |
| KGM00474 | Archimedean Screw pump | 1 |
| KGM00046 | Propellor pump (dry set-up) | 2 |
| KGM00049 | Propellor pump (dry set-up) | 2 |
| KGM00070 | Propellor pump (dry set-up) | 2 |
| KGM00236 | Propellor pump (dry set-up) | 1 |
| KGM00059 | Shaft pump (dry well set-up) | 2 |
| KGM00155 | Shaft pump (dry well set-up) | 1 |
| KGM00235 | Shaft pump (dry well set-up) | 2 |
| KGM00142 | Submersible propeller pump (wet-well setup) | 2 |
| KGM00158 | Submersible propeller pump (wet-well setup) | 2 |
| KGM00482 | Submersible propeller pump (wet-well setup) | 2 |
| KGM00063 | Vertical Centrifugal pump | 2 |
| KGM00072 | Vertical Centrifugal pump | 2 |
| KGM00074 | Vertical Centrifugal pump | 2 |
| KGM00301 | Vertical Centrifugal pump | 1 |
| KGM00320 | No information available | |
| KGM00412 | No information available | |
| KGM00479 | No information available | |

### Create standardisation measures for each component with potential

The various types of pumps make R&R, but also maintenance and operation, more complex as unique solutions are required each time. By decreasing the possible type of pumps to only one, the fragmentation is reduced immensely. An Archimedean Screw Pump (ASP) is chosen because of its high reliability, low maintenance required due to little wear, low operating costs, and a large range in capacity (Spaans Babcock, 2017b).

In general, ASPs are tailored to each specific situation. However, the aim is to standardise using already standardised components. For this, Spaans Babcock's 'quick selection' is used; this selection is based on the required capacity and head and gives an outside diameter for the ASP, see Appendix C.6 (Spaans Babcock, 2017a).

In order to select a pump from the quick selection, the required capacity and the head difference between the two bodies of water are determined.

**Capacity**

Information about the discharge is gathered from Waternet to determine the required capacity of each pumping station, see Table 3.6. The period over which the discharge is known differs for each location. The probability of exceedance is prescribed by law for all hydraulic assets. For non-primary defence structures, it ranges from once every ten years to once every 100 years (Overheid.nl, 2019). For this, measured values are taken to determine the maximum discharge and transformations are applied to include climate change. The normative discharge is assumed to be present in the given period and can be used as the required capacity for the ASP.

The maximum measured discharge for each pumping station, with periods ranging from 90 to 804 days, is presented in Table 3.6. No information is available on the discharge of two pumping stations, KGM00074 and KGM00235. As no estimates can be made about the applicability of the ASP without current information available, they are not considered further. This leaves the Asset Family consisting of 15 assets.

**Table 3.6:** Maximum measured discharges for varying time periods

| KIN-number | $Q_{max,total}$ [$l/s$] | $Q_{max,pump1}$ [$l/s$] | $Q_{max,pump2}$ [$l/s$] | $\Delta T$[days] |
|---|---|---|---|---|
| KGM00046 | 378 | 198 | 180 | 374 |
| KGM00049 | 350 | 175 | 175 | 374 |
| KGM00059 | 1067 | 533 | 533 | 374 |
| KGM00063 | 465 | 223 | 242 | 804 |
| KGM00070 | 433 | 433 | n.a. | 804 |
| KGM00072 | 609 | 305 | 305 | 352 |
| KGM00074 | No information available | | | |
| KGM00106 | 1179 | 1179 | n.a. | 779 |
| KGM00142 | 691 | 346 | 346 | 778 |
| KGM00155 | 367 | 367 | n.a. | 804 |
| KGM00158 | 660 | 330 | 330 | 778 |
| KGM00235 | No information available | | | |
| KGM00236 | 513 | 513 | n.a. | 793 |
| KGM00301 | 440 | 440 | n.a. | 775 |
| KGM00358 | 833 | 833 | n.a. | 804 |
| KGM00474 | 375 | 375 | n.a. | 90 |
| KGM00482 | 667 | 333 | 333 | 667 |

**Head difference**

For the head difference, two simplified scenarios are considered. The first is that only the horizontal length of the ASP is sufficient to connect the two bodies of water (Figure 3.10a). The second is that the horizontal distance between the two bodies of water is too large and must be bridged by an additional pipeline combined with a cistern at the end of the ASP (Figure 3.10b).

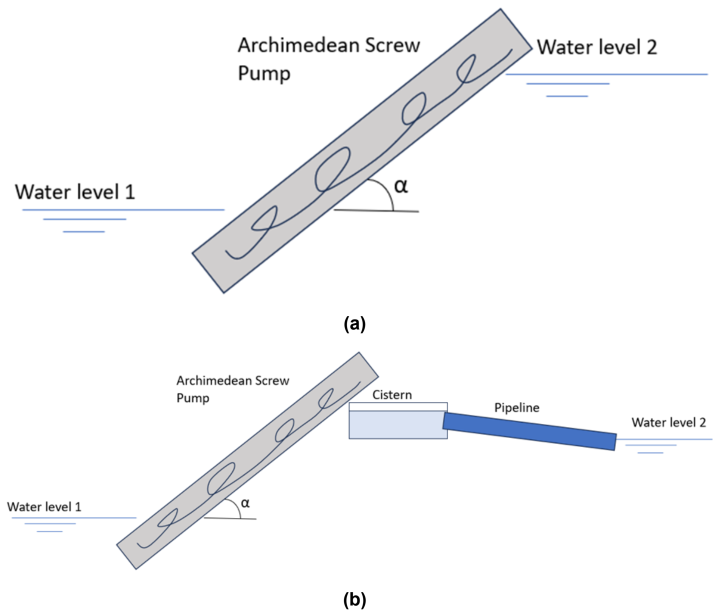



**Figure 3.10:** Sketch: possible scenarios of Archimedean screw pump with and without pipeline

The two scenarios result in different total head losses as there are additional components in case the horizontal distance is too large (Figure 3.10b).

For both scenarios, the water level difference is considered as well as head losses due to obstructing components. This includes the trash rack, which keeps debris out of the ASP, or the in- and outlet valves. Head losses related to the ASP itself are neglected, such as inflow into the upper water level or into the cistern. For Figure 3.10b, besides the water level difference and head loss due to obstructing components, head losses due to friction in the pipeline and in and outflow are considered.

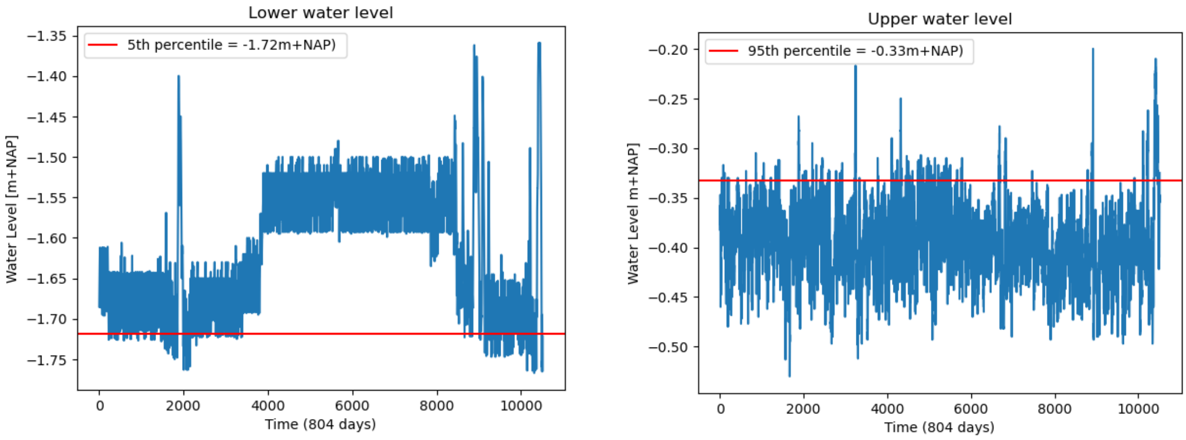
This results in the following (simplified) head loss calculations:

- Only the ASP: Head loss = Water level difference (A) + Head loss due to obstructing components (D)
- ASP with cistern and pipeline: Water level difference (A) + Head losses due to in- and outflow (B) + Head losses due to friction in the pipelines (C) + Head loss due to obstructing components (D)

First, the water level difference (A) is determined for each location. Similar to the capacity, the design water level is designed to include climate change and extreme weather conditions. The normative water levels are assumed to be present in the available data.

A disadvantage of an ASP is the sensitivity to fluctuating water levels. If the lower water level becomes too low for the ASP to reach, no water can be pumped to the upper water body. In addition, back flow will occur through the ASP if the upper water level becomes too high. To limit the possibility of these situations, the 5th percentile of the measured lower water level and the 95th percentile of the measured upper water level are taken. The difference between these values is the normative water level difference considered for the head loss calculations.

For example, Figure 3.11 shows the upper and lower water level over a period of 804 days for KGM00070. The 5th percentile is at -1.72m+NAP, and the 95th percentile is at -0.33m+NAP, resulting in a normative water level difference of 1.39 m. Appendix C.4 shows the normative water level differences for each pumping station.




**(a)** Upper Water Level

**(b)** Upper Water Level

**Figure 3.11:** Water level variations for KGM00070

For the Head Loss due to in- and outflow of the pump or pipeline $H_{inoutflow}$ (B) and due to friction in the pipeline $H_{friction}$ (C), the following assumptions and requirements about the pipeline are made:

- Assumptions:
  - Fully developed steady flow;
  - No bends in the pipeline;
  - The in- and exit is 90 degrees;
  - No added pressure in the pipeline; from the entrance to the exit;
  - Diameter of the pipe is 1.0 or 1.2 m.
- Requirements:
  - The flow velocity must be below 1 m/s to avoid bottom protection, in case $U_pipe > 1$, another pipeline is added.
  - $H_{inoutflow}$ must be below 10 cm, if not: another pipe is added or D increased. $H_{inoutflow}$ is calculated as follows (Elger et al., 2016):

$$\Delta H_{inoutflow} = (K_{e-entrance} + K_{e-exit}) * \frac{U^2}{2g} \tag{3.1}$$

with $K_{e-entrance} = 0.5$, $K_{e-exit} = 1.0$ and calculated as follows (Elger et al., 2016):

$$U = \frac{Q}{\frac{1}{4}\pi D^2} \tag{3.2}$$

  - $H_{friction}$ must be below 15 cm, if not: another pipe is added or D increased. $H_{friction}$ is calculated as follows(Elger et al., 2016):

$$H_{friction} = f\frac{L}{D}\frac{U^2}{2g} \tag{3.3}$$

with f=0.02 (Elger et al., 2016).

An example calculation and all values for the required number of pipes, diameter, $H_{inoutflow}$, and $H_{friction}$ can be found in Appendix C.5.

For head loss due to obstructing components (D), a standard value of 0.2 m is chosen. Summing all head losses (A+B+C+D) leads to the values shown in Table 3.7.

**Table 3.7:** Total head difference for each pumping station

| KIN-number | A | B | C | D | $H_{total}$ |
|---|---|---|---|---|---|
| | $H_{WL_{difference}}$ | $H_{inoutflow}$ | $H_{friction}$ | $H_{additional}$ | |
| KGM00046 | 1.29 | 0.04 | 0.01 | 0.2 | 1.34 |
| KGM00049 | 0.69 | 0 | 0 | 0.2 | 0.69 |
| KGM00059 | 1.21 | 0.07 | 0 | 0.2 | 1.28 |
| KGM00063 | 1.91 | 0.07 | 0.02 | 0.2 | 2.00 |
| KGM00070 | 1.39 | 0 | 0 | 0.2 | 1.39 |
| KGM00072 | 1.26 | 0.05 | 0.02 | 0.2 | 1.33 |
| KGM00106 | 2.64 | 0 | 0 | 0.2 | 2.64 |
| KGM00142 | 0.81 | 0.06 | 0.05 | 0.2 | 0.92 |
| KGM00155 | 1.65 | 0 | 0 | 0.2 | 1.65 |
| KGM00158 | 1.36 | 0.06 | 0.01 | 0.2 | 1.43 |
| KGM00236 | 1.76 | 0.04 | 0.03 | 0.2 | 1.83 |
| KGM00301 | 2.31 | 0.06 | 0.01 | 0.2 | 2.38 |
| KGM00358 | 2.28 | 0 | 0 | 0.2 | 2.28 |
| KGM00474 | 2.50 | 0 | 0 | 0.2 | 2.50 |
| KGM00482 | 2.23 | 0.06 | 0 | 0.2 | 2.29 |

Figure 3.12 shows the total head versus the required capacity of each pumping station, together with the current types of pump.

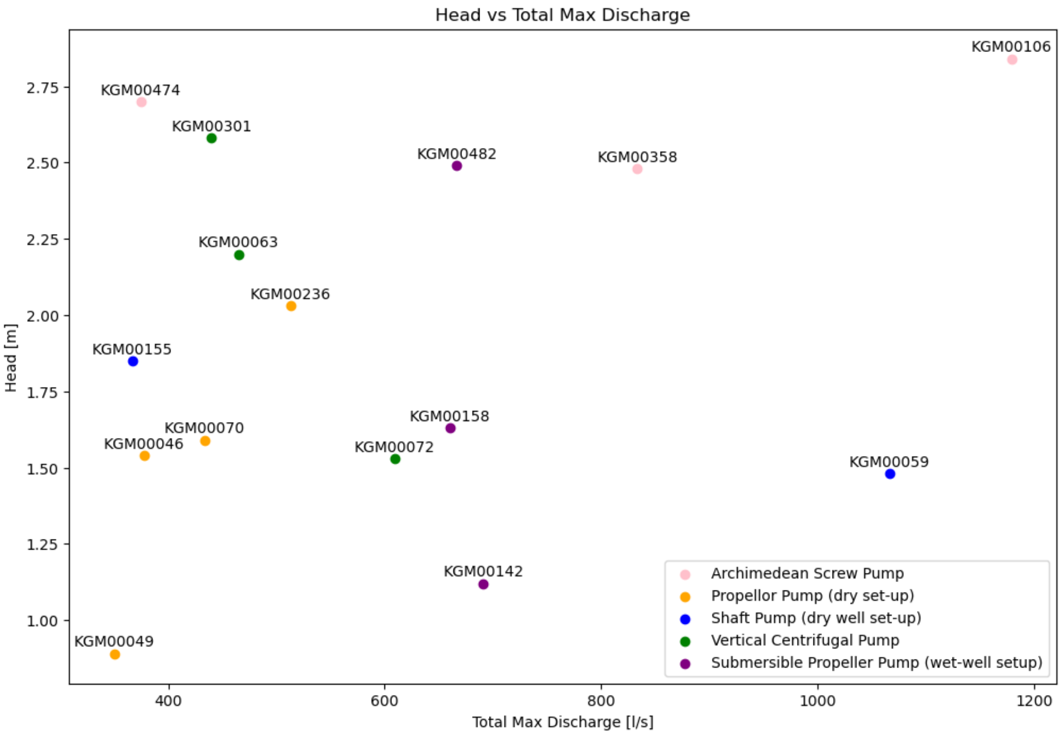



**Figure 3.12:** Required head [m] vs. Required capacity [l/s] per pumping station

### Apply clustering based on technical characteristics

Cluster parameters are required to create clusters. This parameter is based on the technical characteristics of the standard and asset. Three possible parameters for ASPs are the angle, head, and capacity.

With an individual approach, the angle of the ASP can be tailored to the specific situation. However, in the quick selection of Spaans Babcock (App C.6), there is a choice between 30, 35, and 38 degrees. This is because the optimum angle for an ASP lies between 30 and 38 degrees. The 30-degree ASP is most optimal, but more horizontal space is required to obtain the same head with a 30-degree pump as with a 38-degree pump. For this case, the assumption is made that for all locations, enough horizontal space is available for the construction of a 30-degree angle ASP.

In case the head difference is selected as the cluster parameter, the highest head of each cluster defines the length of the ASP. However, the lift for the lower heads would be too high, and the water would be 'dumped' at the top to the required water level. Lifting water higher than required is inefficient and uses more material than needed, affecting the sustainability of the design.

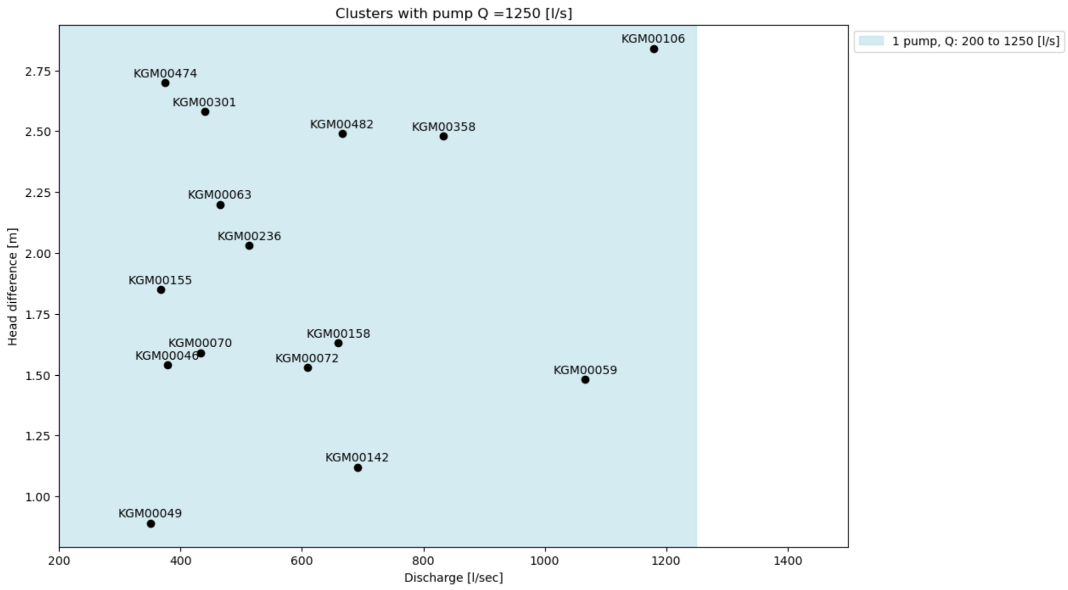
The capacity influences the diameter of the ASP, and the same diameter can be used for various head differences. While using an ASP with a larger capacity than required results in more material used than necessary, it is expected that more optimisations are possible for the clusters based on capacity than clusters based on head difference. Because of this, the capacity is selected as the cluster parameter.

Besides a clustering parameter, cluster requirements are set to define whether the cluster suffices:

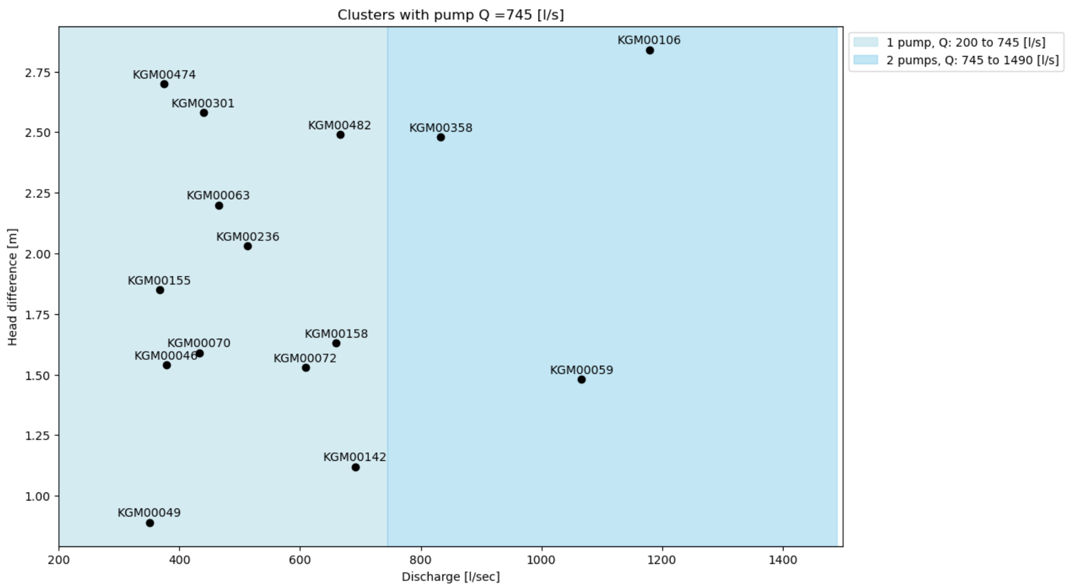
1. At least three assets should be part of a cluster for it to be defined as a cluster.
2. At least 75% of the assets should be in a cluster, with it being accepted if 25% is classified as a Custom Project.

In an ideal situation, one cluster would fit all assets without resulting in unreasonable overdimensioning. The normative pumping station is KGM00106 with a required capacity of 1180 l/s. By increasing the number of pumps and placing them next to each other, the required capacity of each pump decreases. This way, not the same number of pumps has to be placed at each pumping station, limiting overdimensioning. As a first estimation, either one, two, or three parallel pumps are considered:

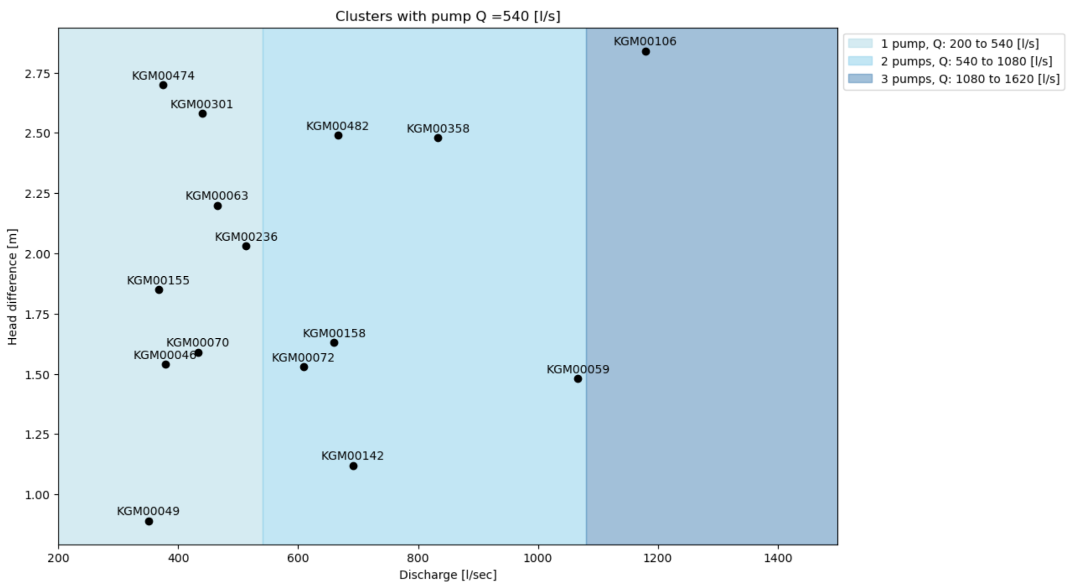
1. If only **one pump** is placed, the required capacity is at least 1180 l/s to fit KGM00106. Looking at Appendix C.6 at an ASP with a minimum capacity of 1180 l/s and a 30-degree angle, a diameter of 2000 mm is the first possible option with a capacity of 1250 l/s. With this distribution, all assets are in the same cluster, as shown in Figure 3.13a. This way, both the first and second cluster requirements are met.
2. Placing **two pumps** would require a capacity of at least 590 l/s per pump. The pump with a diameter of 1600 and a capacity of 745 l/s can be applied. This results in 2 clusters, see Figure 3.13b. Cluster 1 only requires one pump, and Cluster 2 requires two pumps. Both clusters contain three assets (req. 1), and all assets are part of a cluster (req. 2).
3. With **three pumps**, the required capacity is 394 l/s per pump. For this the pump with a diameter of 1400 and a capacity of 540 l/s is chosen, resulting in three clusters, see Figure 3.13c. With this distribution, all assets are in a cluster and Cluster 1 and Cluster 2 both consist of at least three assets. However, Cluster 3 only consists of one asset, not meeting requirement 1. However, with only one asset not being part of a cluster, requirement 2 is still met.




**(a)** One pump with Q = 1250 l/s




**(b)** Two pumps with Q = 745 l/s




**(c)** Three pumps with Q = 540 l/s

**Figure 3.13:** Clusters based on the normative asset

### Asses the level of overdimensioning within standards

Assessing the level of overdimensioning is a consideration between the chosen pump and the number of clusters. For this case, overdimensioning is defined by the efficiency of the pump. The efficiency of the pump is related to the rounds per minute (rpm) it performs. The capacity is, by approach, directly proportional to the rpm. So, the same pump can applied to obtain lower or larger capacities. However, if the pump performs above its capacity, the centrifugal force can become too large, trapping water in the pump. On the other hand, if the rpm is too low, leakage of water through the gap between the screw and the housing can occur. To ensure the efficiency does not drop too low for either of these scenarios to occur, an upper and lower limit is chosen:

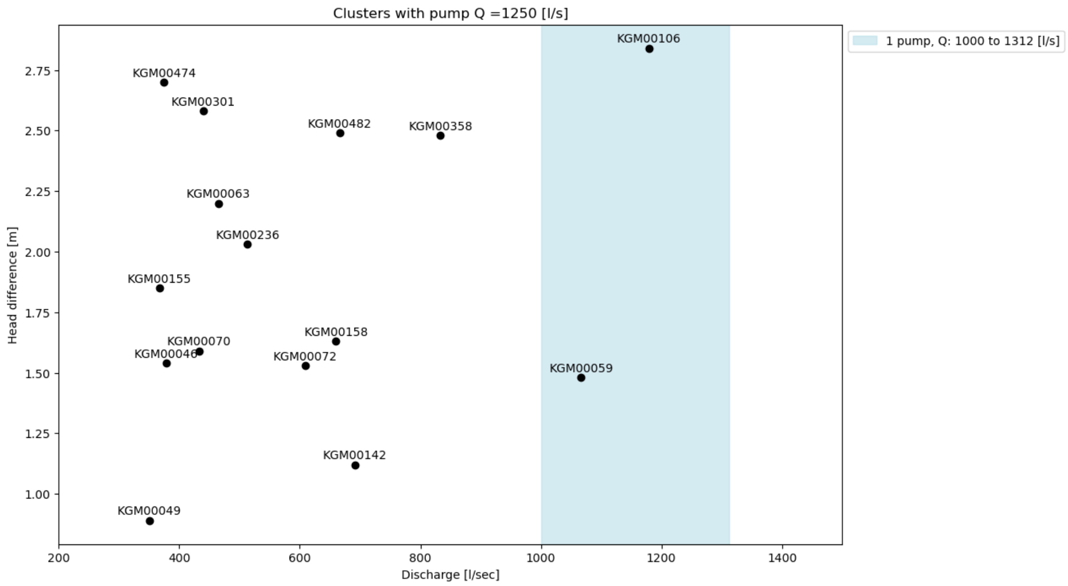
- Lower limit: 80% of the given capacity
- Upper limit: 105% of the given capacity

Adding these boundary conditions to the pumps chosen in Figure 3.13, gives the values presented in Table 3.8.

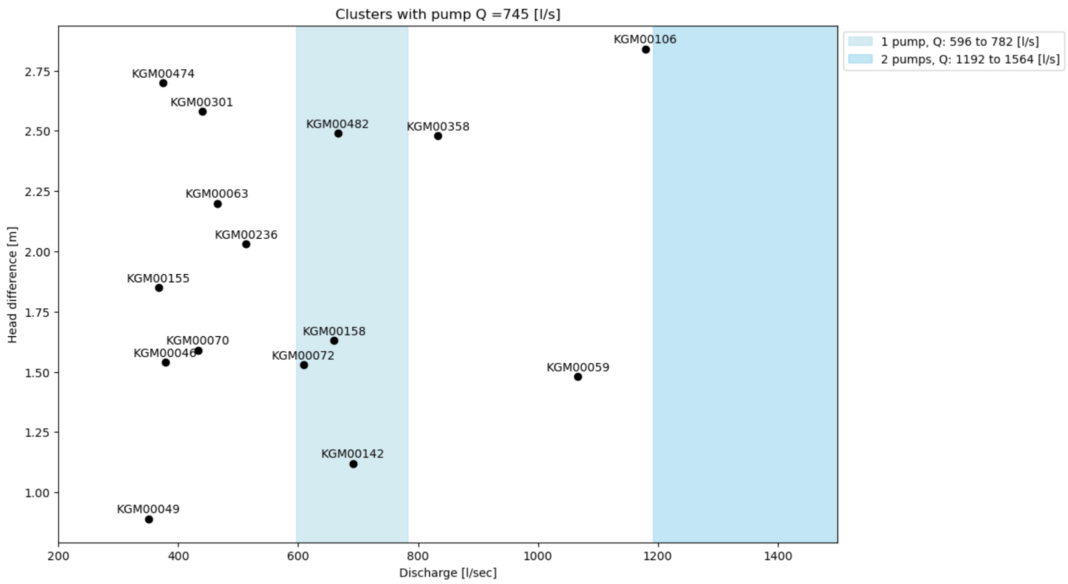
**Table 3.8:** Boundaries of used pumps

| Number of pumps | Given Capacity [l/s] | 80% [l/s] | 105% [l/s] |
|---|---|---|---|
| 1 | 1250 | 1000 | 1313 |
| 2 | 745 | 596 | 782 |
| 3 | 540 | 432 | 567 |

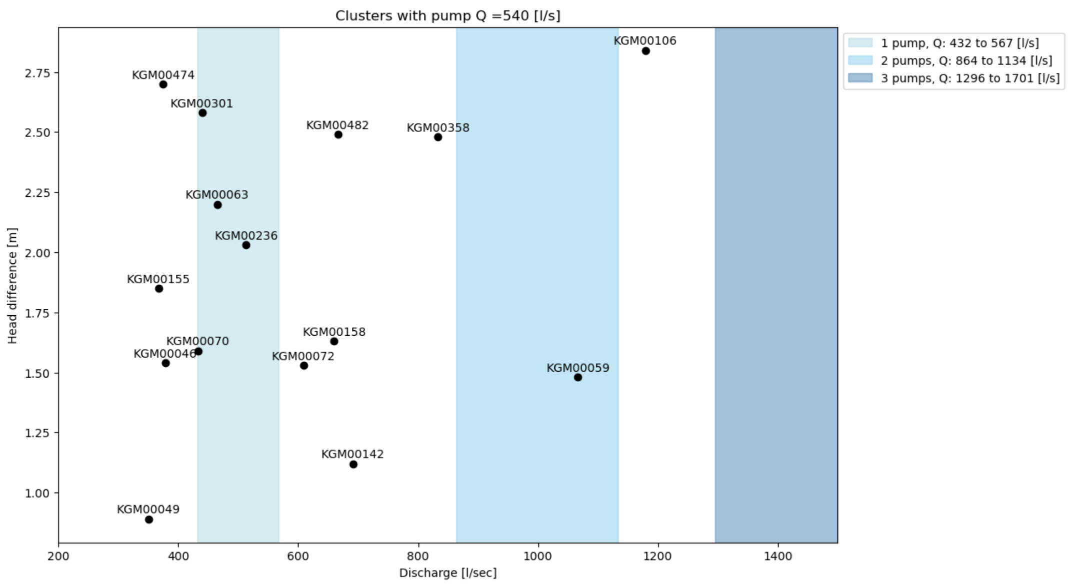
With the efficiency boundary conditions, the clusters shown in Figure 3.14 are obtained. For no configuration of either 1, 2, or 3 pumps, both clustering criteria are met. The only clusters that satisfy criteria 1, at least three assets, are using one pump of Q=745, and one pump of 540 l/s. However, even if these two clusters were both adapted, only 8 of 15 assets would be part of a cluster, not satisfying cluster requirement 2, at least 75% of assets in a cluster. Because of this, an iteration is required with a different approach.




**(a)** One pump with Q = 1250 l/s including efficiency




**(b)** Two pumps with Q = 745 l/s including efficiency




**(c)** Three pumps with Q = 540 l/s including efficiency

**Figure 3.14:** Clusters taking into account efficiency

### Iteration - Apply clustering based on technical characteristics

In this iteration, instead of taking the normative asset (KGM00106) as the guiding asset, the smallest asset, KGM00049, with a required capacity of 350 l/s, is chosen.

The approach of placing the same pump in parallel to increase the capacity still remains. The pump that has the capacity to fit KGM00049 has a diameter of 12000 mm and a capacity of 380 l/s. Figure 3.15 shows the provided capacity with either 1, 2, or 3 pumps.

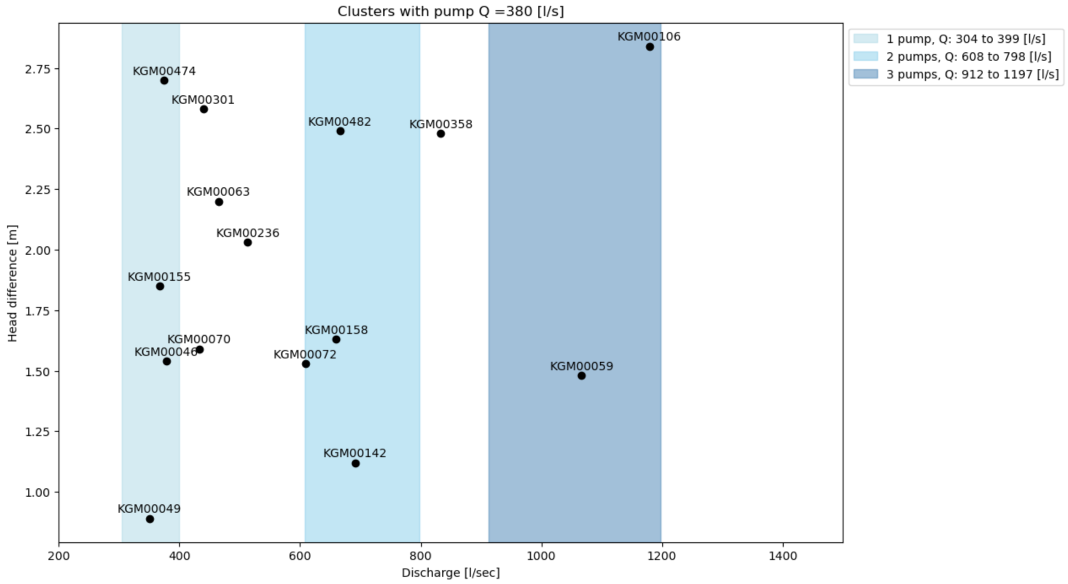



**Figure 3.15:** one, two, or three pumps with Q=380l/s

The third cluster only consists of two assets, not meeting the first cluster requirement (at least three assets). If only the clusters with one and two pumps are taken, 7 assets remain as Custom Projects, which is more than 25%. Because of this, a second pump with a different size is considered: 540 l/s with a diameter of 1400 mm. This is the first cluster of Figure 3.14c. Combining the clusters of 1 or 2 pumps with a capacity of 380 l/s and 1 pump with a capacity of 540 l/s results in Figure 3.16.

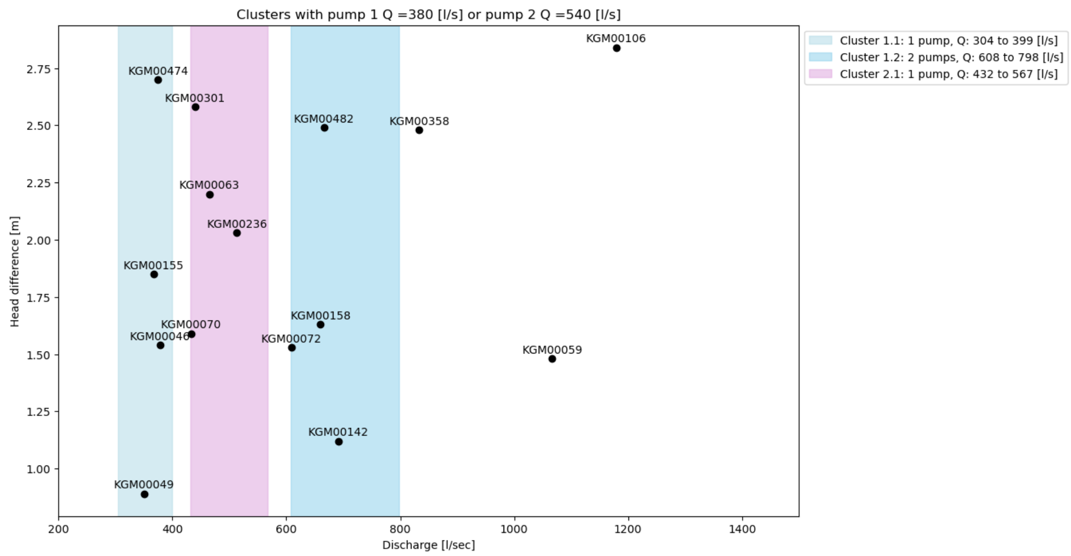



**Figure 3.16:** Clusters with two types of pump, $Q_1$ = 380 l/s, $Q_2$ = 540 l/s

Figure 3.16 shows three clusters where two types of pumps are implemented. The first cluster 'Cluster 1.1' has one pump with a capacity of 380 l/s and a diameter of 1200. 'Cluster 1.2' uses the same pump as Cluster 1.1 but uses two pumps in parallel instead of one. 'Cluster 2.1' has one pump with a capacity of 540 l/s and a diameter of 1400. With this cluster approach, both cluster requirements are met while considering the efficiency boundaries: each cluster contains 4 assets, and 12 of 15 assets (80%) are part of a cluster. Three assets (KGM00059, KGM00106, and KGM00358) are not part of a cluster classified as a Custom Project. For these assets, an individual approach is taken. Table 3.9 summarises the created clusters, chosen pumps, and efficiency boundaries. As Custom Projects are not part of a cluster, no predefined design choices are given for these assets.

**Table 3.9:** Technical details and included pumps per cluster

| Cluster | Outside diameter [mm] | Q [l/s] | Efficiency Boundaries 80%-105% | Pumping stations |
|---|---|---|---|---|
| 1.1 | 1200 | 380 | 304-399 l/s | KGM00046, KGM00049, KGM00155, KGM00474 |
| 1.2 | 1200 | 380 | 608-798 l/s | KGM00072, KGM000142, KGM00158, KGM00482 |
| 2.1 | 1400 | 540 | 432-567 l/s | KGM00063, KGM00070, KGM00236, KGM00301 |
| C.P. | n.a. | n.a. | n.a. | KGM00059, KGM00106, KGM00358 |

### Define cross-correlations between different standards

In this Standard Development, the entire method is executed for only one component: the pump. However, the steps carried out for the pump should also be carried out for the other components. This would result in one or multiple standards being available for the other components. If this is done, one or multiple standards are available for all components. However, not all components can be designed individually without influencing other components. Because of this, the cross-correlations have to be defined between the standards.

The first substep of Step 3, Assess the potential of the components present, discusses the standardisation potential for each category (CIV, ME, EE, PA). It is concluded that the standardisation potential for CIV is too low, as the service life is too long and the boundary conditions are too different. However, it is also concluded that while EE and PA have more potential for standardisation, the priority is lower. This case study does not include the creation of PA or EE standards or investigating what type of PA/EE components are optimal for ASP's. An assumption of standards for EE and PA is made to give insight into the possible cross-correlations. Two standards are assumed for PA, one suitable for the ASP, while the other is not. For EE, it is assumed two standards are suitable for the ASP. Both standards for EE can be applied in combination with one of the PA standards. The standards and cross-correlations are summarised in Figure 3.17.

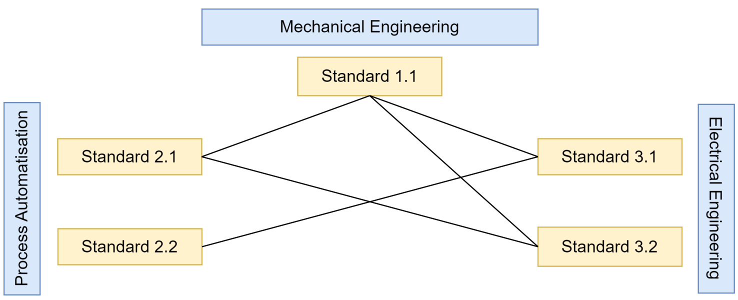



**Figure 3.17:** Assumed cross-correlations between created ME standard and potential PA and EE standards

### Create Standardisation Strategies

Based on Figure 3.17, a choice is made about what standards to implement into the asset. Implementing multiple standards creates more uniformity in the management area. All the chosen standards should not obstruct the others. For example, Standard 3.1 can be implemented in combination with Standard 1.1 and 2.2, but the latter cannot be implemented with each other. In this example, the most significant number of standards applicable together is three: Standard 1.1 (Implementation ofASP clusters), 2.1 (PA standard) and 3.2 (EE standard). It should be noted that if more standards were created and multiple Standardisation Strategies with three standards could be chosen, all would continue to Step 4 - Evaluation of Standards at the System Level. However, in the situation presented in Figure 3.17, only one Standardisation Strategy consists of the maximum number of three standards. Because of this, only one Standardisation Strategy is considered further.

## 3.5. Step 4 - Verification and Evaluation of Standards at System Level

This section covers the verification and evaluation of the chosen Standardisation Strategy at the System Level. The detailed method of Step 4 is repeated in Figure 3.18 along with a simplified representation of the General Decision Method.

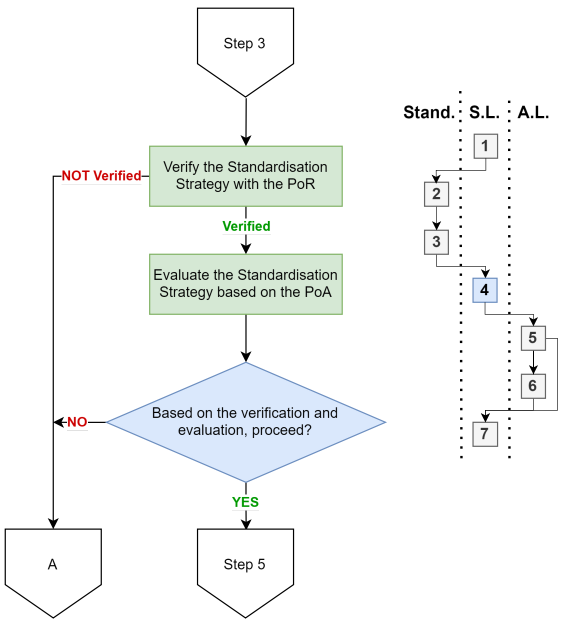



**Figure 3.18:** Step 4 - Verification and Evaluation of Standards at System Level

Before starting the verification and evaluation, the approach to both is described. Every organisation of the method can determine their approach to verification and evaluation. There is a choice between a quantitative or qualitative approach or a combination of both. For this case study, a semi-quantitative approach is taken. For each requirement and ambition, a consideration is made about the possible effects of the Standardisation Strategy. Next, a score is assigned to these effects, ranging from 1 (negative or no change) to 3 (extensive positive change). In addition, weighting factors are applied to differentiate between requirements and ambitions, ranging from 1 (less important) to 2 (very important). The chosen values, shown in Table 3.10, are indicative and would differ for each method user. These scores and weighting factors are presented in a Trade-off Matrix (TOM), combining the verification and evaluation.

**Table 3.10:** Indicative values scores and weighting factors

| | |
|---|---|
| **Score** | |
| 1 | Not at all: Negative or no change |
| 2 | Moderately: A noticeable but not overwhelming positive change |
| 3 | Extensively: A significant positive change |
| **Weighting Factor** | |
| 1 | Less important - Ambition |
| 2 | Very important - Requirement |

### Verify the Standardisation Strategy with the PoR

The verification determines if the chosen Standardisation Strategy satisfies the PoR described in Table 3.3. If this is not the case, alterations should be made to the standards or the Standardisation Strategy in an iterative jump to Step 3 - Standard Development. From Figure 3.17, the Standardisation Strategy containing the most standards is chosen. If more Standardisation Strategies containing the same number of standards were possible, all of these should be verified. Then the evaluation shows the most optimal Standardisation Strategy of the verified strategies.

For each requirement stated in Table 3.3, a semi-quantitative consideration is made on what score should be assigned to each requirement. A minimum score of 2 should be obtained for each requirement for a Standardisation Strategy to be deemed verified. It is important to note that this step verifies the considered Standardisation Strategy, not the entire asset. First the requirement is repeated, next a consideration made if the requirement is met, followed by the score.

- **Function**: **Assets can fulfil their respective function for the predetermined functional lifetime, taking into account future developments such as climate change.**

  For this Standardisation Strategy, this requirement relates to the functional lifetime of 25 years of the pump. In other words, the pump should be designed for the hydraulic conditions of 2050.

  The effects of climate change are increased water levels and larger rain showers (KNMI, 2023). If the water level increases, backflow could occur through the pumping station. Increasing the discharge of the pumping stations would influence the other assets connected to the water bodies. Taking the surrounding system into account is outside the scope of this thesis.

  It is assumed that an overcapacity of 5% is required for the effects of climate change to be considered handled sufficiently (RWS, 1987).

  Table 3.11 shows the currently required capacity of each pumping station, the maximum capacity of the chosen pump, and the allowed increase in required discharge.

**Table 3.11:** Available capacity for future developments

| KIN-number | Cluster | $Q_{max,required}$[l/s] | $Q_{max,cluster}$ [l/s] | $Q_{increase}$ [l/s] | $Q_{increase}$ [%] |
|---|---|---|---|---|---|
| KGM00046 | 1.1 | 378 | 399 | 21 | 5.3% |
| KGM00049 | 1.1 | 350 | 399 | 49 | 12.3% |
| KGM00155 | 1.1 | 367 | 399 | 32 | 8.1% |
| KGM00474 | 1.1 | 375 | 399 | 24 | 6.0% |
| KGM00072 | 1.2 | 609 | 798 | 189 | 23.6% |
| KGM00142 | 1.2 | 691 | 798 | 107 | 13.4% |
| KGM00158 | 1.2 | 660 | 798 | 138 | 17.3% |
| KGM00482 | 1.2 | 667 | 798 | 131 | 16.5% |
| KGM00063 | 2.1 | 465 | 567 | 102 | 18.0% |
| KGM00070 | 2.1 | 433 | 567 | 134 | 23.6% |
| KGM00236 | 2.1 | 513 | 567 | 54 | 9.5% |
| KGM00301 | 2.1 | 440 | 567 | 127 | 22.4% |

The required discharge is the maximum value measured in the chosen pump. This gives additional overcapacity on general days. For example, KGM00046 has the lowest overcapacity of all the pumping stations, with 5.1%. The maximum discharge was measured 51 out of 374 days, meaning that for 13.7% of the days, there exists an overcapacity of 5.1%, slightly above the minimum of 5%. Because not all assets are highly above the minimum, a score of 2 is assigned, a noticeable but not overwhelming positive change.

- **Time**: **The time it takes to replace and renovate (initiation, definition, design, preparation, and realisation) all assets due for R&R decreases after implementation of the standard compared to the current approach.**

  The time requirement is divided into the five phases that make up the R&R process. Each phase is considered and assigned a score. Then, the mean score is calculated to determine whether the Standardisation Strategy obtains the minimum score of 2.

  - The **initiation phase** is expected to become less time-consuming. The creation of clusters within an Asset Family makes more efficient prioritisation of those assets possible. Defining the prioritisation strategy on the resources of the asset management organisation ensures that enough is available when the asset reaches its end of service lifetime. This clarity results in an assigned score of 3.
  - The **definition phase** is expected to become less time-consuming as both the PoR and the PoA at Asset Level are partially predetermined due to the PoR and PoA at the System Level (Step 1 - System Analysis and Design Definition). However, it should be determined if no system-level requirements or ambitions conflict with ones at the individual Asset Level. On the other hand, with the same pump being applied in a cluster, personnel become familiar with possible bottlenecks and how to solve these. Because of this familiarisation, less time is spent on the definition of the design. These considerations result in an assigned score of 2.
  - This familiarisation is also essential for the **preparation phase**. Both executing parties and management will become more efficient if the same tasks are performed each time. The preparation phase can be further optimised with both the personnel and external parties being able to estimate preparation steps more accurately for each project. Because of this increased efficiency, a score of 3 is assigned.
  - Altering steel or concrete in civil structures is time-consuming regardless of the type of alteration. However, replacing a pump with a different type requires more extensive alterations than replacing one with the same type but with an updated model. Because of the alterations required to fit the ASP into each location, the **realisation phase** is affected and more time consuming. This additional work results in an assigned score of 1.

- **Budget: The TCO (CapEx + OpEx) decreases compared to the current approach after the implementation of the standard.**

  For the Budget requirement, the effects on the CapEx and OpEx are discussed, followed by a score. The mean is taken to determine the final score for the Budget requirement. Only the assets in clusters are considered as the costs for the Custom Projects do not change compared to the current individual approach.

  - **CapEx** are the one-time investments related to asset design, construction, R&R, and demolition. Resources are required to define and test the standards. While the prescribed standards potentially save some design costs, checks would still be required to ensure all location-specific requirements are met. In addition, changing the pump to an entirely different type and constructing a pipeline in case the horizontal distance is too large would add to the R&R costs. The demolition and other construction costs might also increase due to the extra material required to fit the new pump. Because of all the expected extra costs, CapEx is assigned a score of 1.
  - **OpEx** are continuous costs related to personnel and assets performing their tasks. As previously described in the time requirement, personnel are expected to become more efficient due to familiarisation with assets and procedures. With fewer types of pumps present in the system, fewer types of spare parts are required. This could make keeping stock more

financially feasible for spare parts that are often needed or even a few lesser-required parts. In addition, the required specific knowledge is expected to decrease with a more uniform management area. Personnel only have to know how to perform maintenance on the chosen type of pump and its variants, as well as the few Custom Projects and their physical aspects. This potentially increases efficiency, making maintenance less time-consuming and resulting in a decrease in personnel hours.

Regarding the costs related to assets performing their tasks, a larger pump typically requires more electricity per hour to operate. On the other hand, with a larger capacity, the number of operative hours could be decreased, compensating for the increased electricity costs. Increased efficiency of maintenance would also affect the operation of assets. Some downtime of the asset is planned. However, if an asset fails or unplanned downtime occurs, solutions to maintain the water levels must be found. For example, mobile pumping stations could be used. The lower the unplanned downtime, the lower the costs related to risk management.

Finally, technical standardisation would not affect some costs. For example, an organisation's offices still require rent to be paid, regardless of the assets.

Because of the significant expected contributions to the efficiency of maintenance and operation, a score of 3 is assigned to OpEx.

For the verification, each requirement defined in Table 3.3 should at least score a minimum of 2 to pass. The mean values are calculated for both the Time and the Budget requirement, see Table 3.12. Each requirement is met with a minimum score of 2, so no iterative jump is required, and the evaluation can commence.

**Table 3.12:** Scores of Verification

| **Requirement** | **Score** |
|---|---|
| **Function** | 2 |
| | |
| **Time** | |
| Initiation | 3 |
| Definition | 2 |
| Design | 2 |
| Preparation | 3 |
| Realisation | 1 |
| Mean | 2.2 |
| | |
| **Budget** | |
| CapEx | 1 |
| OpEx | 3 |
| Mean | 2 |

### Evaluate the Standardisation Strategy based on the PoA

Contradictory to requirements, the ambitions described in Table 3.3 are desired but not essential to the improvement of R&R. Because of this, they are not obligated to reach a minimum score of 2. The effect of the Standardisation Strategy on each ambition is considered, and a score is assigned.

Note that if multiple Standardisation Strategies were verified in the previous step, this evaluation would be executed for each strategy.

- **Operation: The operation phase is improved by making management (operation, planning) and maintenance more efficient.**

  As described in the verification, the most considerable consequence in the operation phase is anticipated to be in the maintenance of the assets due to the increased uniformity and personnel efficiency. This decrease in complexity makes it possible to keep spare parts, which improves the overall asset management experience during the operation phase. In addition, with better maintenance, the service lifetime of assets can possibly be extended due to the good condition of the assets.

In short, the operation phase is expected to become more efficient, saving resources for other aspects of asset management. This results in an assigned score of 3.

- **Adaptability: Standards can be adapted to fit new norms and guidelines that emerge in the following years.**

  The standards did not consider possible adaptations to fit new norms or guidelines. This requires estimating what norms and guidelines appear as they could act as boundary conditions. Because of this non-adaptability, a score of 1 is assigned.

The values for both the Operation and Adaptability ambition are summarised in Table 3.12.

**Table 3.13:** Scores of Evaluation

| Ambition | Score |
|---|---|
| Operation | 3 |
| Adaptability | 1 |

### Decide based on the evaluation and verification to proceed or not

The final scores, including weighting factors, are shown in Table 3.14. The final score of the Standardisation Strategy is 68% of the possible maximum score. The chosen Standardisation Strategy of Figure 3.17 is deemed sufficient to improve the R&R process. Note that this evaluation only describes the effects of the pump and not the effects of standardising a complete asset. In case more standards were created, the score could be affected. In addition, only one Standardisation Strategy is considered. Multiple tables like Table 3.14 would be created if multiple strategies were verified and evaluated. Based on these tables, an asset management organisation could consider the most optimal strategy for improving the R&R process.

**Table 3.14:** Final verification and evalution scores including weighting factors

| | Score | WF | Final | Max |
|---|---|---|---|---|
| Function | 2 | 2 | 4 | 6 |
| Time | 2.2 | 2 | 4.4 | 6 |
| Budget | 2 | 2 | 4 | 6 |
| Operation | 3 | 1 | 3 | 3 |
| Adaptibility | 1 | 1 | 1 | 3 |
| | | **Total** | 16.4 | 24 |

## 3.6. Step 5 - Verification of Standards at Asset Level

While in Step 1 - System Analysis and Design Definition, the Masterplan (AGV, 2022) is used to define bottlenecks at a System Level, Step 5 focuses on the bottlenecks at the Asset Level. The detailed method of Step 5 is repeated in Figure 3.19 with a simplified representation of the General Decision Method.

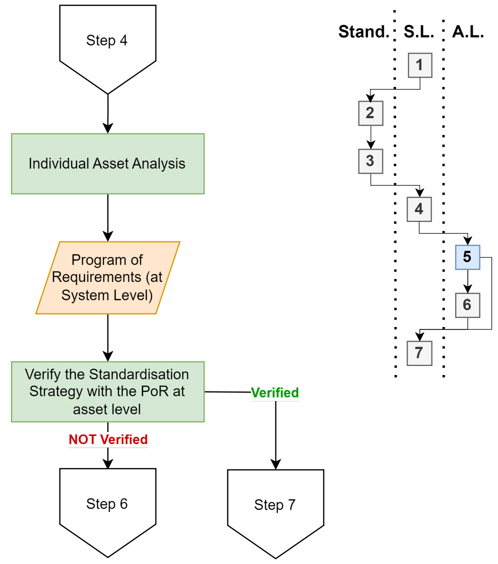



**Figure 3.19:** Step 5 - Verification of Standards at Asset Level

### Individual Asset Analysis

Typically, fieldwork is performed to assess the condition of assets, e.g. investigations regarding the soil, surroundings, stakeholders, and current (technical) state of the asset. The provided information, the Masterplan and LTAP, is assumed to be sufficient for technical verification at the Asset Level.

For the assets that are part of a cluster, the current condition levels for CIV, ME, EE, and PA, as well as the mean, are shown in Table 3.15. The minimum required condition level for each component is 5. This means that if the current condition level is 6 or 7, intervention should take place. This follows the same NEN-2767 method as Step 1 - System Analysis and Design Definition, see Appendix C.1. In Step 3 - Standard development, it is defined that an asset is due for R&R in case either the CIV or ME components reached their end of service lifetime. This is the case for 7 out of 15 assets.

**Table 3.15:** Current condition level of the cluster assets

| KIN-number | CIV | ME | EL | PA | Mean |
|---|---|---|---|---|---|
| KGM00046 | 1 | 2 | 5 | 6 | 3 |
| KGM00049 | 1 | 2 | 5 | 6 | 3 |
| KGM00063 | 2 | 6 | 2 | 6 | 4 |
| KGM00070 | 2 | 6 | 3 | 6 | 4 |
| KGM00072 | 2 | 6 | 2 | 5 | 3 |
| KGM00142 | 3 | 6 | 2 | 5 | 4 |
| KGM00155 | 6 | 1 | 2 | 5 | 3 |
| KGM00158 | 6 | 6 | 2 | 5 | 4 |
| KGM00236 | 6 | 6 | 2 | 5 | 4 |
| KGM00301 | 2 | 3 | 3 | 5 | 3 |
| KGM00474 | 1 | 2 | 2 | 6 | 2 |
| KGM00482 | 1 | 2 | 3 | 6 | 3 |

### Design Definition at Asset Level

The results found in the individual asset analysis can be translated into requirements and ambitions regarding the R&R of the asset. For this case study, to demonstrate the use of the method, a limited PoR is created consisting of technical requirements and one social requirement.

The technical requirements are formulated based on the four categories (CIV, ME, EE, PA) used in the system and individual asset analysis:

T1. CIV: After completion, the service lifetime of the civil structure of the pumping station is at least 50 years.

T2. ME: After completion, the service lifetime of ME components is at least 25 years.

T3. EL: All electrical components, such as navigation lights in and around the pumping station, should have a service lifetime of 13 years (Waternet, 2022).

T4. PA: For PA, there are guidelines set by Waternet, and thus, the components related to PA are up to date according to the guideline 'Process Automatisation' of Waternet, with a service lifetime of 8 years (Waternet, 2022).

The social requirements are related to a disadvantage of using an ASP: the noise coming from the pump. All types of pumps generate noise. However, smaller pumps, such as submersible screw pumps, can be placed inside an isolated pumping station. The size of an ASP limits the construction of large pumping stations. The noise can be a nuisance for stakeholders like people living near the pumping station. Because of this, the following social requirement is formulated:

S1. In case the pumping station is located within 50 m of the living space of residents, additional measures have to be taken to reduce the noise coming from the ASP.

The PoR at Asset Level is summarised in Table 3.16.

**Table 3.16:** Program of Requirements at Asset Level

| Program of Requirements (Asset Level) | |
|---|---|
| **T** | **Technical** |
| T1 | After completion, the service lifetime of the civil structure of the pumping station is at least 50 years. |
| T2 | After completion, the service lifetime of ME components is at least 25 years. |
| T3 | All electrical components, such as including navigation lights in and around the pumping station, should have a service lifetime of 13 years. |
| T4 | Components related to PA are up-to-date based on the Waternet guideline 'Process automatisation', with a service lifetime of 8 years. |
| **S** | **Social** |
| In case the pumping station is located within 50 m of the living space of residents, additional measures have to be taken to reduce the noise coming from the ASP. | |

### Verification of Standards

In the Verification, it is tested if all the requirements defined in the PoR at an Asset Level (Table 3.16) are met. For each requirement, the consideration is made if the Standardisation Strategy results in an asset that meets the requirement. The Standardisation Strategy consists of the implementation of an ASP, an EE standard, and a PA standard.

For the technical requirements, a group assessment is made per requirement:

T1. CIV: For the construction of the ASP, the civil structure is replaced and tailored to the chosen ASP, resulting in a service lifetime of at least 50 years.

T2. ME: Components related to ME are replaced to fit the chosen ASP, such as closing valves. Due to this, the service lifetime of the components is at least 25 years.

T3. EE: A standard for EE is included in the Standardisation Strategy, but the execution is not specified. It is assumed that this standard does result in all EE components obtaining a service lifetime of 13 years.

T4. PA: Similar to EE, in Step 3, a standard for PA is included in the Standardisation Strategy but not specified. It is assumed that this standard does result in all PA components obtaining a service lifetime of 8 years.

In short, the Standardisation Strategy for the 12 assets part of clusters is verified for all technical requirements. For the social requirement, an individual assessment is made for each pumping station.

S1. Table 3.17 shows for each pumping station if the distance between the ASP and surrounding residents is below 50 m. This is the case for 4 out of 12 assets, resulting in Adjustment Measures being required.

**Table 3.17:** Determination if the distance between ASP and residents is less than 50 m (Google, 2016-2023)

| KIN-number | Distance <50m? | Cluster |
|---|---|---|
| KGM00046 | no | 1.1 |
| KGM00049 | no | 1.1 |
| KGM00063 | yes | 2.1 |
| KGM00070 | no | 2.1 |
| KGM00072 | yes | 1.2 |
| KGM00142 | yes | 1.2 |
| KGM00155 | no | 1.1 |
| KGM00158 | no | 1.2 |
| KGM00236 | yes | 2.1 |
| KGM00301 | no | 2.1 |
| KGM00474 | no | 1.1 |
| KGM00482 | no | 1.2 |

## 3.7. Step 6 - Creating Additional Design Measures

This section describes the creation of additional design measures after the conclusion that noise coming from four pumping stations has to be limited. The detailed method of Step 6 is repeated in Figure 3.20 along with a simplified representation of the General Decision Method.

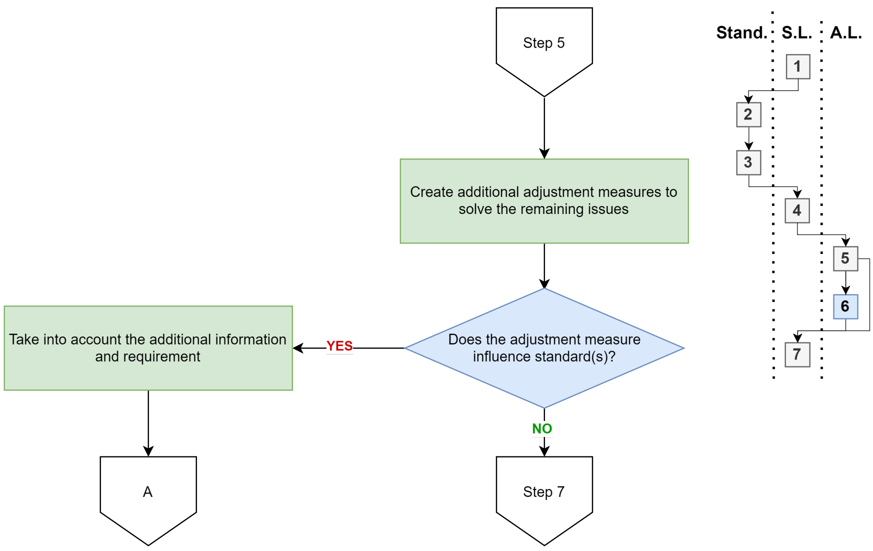



**Figure 3.20:** Step 6 - Creating Additional Design Measures

### Create additional Adjustment Measures to solve the remaining issues

An approach to decreasing the noise coming from the ASP is to apply a cover. This cover can be executed in steel, concrete, textile, or other materials. An example of a cover over an ASP is given in Figure 3.21.


**Figure 3.21:** Pumping station with textile cover (Image courtesy of Witteveen+Bos)

As shown in Table 3.17, for two assets from cluster 1.2 and two assets from cluster 2.1 a cover is required. The cover depends on the diameter of the ASP, resulting in two different covers being required. Because of this, creating additional standards for assets where a cover is required is not feasible for this case, as a cluster with only two assets does not satisfy the first cluster requirement defined in Step 3 (at least three assets in a cluster). However, from now on, it is known that noise is an additional boundary condition necessary for the design of the asset. This can be taken into account for future standardisation attempts at pumping stations.

#### Decide if the Adjustment Measures influences the Standard(s)

The cover does not influence the EE or PA standard. In addition, covers are tailored to fit the chosen diameter of ASPs. In short, the technical characteristics of the created standards are not affected. However, there will be an effect on the verification as, for example, the material costs would increase. In addition, with a cover, the ASP is more complicated to reach for maintenance, affecting the operation phase and thus the evaluation.

For this case study, it is assumed that the effects of only four covers do not sway the verdict of the verification, evaluation, or validation in Step 4. In addition, it is assumed that all technical and social requirements are met in Step 5 by adding the cover. Thus, no additional Adjustment Measures are required after this iteration, and Step 6 is concluded.

## 3.8. Step 7 - Adapting the R&R Process

This section describes an example of the adaptation of the R&R process based on the created clusters. The detailed method of Step 7 is repeated in Figure 3.22 along with a simplified representation of the General Decision Method.

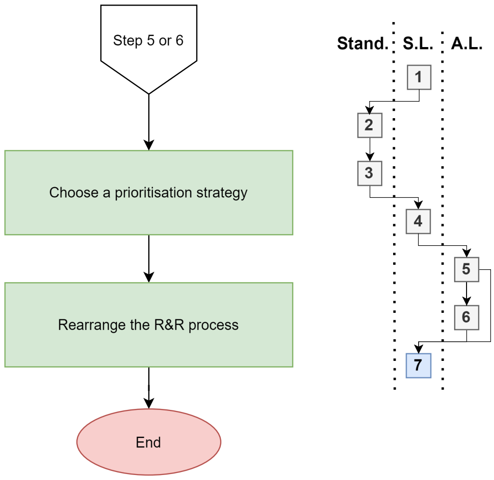



**Figure 3.22:** Step 7 - Adapting the R&R process

### Choose a prioritisation strategy

While standards are created for the Asset Family, the reason for standardisation is not to standardise the management area but to improve the R&R process. The method focuses on the improvement of the R&R process through prioritisation of the assets based on the created clusters. As shown in Figure 2.11, there are multiple levels for which prioritisation can take place within the total management area: System Families, Asset Families, and clusters. Standards have been created for one Asset Family containing 15 assets divided into three clusters and three Custom Projects. Because of this, a prioritisation strategy is created for these 15 assets.

There are several prioritisation strategies, for example, based on the remaining service lifetime, importance, available budget, or risk in case of failure. The Masterplan (AGV, 2022) states that risk-based prioritisation should be adapted. This relates to the importance of the assets and the current condition of the assets. However, the importance of all assets considered is equal according to Waternet (Waternet, 2022). Because of this, the chosen prioritisation strategy is current-condition level. In addition, as the focus is on assets due for R&R, which is the case when either CIV or ME components are at their end of service lifetime, EE and PA components are of less priority. Because of the large civil engineering adaptations required to R&R the assets to fit the ASP, no difference is made between the priority of ME and CIV components.

### Rearrange the R&R process

Table 3.18 shows an expansion of Table 3.15, with the current condition level of the 15 assets and their cluster. Besides choosing the current condition level as the prioritisation strategy, the following assumptions are made:

- R&R can be executed for one asset at a time. This results in a R&R process with assets placed in series instead of parallel.
- Life prolongation measures are possible for assets that are due for R&R to extend the service lifetime up till the desired moment.

**Table 3.18:** Current condition level per category (Waternet, 2022)

| Cluster | KIN-Number | CIV | ME | EE | PA | Mean |
|---|---|---|---|---|---|---|
| 1.1 | KGM00046 | 1 | 2 | 6 | 6 | 3 |
| | KGM00049 | 1 | 2 | 6 | 6 | 3 |
| | KGM00155 | 6 | 1 | 2 | 5 | 3 |
| | KGM00474 | 1 | 2 | 2 | 6 | 2 |
| 1.2 | KGM00072 | 2 | 6 | 2 | 5 | 3 |
| | KGM00142 | 3 | 6 | 3 | 5 | 4 |
| | KGM00158 | 6 | 6 | 3 | 5 | 5 |
| | KGM00482 | 1 | 2 | 3 | 6 | 3 |
| 2.1 | KGM00063 | 2 | 6 | 2 | 6 | 4 |
| | KGM00070 | 2 | 6 | 3 | 6 | 4 |
| | KGM00236 | 6 | 6 | 3 | 5 | 5 |
| | KGM00301 | 2 | 3 | 3 | 5 | 3 |
| C.P. | KGM00059 | 1 | 2 | 4 | 5 | 3 |
| C.P. | KGM00106 | 6 | 6 | 6 | 5 | 5 |
| C.P. | KGM00358 | 1 | 2 | 3 | 5 | 2 |

The efficiency of the R&R process comes from repetition and similarities in activities. Thus, the approach taken for prioritisation is to take one cluster that uses the same standard and performs R&R for these assets in series, then continue to the next cluster. The Custom Projects are also integrated into the rearrangement of the R&R process. The following decisions are made to define the priority of each cluster or Custom Project:

- The first Asset chosen for R&R is Custom Project KGM00106, due for R&R for both CIV and ME. This asset is placed before the clusters as it is a single asset, taking less time than four assets in a cluster.
- Next, either cluster 1.2 or 2.1 should be considered. Both clusters contain three assets due for R&R based on the ME component and one because of the CIV component. However, the fourth asset of cluster 2.1 (KGM00301) is in slightly less optimal condition than the fourth of cluster 1.2 (KGM00482). Because of this, cluster 2.1 is chosen.
- After R&R is executed for all assets in cluster 2.1, cluster 1.2 follows.
- Cluster 1.1 and two Custom Projects (KGM00059 and KGM00358) remain. Because Cluster 1.1 has 1 asset that is due for R&R while the two C.P.s are not yet due, Cluster 1.1 is selected.
- At last, a distinction is made between the remaining two Custom Projects based on the mean of the current condition level, thus placing KGM00059 before KGM00358.

Within clusters, the assets should again be prioritised. The following decisions are made to define the priority of each asset within clusters:

- Cluster 1.1: Starts with KGM00155 based on the CIV components being due for R&R. For the remaining assets, KGM00046 and KGM00049 are equal in all scores, so they are equally important. This cluster is finished with the R&R of KGM00474.
- Cluster 1.2: KGM00158 is first based on both CIV and ME components being due for R&R. The order of the remaining assets is based on the CIV components score: first KGM000142 (3) followed by KGM00072 and finally KGM00482.
- Cluster 2.1: KGM00236 is first based on both CIV and ME components being due for R&R. KGM00070 and KGM00063 are both due for R&R based on the ME components, but the CIV components are in an equal state. Because of this, the choice is made based on EE, with KGM00070 having a lower score of 3 while KGM00063 has a score of 2. This cluster is finished with the R&R of KGM00301.

The example of adapting the R&R process based on the prioritisation strategy and the defined clusters is summarised in Figure 3.23.

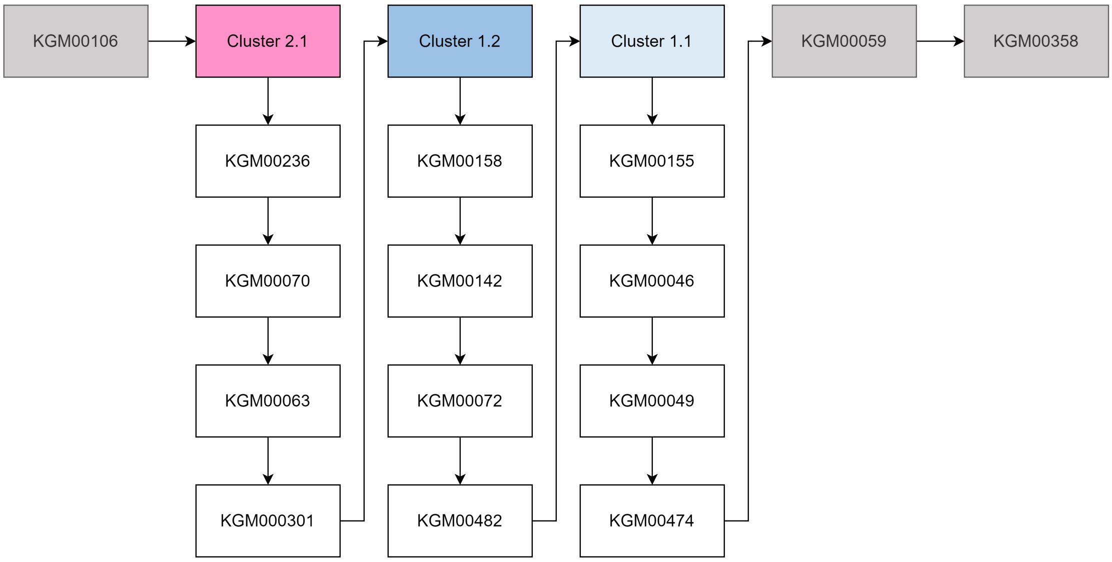



**Figure 3.23:** Example of adapted R&R process

## 3.9. Concluding remarks

After creating the prioritisation strategy and adapting the R&R process, the decision method is finished, and the case study is concluded.

The case study shows that the decision method is executable for a management organisation such as Waternet as long as a sufficient amount of information is available. Due to time constraints, not all required input could be gathered, so simplified assumptions were made. Furthermore, not all required output was generated due to time constraints, but assumptions were made based on the expert knowledge provided by the interviews and literature. However, this decision method does not and should not prescribe how each organisation defines its approach to gathering the required input and generating the output. Because of this, the level of detail in the case study is deemed sufficient for verifying the decision method.

In addition, pumping stations are a sufficient choice for a first execution as most components are related to the pump and its function. This results in less normative boundary conditions, placing the focus on the decision method rather than the creation of a standard design.

To conclude, the case study showed that the decision method can be used as a first approach to implementing standardisation into the R&R process of an asset management organisation.

# 4. Validation

This chapter describes the validation of the decision method. First, the objective of the validation is discussed, followed by the organisation of the validation meeting. Then, the results are presented and possible improvements are identified. At last, the decision method is adjusted based on the identified improvements. After the adaptations based on the results of the validation, the decision method is finalised. An overview of the final General Decision method and fully developed method can be found in Appendix E.

## 4.1. Objective of the Validation

The validation is the confirmation, obtained through objective evidence, that the system will perform its intended functions. Validation checks whether the right system has been designed (TU Delft, 2020). In the context of this thesis, the objective of the validation is to check whether the designed decision method is the desired method and would be beneficial for asset management organisations who want to improve their R&R process through standardisation. The validation will identify any discrepancies between this study's decision method and the client's ideas.

## 4.2. Organisation of the Validation

For the validation, a meeting with two experts at Waternet took place, Mies and Havers. Mies' function is described as 'asset manager technical assets'. He is responsible for ensuring all (technical) assets are in their minimum required condition. Hamer, is an advisor in Mies' team and supports Mies in managing the technical assets. The experts are involved in solving the gap between Waternet's required and available capacity. Two validation meetings took place. The first meeting took two hours, and only Hamer was present. Both Hamer and Mies were present at the second meeting, which took one hour. Before the meetings Chapter 2, Decision Method Development, and a presentation about the decision method and the case study were sent so that the experts could prepare.

In the validation meetings, this study's decision method is discussed to check whether the designed decision method is the desired method and would be beneficial for asset management organisations who want to improve their R&R process through standardisation. For this, three questions were posed. Their answers are discussed in Section 4.3.

- **Is the right method designed?**

  The decision method should help asset management organisations implement standardisation into their R&R process, limiting obstructions to standardisation presented in the problem analysis, such as fragmentation.

- **Is the method complete?**

  The decision method should consider all relevant input and output, as well as all essential design processes, in the correct order. It should also support the user in formulating an answer on the feasibility of standardisation.

- **Is the quality of the method sufficient?**

  The decision method should be ready for direct implementation, providing clear practical guidance while remaining sufficiently objective. In addition, the quality relates to the intended user of the method and the amount of specific knowledge required to use it.

## 4.3. Results

The results are presented following the order of the questions. The answers to the questions are based on the two expert interviews and discuss several aspects of the decision method and its validation.

### 4.3.1. Is the right method designed?

The experts base the definition of the desired method on the defined aim of standardisation in the Masterplan (AGV, 2022). The Masterplan states that standardisation should be implemented because it was assumed to be more efficient and cheaper. However, it also states that standards should be created without prejudice towards standardisation, meaning that objective decisions should be possible. In addition, the Masterplan states that standards should be created for bulk (present in large numbers) assets and components first.

#### Ensuring cheaper and more efficient R&R

First, the statements of the Masterplan that standardisation should be implemented because it is assumed to be more efficient and cheaper, and the request for objective decision-making is discussed.

It was clear to the experts that the decision method does not generate standards that certainly result in a more efficient and cheaper R&R process. However, it does guide organisations in creating criteria for the verification and evaluation of the effects of standards on the R&R process.

The experts liked that the decision method starts with a system analysis of the entire management area instead of analyses of individual assets. They thought that this approach would lead to better evaluation and verification criteria than the approach of starting by assessing the standardisation potential of assets and then defining the criteria. They acknowledged that efficiency and budget criteria could be included in Step 1 in order to test the statement of the Masterplan that standardisation is more efficient and cheaper in Step 4. Moreover, they liked that the decision method is not limited to these two criteria and more can be included. However, they also mentioned that this would take more time. This is further addressed in Section 4.3.2.

#### Objectivity of the method

This approach would not lead to full objective criteria and decisions as requested by the Masterplan. However, Mies stated that asset management is always subjective, as everyone has preferences for design choices and approaches that act as input for the decision method. Both experts thought the decision method helps to create a level of objectivity by being designed for a team, not an individual. Moreover, the experts highly valued that advocates and opponents of standardisation are forced to compromise to find the optimum solution. They noticed this in multiple steps. They mentioned Step 3 - Standard Development as an example, where positive prejudice is limited by creating cluster and overdimensioning requirements. Positive prejudice is also limited in Step 5, as some improvements do not guarantee the approval of standards. On the other hand, they noticed that negative prejudice is limited by the iterative jumps in Steps 4 and 5, as the standard might not meet the requirements yet, but it might with some adaptations.

Furthermore, the experts mentioned that the transparency of the method also contributes to objectivity. They specifically mentioned Step 4 as the experts liked that the step focuses on showing what score was obtained due to implementing which standard or Standardisation Strategy. The experts deemed this transparency necessary.

#### Application for bulk assets

Next, the statement of the Masterplan that standardisation should be implemented for bulk assets and components was addressed. The experts followed the analogy of starting with the larger management area and choosing a selection of assets that have similar boundary conditions based on priority and potential. The case study selected 15 pumping stations based on their priority and potential, also considering the number of assets present. While 15 assets are not considered as bulk, the experts did think that the decision method is applicable to assets present in larger numbers. They approved the decision to include priority instead of only potential and valued that clusters are based on technical characteristics as this makes it possible to place additional assets into the right cluster based on their technical characteristics.

To conclude the first question, the experts thought the decision method aligned with the description of the Masterplan. However, they did think more case studies were required to fully understand the applicability of the decision method. In addition, considering the total management area could be time-consuming. All points of attention are summarised in Table 4.1

**Table 4.1:** Overview points of attention from the first question

| Benefits | Points of consideration |
|---|---|
| Creates level of objectivity through transparency and limiting prejudice | Considering all criteria is time-consuming |
| Includes potential and priority when selecting assets | More case studies are required |

### 4.3.2. Is the method complete?

The experts mentioned three requirements for the decision method to be complete:

- The decision method should always provide a result of whether standardisation is feasible, and if so, the decision method should describe the standards and to which assets they should be applied;
- The results must be substantiated, and it should be possible to trace back the result to the goals defined initially;
- The order of the method should be logical. Otherwise, people will skip steps or perform them before the given moment;

#### Ensuring results and description of standards

Starting with the first requirement, a drawback that the experts found is that there are no limits to the iterative process. An iterative jump is made to Step 3 if a standard is insufficient in Step 4 or has to be adjusted in Step 6. The experts argued that while it is good that negative results are highlighted in these steps and that the iteration aims to solve these, it should be defined when the assumed standardisation potential is insufficient for real standardisation. Otherwise, the iterative process will go on forever, costing much time without providing a final answer on the feasibility of standardisation. However, rejecting standardisation should be a last resort after multiple iterations. Otherwise, opponents of standardisation might divert to that route before thoroughly researching the potential of standardisation. The experts thought this exit route and limitation to standardisation needed to be visible in the decision method, which is not the case yet.

The experts did think that in case standardisation is feasible, Step 3, Standard Development, made clear how standards can be assigned to assets based on cluster and efficiency requirements. However, they expressed that the case study was required to fully understand the description of the decision method. This clarity is further addressed in Section 4.3.3.

#### Substantiating and traceability of results

Considering the second requirement, the experts highlighted the distinction between the different active processes (Section 2.2.2) and acknowledged it would help explain design choices to others.

Substantiating the results was deemed partially possible due to Step 1, where clear evaluating and verification criteria are defined, which are later used in Step 4 to approve or reject standards. With this, assigning positive or negative effects to specific standards and iterating to improve this is possible. The distinction between system and asset verification added to the clear substantiation of design choices. The experts expressed that this would contribute to explaining to other stakeholders why some design choices were approved while there are some negative effects. In addition, they approved Step 5 as one essential part of users being able to reason backwards from the result to the goals defined initially.

#### Order of the method

For the third requirement, regarding the order of the method; the experts were positive that the method starts at a System Level to define bottlenecks in the R&R system and that the end was also at a System Level to improve the R&R process with the created standards.

Moreover, both experts thought that the order and contents of the decision method solved an issue of contradictory demands in projects. They elaborated that sometimes requirements defined by management are not always possible in combination with other requirements set by management or location-specific requirements. They identified Step 3 and Step 6 as the possible solution to this problem. In Step 3, requirements set by management are streamlined by defining the Standardisation Strategies. Because of this, no standards are chosen to consider contradictory demands at the System Level. Then, Step 6 identifies the disconnect between the chosen standards and location-specific requirements and tries to solve this without adjusting the created Standardisation Strategy. With the iterative jump, the standards can be adjusted to fit both the System and the Asset Level.

However, Mies stated that he would start with selecting a System Family before starting Step 1 due to time constraints. This was partially mentioned in Section 4.3.1, where the experts stated that they liked that the decision method is not limited to budget and efficiency and more can be included. By considering a large management area, many criteria can come up, that possibly are not of influence on the chosen assets later on in the method. In addition, performing a system analysis for a total management area is very time and capacity-consuming. Executing the total system analysis each time the method is executed would make it inefficient.

Because of this, Mies would first select a System Family and perform the system analysis for this smaller selection. Next, he would still define the Asset Families (second step of Step 2) to define the System Family in smaller pieces based on potential and priority. Hamers added that picking a smaller selection would also improve the PoR and PoA at a System Level as more asset type-related requirements and ambitions could be integrated. These would otherwise be identified later on in Step 5. However, Mies argued that this would also happen based on experience from previous projects and that taking into account location-specific boundary conditions could obstruct the implementation of standards as some conditions could be solved by simple additions, but creating standards fit for all might not be possible. Because of this balance, it was argued that while zooming in on a selection of assets prior to Step 1, it should not be more specific than selecting an asset type.

At last, they questioned whether it would be possible to start Step 7 if the standardisation potential was only assessed for some components. Continuing to Step 7 while still developing standards would be desirable because creating standards takes time, especially for a large number of components. This remark relates to the iterative nature and the question of when to stop iterating or explore additional measures. The discussion concluded that it should be defined for how many components it is desired to create a standard and what to leave to individual engineering.

To conclude the second question, the experts liked the approach to creating and assigning standards to assets. Moreover, they valued the transparency and the prevention of contradictory demands. However, they found that the decision method should include a limit to the iterative process to make it less time consuming. All points of attention are summarised in Table 4.2.

**Table 4.2:** Overview points of attention from the second question

| Benefits | Points of consideration |
|---|---|
| Standards can be assigned to assets with cluster and efficiency requirements | Iterative nature should be limited in case standardisation is not feasible |
| Clear boundary between active processes | System Family should be selected before starting the system analysis |
| Results can be traced back to choices of influence | Starting adapting R&R process after creating standards for all components is time-consuming |
| Focus on improvement at a System Level | |
| Prevents contradictory demands | |
| Possible to include varying criteria | |

### 4.3.3. Is the quality of the method sufficient?

The experts divided the definition of quality into multiple elements: completeness, clarity, instant use, possible users, and room for interpretation. However, whether the decision method is complete was discussed in Section 4.3.2 and will not be discussed further in this section.

#### Clarity and instant use

The decision method's clarity relates to whether each step is described and whether the users know what to do. This can be seen as the level of practical guidance. Both experts mentioned that while the decision method is clear at first glance, users have to become familiar with each step before fully understanding how each step relates to the general objective of the decision method.

Discussion followed about the approach to this familiarisation. It was concluded that executing the decision method on fictional cases is required before implementing it in the real R&R process. The case study can be used as additional guidance, but it should be remembered that it is executed for a specific case. This is partially due to the experts stressing that they want to use the decision method in project teams. Other involved parties, such as contractors or engineering companies, would also be part of these teams. In these projects, Waternet should act as a guide through the decision method. While this shows that the decision method is not developed enough for instant use without investing time, the experts said that they think Waternet could still start instantly with this familiarisation and implement the decision method without large adjustments to the method.

#### Intended user and room for interpretation

Next, the intended user of the decision method was discussed. They did not think the decision method was limited to a specific type of user or case, such as a technical asset manager. In addition, it was considered a positive aspect of the decision method that it leaves room to fill in your own context. For example, the case study started with the total management area, but this could also be something smaller, and different criteria could be developed. However, this requires some experience with asset management. Ultimately, the experts saw this decision method as a starting point to change the approach to implementing standardisation into the R&R process.

To conclude the third and final question. The experts thought the decision method could help organisations in starting with implementing standardisation. However this requires some experience with asset management and familiarisation with the decision method. All points of attention are summarised in Table 4.3.

**Table 4.3:** Overview points of attention from the third question

| Benefits | Points of consideration |
|---|---|
| Not limited to one specific user | Requires familiarisation with the decision method |
| Not limited to one case or context | Requires some experience with asset management |

## 4.4. Adapting the method based on the results

The findings from the validation are summarised in Tables 4.1, 4.2, and 4.3. Multiple address recommendations before starting with executing the method, such as familiarisation and additional case studies. However, two main attention points address the contents of the decision method itself. The first is expediting the context creation of Step 2 before the System Analysis and Design Definition in Step 1. The second main point is limiting the iterative process. This section describes the required adjustments to the decision method, followed by the visualisation of the adapted General Decision Method. The effects on individual steps are visualised in Appendix D. An overview of the final General Decision method and fully developed method after Validation can be found in Appendix E.

### 4.4.1. Adding Context Definition

Defining the context before Step 1- System Analysis and Design Definition starts will make the decision method more efficient and ensure that the entire method is followed. This is based on the statement of

Mies that he will most certainly start with a defined selection of assets, as performing a system analysis on the entire management area is very time-consuming. Because this first selection of assets depends on directions of other parties, such as the board, that are not involved in the rest of the decision method, this additional step is implemented before Step 1, and called Step 0 - Context Definition, see the new step in Figure D.1. Furthermore, this affects Step 2 (Figure 2.5). Step 2 now only encompasses the prioritisation of Asset Families, see the adapted step in Figure D.2. The defined approach in Step 1 (Figure 2.3) is not affected as only the context for which the system analysis is performed is defined in this step.

### 4.4.2. Limiting the iterative Process

Two forms of limitation are suggested:

1. Defining when standardisation is not feasible and iteration with the aim of optimizing standards should be stopped. This is called an exit strategy.

   The current decision method describes that iterations are allowed for optimisation without limits. However, the exit strategy can be defined by limiting the number of iterations allowed per Standardisation Strategy. The strategies are defined based on the cross-correlations between standards at the end of Step 3 - Standard Development. For example, if a limit of $L = 1$ iterations per Standardisation Strategy is chosen, the following procedure is suggested:

   - As a first option, the Standardisation Strategy containing the largest number $N$ of standards possible should be chosen, as shown in Figure 3.17.
   - The first iteration takes place if it is concluded that either the Standardisation Strategy is insufficient to improve the R&R process (Step 4) or that adjustment measures are required that influence standards (Step 6). In this first iteration, the chosen strategy is optimised based on the obtained knowledge from Steps 4 or 6.
   - If after the first iteration, again, it is concluded that either the Standardisation Strategy is not sufficient to improve the R&R process (Step 4) or that additional design measures are required that influence standards (Step 6). One standard is eliminated from the Standardisation Strategy, thus increasing the design freedom for each project.
   - The second iteration starts with the new Standardisation Strategy consisting of N-1 standards.
   - Repeat this process until a Standardisation Strategy is defined of N-i standards, which might require adjustment measures but do not influence the chosen standards.

   This way, the iterative process is limited to $N_{standards,optimal} * L$ iterations. However, it should be tried for all possible Standardisation Strategies consisting of N standards, to see which strategy performs best. In total, the iterative process is limited to: $\Sigma N_{strategy,i} * L$.

   Steps 4 and 6 before and after adaptation based on the described results are shown in Figure D.4 and Figure D.5.

2. Defining when enough standards are created for Step 7 - Adapting the R&R process to start.

   Chapter 2 described that Step 7 can start once a Standardisation Strategy either reaches Step 5 and is completely verified at the Asset Level or Step 6, without adjustment measures being required that influence standards.

   However, if not for all components with potential a standard has been created, it is not ensured if the most optimal Standardisation Strategy is created. To solve this, a requirement should be set when enough standards are created. This should depend on the priority of the components for which the standards are created.

   In Step 3 - Standard Development, components are assessed based on their standardisation potential. However, an additional assessment based on the priority of the components could be made. The priority is based on the function it plays in the asset. There will be components with priority and potential, assets with only potential, and assets with only priority. However, for assets with only priority and no standardisation potential, no standards will be created, and an individual approach will be taken. Step 7 can start once standards have been created for all of the assets with both priority and potential, and a Standardisation Strategy is chosen based on those standards. This way, standard development can continue for the assets with potential but no priority, while Step 7 can start with the most important components included.

Step 3 before and after adaptation based on the described results are shown in Figure D.3.

The final General Decision Method after validation is shown in Figure 4.1. For each adapted step, a before and after validation visualisation is given in Appendix D. The full method is shown in Appendix E.

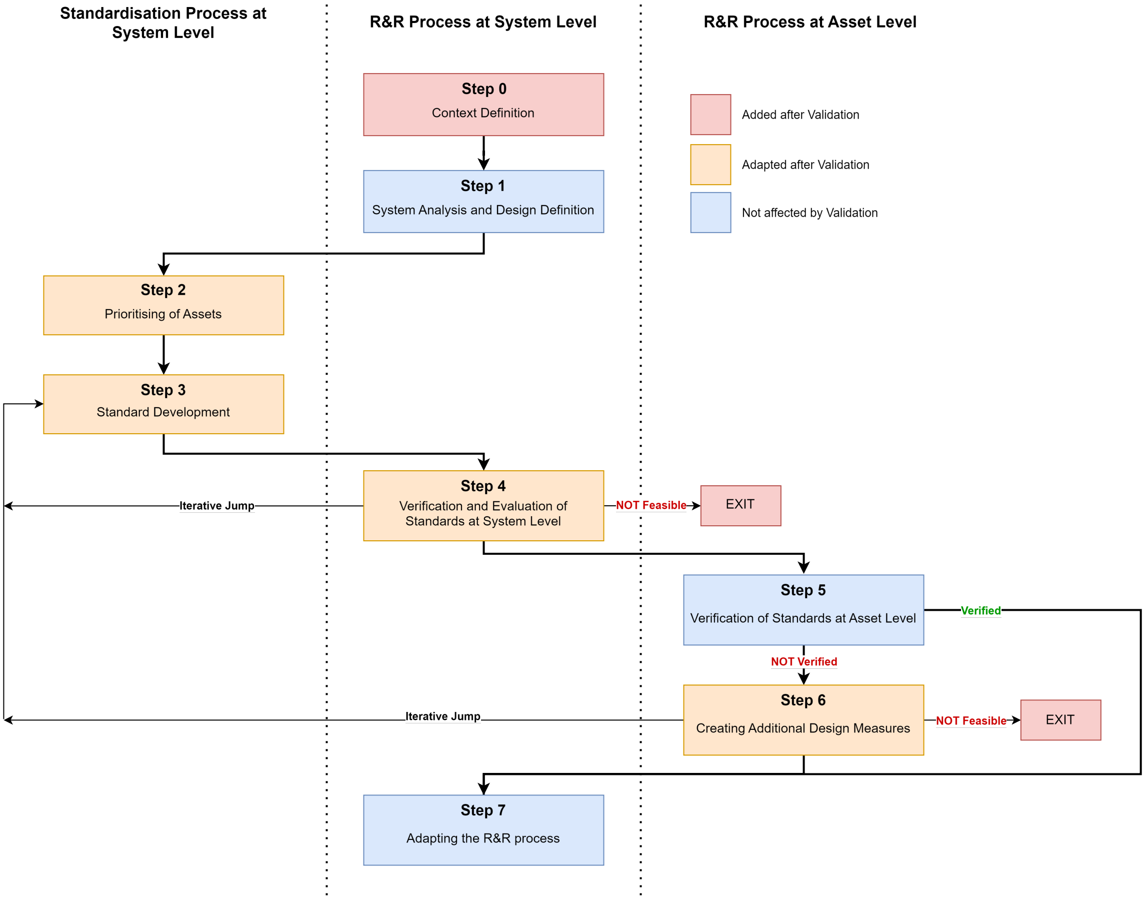



**Figure 4.1:** General Decision Method after Validation

# 5. Generalisation

The decision method divides assets in a management area into System Families and Asset Families (Figure 2.4) based on their technical characteristics. In Chapter 3, a case study is conducted on the management area of Waternet to verify the created decision method. It is concluded that the decision method can be used for a single asset family consisting of pumping stations. Next, in the validation (Chapter 4), adjustments to the method are made to result in a fully developed decision method suitable for improving the R&R process through standardisation for all types of technical assets. However, there are still limitations to the application of the decision method. This chapter discusses what (in)dependent variables are present in the decision method and what is required for a case to be fit for the method's application.

First, the generalisation to other Asset Families is discussed, i.e. other assets of the same types but with different technical characteristics. Next, the generalisation to other System Families, i.e. other asset types, is discussed.

## 5.1. Generalisation to other Asset Families

Within a System Family, all assets are of the same type regarding functionality and the design depends on the same boundary conditions. Independent of what Asset Family was chosen within the System Family of pumping stations, the required capacity and head difference would have been determined. These are characteristics related to the primary function of the technical asset. The values of the characteristics and the number of clusters might change if a different Asset Family is selected, but the required information will stay the same and similar standards might be possible. This shows that the decision method does not depend on the chosen Asset Family.

## 5.2. Generalisation to other System Families

However, once a different System Family is selected, such as locks instead of pumping stations, different technical characteristics define Asset Families. Levinson (2018) used the height and width of the lock gate to distinguish between them, while this study's case study used capacity and head difference. For each asset type, the normative characteristics related to the primary function of the asset type should be determined. These are different for each asset type and, consequently, for each System Family. Still, the decision method can be used for the other System Families as the described steps are not focused on a single technical asset type.

Finally, there are examples of components that are not divided into Asset or System Families but are universally applicable to multiple Asset and System Families. Electrical components, such as lighting in and around assets, are most often not asset-specific. Another example is mentioned by the experts in the validation (Chapter 4). They described placing flags at assets as part of the board's brand awareness ambition to increase their assets' visibility. This ambition could be considered for the Program of Ambitions in Step 1 - System Analysis and Design Definition. However, the boundary conditions for when a flag should be placed are not specifically related to the asset at which it is placed. While the flags could be considered a component in the design of a pumping station, they are not defined by the characteristics of a pumping station. Because of this, these types of universal components should be considered as a different System Family. However, they are not considered a technical asset and thus are outside the scope of this thesis.

# 6. Discussion

This chapter discusses this study's decision method. First, the contribution of the decision method developed in this study to asset management is discussed. Next, other methods and techniques that could fulfil part of the created decision method are described, and differences are highlighted. Then, assumptions that were made during the study and their effects on the research are defined and elaborated on. At last, the sensitivity of the decision method is discussed.

## 6.1. Limitation to technical standardisation within the R&R process

The scope of this thesis is limited to technical standardisation within the R&R process. This section covers expanding this scope to another type of standardisation and other asset management elements.

### Combination with process standardisation

The decision method was created based on identified improvement points in the R&R process and in the implementation of standardisation. These improvement points were derived from semi-structured interviews conducted at RWS and Waternet, the executive party of AGV. These are two organisations with much knowledge about asset management and related tasks. The result is a decision method with the scope limited to technical standardisation, which refers to the technical assets themselves and aims to create more uniformity in the management area through standard design choices. However, different solutions and strategies may have resulted from considering other asset management organisations with an interest in implementing standardisation into their R&R process.

An example of standardisation efforts with a different solution can be seen at water authority Drents Overijselse Delta (WDODelta), number 6 in Figure 3.1a. WDODelta is also actively researching the standardisation of pumping stations (WDODelta, 2024). Instead of technical standardisation, WDODelta focuses on process standardisation, which refers to contracts, procedures, and approaches in the R&R process. WDODelta started with process standardisation by creating building teams where WDODelta enters into a four-year commitment with three contractors, each responsible for one-third of the renovation program (WDODelta, 2022). This different tender procedure increases efficiency as the involved parties become familiar with the R&R approach, shortening the design process.

The approach of WDODelta shows that process standardisation is also a possible solution to partially address the identified bottlenecks of fragmentation, time constraints and budget limitations. Nonetheless, the potential of both technical and process standardisation would be maximised if a hybrid solution is applied. This study's decision method is the first effort to implement technical standardisation in the design process, creating potential for combination for a combination. For example, each building team could adopt the decision method, increasing efficiency further and decreasing fragmentation.

### Aspects of asset management other than R&R

This study's decision method relates technical standardisation solely to the R&R of already existing assets. However, asset management organisations are also responsible for other parts of asset management.

For example, constructing assets at new locations that fulfil new functions. This decision method can be used to create standards for these new assets. Moreover, it can be used to find standards fit for both R&R projects and new construction. This way, the design time is reduced in all projects and the uniformity between old and new assets increases. For this the NEN standards should be included in the process.

## 6.2. The chosen method for standard selection

This section describes an alternative method that could potentially fulfil part of this study's decision method.

Step 3 of this study's decision method, Standard development, concludes with the definition of cross-correlations between standards and the creation of standardisation strategies. In the case study, this is executed for five standards by visualising each positive cross-correlation between standards and selecting the maximum number of standards that can be implemented simultaneously. However, an asset consists of many more components than five, each for which standards could be created. with many components, visualising each positive cross-correlation could create a chaotic overview, complicating the definition of the most optimal standardisation strategy.

An alternative to presenting the cross-correlations was presented by Knippenberg (2021). Design structure matrix (DSM) modelling and value analysis methods were used to obtain a ranked set of feasible lock configurations that meet the specific requirements for a particular lock location while simultaneously addressing the fragmentation issue in the family of locks of MWW. The configuration finding algorithm could produce many feasible configurations, which had to be prioritised over one another to obtain the best configuration. For this, Knippenberg (2021) used the value analysis method of Pahl and Beitz (2007) to rank components quantitatively and subsequently value configurations in their entirety.

To provide a structured overview of compatible component pairs, Knippenberg (2021) constructed a component interface matrix (CIM) showing what components could be used in the same design to fulfil (almost) all required functions together. Knippenberg (2021) suggested that the next step is to determine the subset of feasible components for each lock in the portfolio to configure that specific lock. This determination was done for one lock.

The CIM presented by Knippenberg (2021) would be the desired final result of this study's Step 3 when all components present in assets are assessed. The difference between both methods lies in the selection of components for assets. The decision method presented in this thesis creates clusters of assets for which the same subset of feasible components can be applied, while Knippenberg (2021) uses a different subset for each lock. Both methods use standards for components, decreasing the number of unique components used. However, this study's method also creates more similar assets.

## 6.3. Assumptions of influence

This section describes relevant assumptions and their effects on the results of the decision method.

### Additional acting frameworks

Frameworks are external plans that create additional boundary conditions, requirements, or ambitions within the design process. Examples of acting frameworks are legislation and destination plans at different levels. The case study assumed that all relevant frameworks were presented in the Masterplan (AGV, 2022). However, this did not consider whether assets were classified as monuments located near or in a Natura2000 area. This could alter standards or even exclude assets of standards. The user of the method should define the relevant frameworks for each case to ensure the required support for implementation. The decision method allows users to insert these as additional boundary conditions in the PoR or PoA in Step 1 - System Analysis and Design Definition or Step 5 - Verification of Standards at Asset Level. It can also be used as a cluster parameter in Step 3 - Concept development. In short, the case study excluded multiple frameworks, but this is not determinative for other cases.

### Avoidance of vendor lock-in

In the case study, already standardised components of suppliers were used to create standards and clusters. However, this approach could lead to vendor lock-in. Vendor lock-in is the phenomenon in which an organisation becomes so dependent on a supplier that switching to another supplier is not possible without significant (financial) consequences (PIANOo, 2024c). For example, if required unique parts are discontinued or suppliers go bankrupt, R&R and maintenance are obstructed. Consequently, additional investments are needed to alter the assets to another type of part or to create the part at another supplier. Because of this, it must be ensured that multiple suppliers are available for the same component before it is chosen as a standard to avoid vendor lock-in.

### Prioritisation strategy

The case study presented an example of a possible adaptation of the R&R process based on the created clusters. For this, it was assumed that R&R can only occur in series, one asset at a time. However, in reality, R&R can take place for multiple assets as long as the organisation has the resources to do so. For example, with enough resources, the management organisation can decide to execute R&R for the clusters in parallel, further decreasing the required time. Each organisation should consider its available resources and the best approach to adapting the R&R process.

## 6.4. Sensitivity of the decision method

In Chapter 4, validation, the subjectivity of this study's decision method was discussed. It was argued that both advocates and opponents of standardisation could influence the decision method to sway the results in their favour. This is because the decision method is based on a semi-quantitative approach, depending on the user's experience with asset management and standardisation to find and evaluate standards. With this approach, not all subjectivity can be filtered out of the result, as the user creates the verification and evaluation criteria.

However, the intended user of this study's decision method is an appointed team that is representative of the organisation(s) stakeholders. With a representative team, the verification and evaluation criteria should not be biased towards or against implementing standardisation. This is maximised by the transparency of results, making it possible to define what design choices or criteria influence the result more than others. This, together with the iterative nature of the decision method, draws both advocates and opponents to a middle ground of consensus, creating a level of objectivity.

Whether one or multiple asset management organisations are considered, the composition of the team should be representative of all involved organisations. With multiple organisations, multiple destination plans of the management areas and the different stakeholders' priorities, wants and needs in the different organisations should be considered. However, it is key that both the PoR and PoA are precisely defined otherwise the verification and evaluation will not result in consensus. In addition, if the organisation does not support the appointed team, the results will not be implemented, with the current bottlenecks remaining.

In short, the decision method's success relies on a team consisting of representative stakeholders supported by the organisation(s) and the possibility of reaching a consensus. However, as long as this is ensured, the method's transparency and iterative nature push the user to a level of objectivity.

# 7. Conclusions and Recommendations

A decision method to support asset management organisations in implementing standardisation into their R&R process is developed in this study. This decision method consists of a systematic series of steps individuals or groups follow to determine the best course of action to implementing standardisation into the process of R&R of technical assets. This chapter starts with the conclusions of this study, followed by the recommendations for future research.

## 7.1. Conclusions

The objective is defined as:

> **To develop a decision method for implementing and assessing standardisation in order to improve the Replacement and Renovation process of Hydraulic Structures.**

The developed General Decision Method is presented in Figure 7.1.

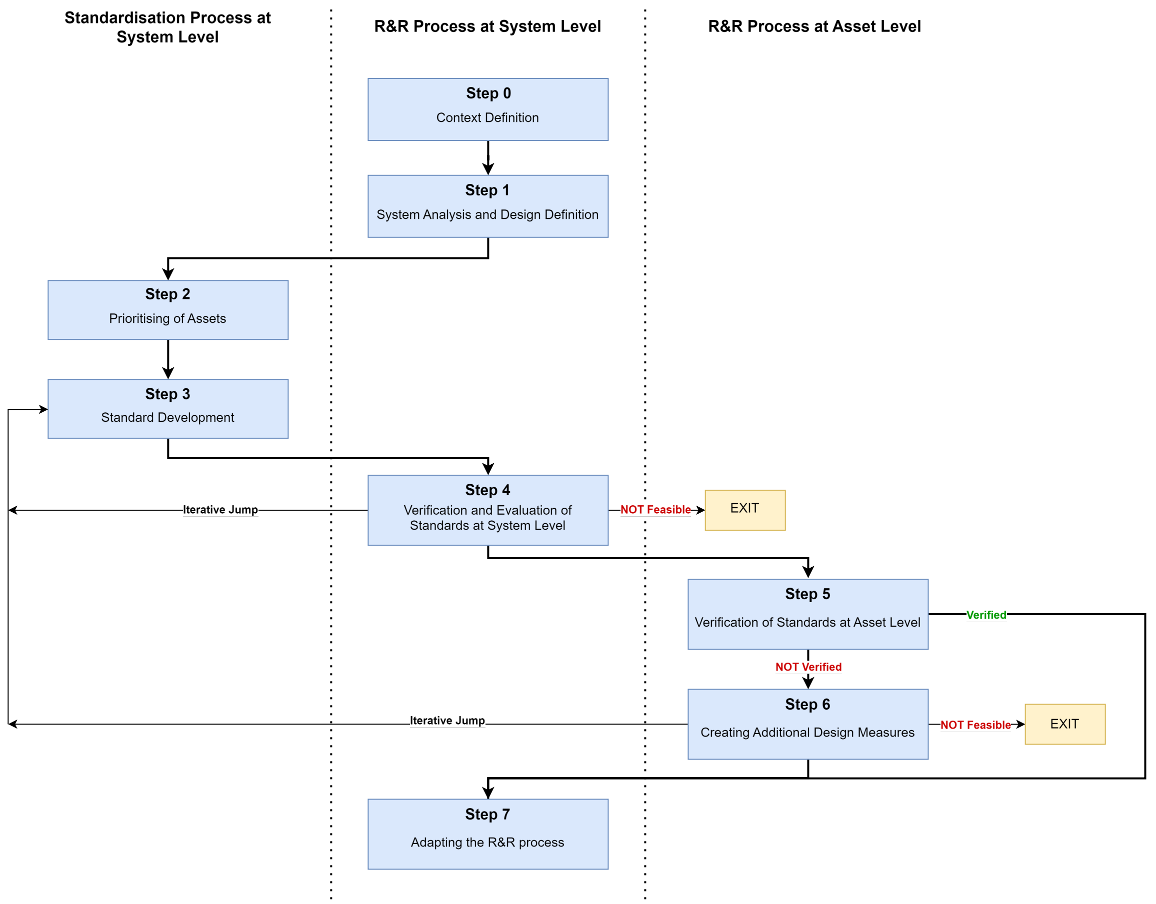



**Figure 7.1:** General Decision Method

Two conclusions are drawn addressing whether the developed decision method reaches the objective:

1. **The decision method enables organisations to implement and assess standardisation of assets and applies to a broad selection of cases.**

   While the method does not prescribe standards based on the asset management organisation's input, it does guide the organisation in creating efficient standards that are implementable in multiple assets while limiting the possibility of switching to an individual approach. This is due to three elements in the decision method. The first is that standards are created for a selection of assets. This selection is based on the technical similarities, priority and potential of assets. This starting point ensures that standards are suitable for multiple assets without requiring additional engineering. The second element is that the decision method supports organisations in creating clusters for standards to limit overdimensioning. Cluster requirements prevent organisations from creating many clusters with few assets. The third is that the generalisation showed that the decision method applies to technical assets with similar boundary conditions. This again supports the creation of efficient standards. These three elements of the decision method all limit the adoption of an individual approach for R&R and address the fragmentation issue.

   In addition, the method guides organisations into creating verification and evaluation criteria using measurable parameters, such as time or budget. The criteria are created before starting the standardisation process (Step 1). As the method is developed for both a qualitative, semi-quantitative, or full-quantitative approach, an organisation is facilitated to create their own criteria and approach to finding solutions fit for their unique management area. However, independent of the approach, the method guides organisations to assess the effects of standardisation at both a System Level and Asset Level. This assessment at two levels with verification at both levels prevents contradictory demands while highlighting that the system is more important than a single asset.

2. **The decision method's transparency, iterative nature with limits, and integration of standardisation into the larger R&R process pushes asset management organisations to break through the bottlenecks (e.g. time or capacity) that normally limit the implementation of standardisation and/or hinder the R&R process.**

   There are multiple key elements that indicate that the decision method can be used to improve the R&R process. First, the method integrates the standardisation process into the R&R process, making it a central element in the R&R of assets rather than a side project. Moreover, it is possible to relate negative (and positive) results to the design choices of influence, and iterative jumps for optimisation are indicated. The decision method's iterative nature and transparency push both opponents and advocates of standardisation to speed up the R&R process towards an optimum solution.

   Furthermore, to stop the endless optimisation of standards and never seeing results, the method guides the organisation in defining what parts of the required R&R are a must-have (requirement) and what is a nice-to-have (ambition). At last, the method guides management organisations in using the verified and evaluated standards to improve the prioritisation of the R&R process. This optimisation helps asset management organisations allocate their resources efficiently.

   At last, because the decision method includes iteration limits and exit strategies, a possible endless process of optimising standards without seeing results is avoided. This limit defines a clear moment in the process where an organisation can disregard specific standards or standardisation in general for the considered assets.

This decision method is a starting point for asset management organisations that want to start with implementing standardisation into the R&R process. A potential benefit of using the decision method is increased efficiency of the design process, as a learning curve is expected, saving time and money. Furthermore, the results can be used for an in-depth discussion about the feasibility of standardisation in the considered management area.

## 7.2. Recommendations

The results of this study are promising and can be used as a step in the more extensive process of implementing standardisation into asset management. However, there are various possibilities for future research.

### Recommendations for testing the method for more applications

- Execute the decision method for the same asset type considering a different management area.

  The case study was executed for pumping stations in Waternet's management area, resulting in standards with multiple clusters. To make comparisons possible, the decision method should be executed for pumping stations in other management areas. This could help define the decision method's sensitivity.

- Execute the decision method for other asset types due for R&R.

  While the decision method was verified and validated for a single asset type, pumping stations, the method should also be executed for other asset types. Other asset types will contain different components defined by other normative boundary conditions.

- Perform additional case studies using the decision method for the design process of new assets.

  The developed decision method focuses on technical standardisation within the R&R process. The generalisation showed potential for using the method in other aspects of asset management, such as new construction. Additional case studies should be performed using the decision method for the design process of new assets, followed by case studies considering a combination of new construction and R&R projects. If the combination results in efficient standards, the fragmentation issue could be further addressed.

- Execute the decision method using different approaches to visualise cross-correlations between standards.

  The cross-correlations between components should be clear even with many components and standards present. Knippenberg (2021) presented one approach for finding the optimal standard for one asset using a CIM. However, within this study's decision method, multiple assets are considered simultaneously, and the optimal approach to presenting the cross-correlations should be found.

- Execute the decision method using a full-quantitative approach.

  The quantitative effects on budgets and time are the most important as these affect the resources of asset management organisations and will determine whether standards are accepted. This study used a semi-quantitative approach, but a full-quantitative approach is required to fully understand the input and effects of design decisions.

### Recommendations for further development

- Create a programme with a Graphical User Interface (GUI).

  This decision method does not automatically generate output based on the asset management organisation's input. Multiple steps require the organisation to create graphs to visualise the effects of specific design choices. To make the decision method more user-friendly, a programme could be created that visualises the effects of design choices made by asset management organisations on the requirements and ambitions.

- Create a bridge between technical standardisation and process standardisation.

  The interviews showed that organisational changes are required to implement technical standardisation. The current individual approach does not share the approach of the decision method to consider multiple assets simultaneously. Because of this, a bridge should be created between technical standardisation and process standardisation. This would affect the contract procedure. Instead of adopting an individual approach, where a new contract is created for each asset, one tender should be created for multiple assets (projects). This would require the asset management organisation to define the System Families of even the Asset Families beforehand, depending on the desired size of the tender contract.

#### Recommendations for asset management organisations experiencing the described bottlenecks

- Switch the mindset of ‘Proof of success before starting’ to ‘Start to see results’

  While this decision method leaves multiple possibilities for future research, it is still a starting point for organisations to integrate standardisation into their R&R process. It supports the organisation in creating substantiated results and helps them define whether standardisation is the solution to their bottlenecks. However, to reach this consensus, organisations have to start with the process instead of expecting to see results prior to investing resources.

- Start with familiarisation before implementation.

  Asset management organisations should begin by familiarising themselves with the decision method and executing case studies on their respective management areas. Then, when the organisation is sufficiently familiar with the decision method, other stakeholders should be included.

- Assign a team to oversee the process and objectivity.

  A control team should be assigned to ensure that no premature decisions are made before the method indicates a decision moment. The team should consist of employees from different hierarchical levels, each with their own expertise. This way, standardisation is given a fair shot and a substantiated decision can be made in the end.

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# A. Interview at Rijkswaterstaat

Datum: 5 juli 2023
Locatie: Rijkswaterstaat, Utrecht
Aanwezig: Maurice de Graaf (Rijkswaterstaat), Iris Kolk

**Kolk**: Het project ‘MultiWaterWerken’ loopt al enige tijd, zou je een update kunnen geven over het project en de rol van standaardisatie daarbinnen?

**De Graaf**: Het is van belang om te weten waarom je standaardisatie toepast, hierin zijn namelijk verschillende gedachtegangen. Een voorbeeld is internationale partners, zoals Duitsland. Duitsland is heel erg van de engineering time, dus enigszins open capaciteit in de oplossing, robuustheid vinden ze niet erg want het moet snel worden gedaan.

Bij MWW is een gedeelte ook deze vraagcapaciteit maar het stukje beheer en onderhoud, dus beschikbaarheid en betrouwbaarheid, is ook erg belangrijk. Hierbij ga je veel meer kijken naar de uitwisselbaarheid van onderdelen, of ze op de plank kunnen liggen. Dat zorgt ervoor dat onderdelen, zoals bewegingswerken bij sluizen, eerder gekozen worden om te standaardiseren. Terwijl, als je gaat kijken naar een onderdeel zoals sluisdeuren, waar meer engineering in zit, dan ontwerp je het en dan raak je het de volgende 50 jaar niet meer aan. Dit maakt sluisdeuren minder interessant voor het gedeelte beheer en uitwisselbaarheid.

Voor waterschappen is het definiëren van het doel ook belangrijk. Willen ze de engineering time omlaag halen of vooral de beschikbaarheid en betrouwbaarheid verhogen.

Waar we nu staan met RWS bij MWW. We hebben nu meerdere onderdelen voor elkaar. Bijvoorbeeld het stukje bewegingswerken. We hebben de eerste concepten en een standaard vraagspecificatie. Daarnaast hebben we gekeken naar het proces van keuzes maken. Hierbij staat LCC (Life Cycle Costs) centraal, hoeveel kost het om te maken over de gehele levensduur. De milieulast wordt ook steeds belangrijker, de LCA (Life Cycle Analysis). Deze bestaat uit vier modules. In het begin van de cyclus is het relatief makkelijk om mensen op één lijn te krijgen. Aan het einde van de levensduur, module C en D, wanneer je eventueel weer grondstoffen terug wilt winnen, daar wordt het helemaal lastig. Juist door een stukje standaardisatie, zou in deze fase extra winst te behalen zijn. Je hebt bijvoorbeeld soms een bepaalde hoeveelheid afval nodig voordat je kunt recyclen, dit is dan beter uit te zoeken.

**Kolk**: Dus de standaardisatie is dan eigenlijk meer voor het geheel?

**De Graaf**: Het geheel en een gedeelte wat gestandaardiseerd kan worden is ‘op welke manier maken we de afweging?’. Dat is vaak relatief hoog over, maar het helpt een stuk. Bijvoorbeeld bepalen hoeveel geld extra opzijgezet wordt voor een stukje duurzaamheid. Als dit alleen al op hoog niveau besloten wordt en niet per project gekeken wordt, scheelt dat veel tijd.

Naast tijd scheelt het ook moeite. Bijvoorbeeld voor bewegingswerken. Van de week zat ik met de fabrikanten en zij zijn ook voorstander van een standaard vraagspecificatie. Zij weten dan wat de sample van RWS is en RWS weet wat ze kunnen verwachten. Ze vertelden dat ze laatst een project met een andere klant hadden, waarbij voor 25.000 euro materiaal kosten waren en bijna 20.000 euro aan alle man uren. Door standaardisatie zijn minder man uren nodig en is het niet nodig om elk project een mappenlijst aan te leveren met het bewijs dat bepaalde onderdelen voldoen.

**Kolk**: Zijn veel onderdelen niet al gestandaardiseerd omdat fabrikanten maar bepaalde formaten/-materialen produceren? Ik zou damwanden als voorbeeld noemen. Is het dan specifiek bij bewegingswerken dat er nog veel gestandaardiseerd kan worden?

**De Graaf**: Er zijn inderdaad standaarden, bijvoorbeeld staal S235 of S355. Je maakt hierin een keuze omdat jij als organisatie weet uit ervaring wat wel en niet voldoet. Maar als je gaat kijken naar bescherming van staal heb je thermisch verzinkt, elektrolytisch verzinkt, wel of geen afroesting enzovoorts. Dit zijn allemaal keuzes waarin je een standaard keuze kan maken, zodat het proces vervolgens sneller gaat. Standaarden van keuzes kunnen al een groot verschil maken.

**Kolk**: Wat zijn tips voor iemand die ook standaardisatie toe wil gaan passen bij een project?

**De Graaf**: Les één is: iedereen is voorstander van standaardisatie, totdat ze er achter komen dat het niet hun standaard is, dan komt er weerstand.

**Kolk**: Is dat dan iets waar jullie veel tegen aan lopen nu? En bij fabrikanten dan of werknemers?

**De Graaf**: Intern lopen wij daar tegen aan. Bij fabrikanten moet je uitkijken dat je niet maar één fabrikant overhoudt, en daarmee een monopolie positie krijgt. Een voorbeeld dat nog een obstakel schetst zijn de sluisdeuren. Wij hebben gekeken naar de uitvoering, met als mogelijke materiaal keuzes hout, staal, vezelversterkt kunststof en nog een soort hybride vorm. Vezel versterkt kunststof is een wat nieuwe materiaal, en had veel meer moeite met al het benodigde papierwerk op orde te krijgen, zoals antwoorden op de vragen hoe lang het materiaal mee gaat en wat nodig is aan het einde van de levensduur. Hout kan deze vragen wel beantwoorden maar hout is een natuurlijk materiaal, wat aantrekkelijk is vanwege duurzaamheid, maar RWS werkt normaal gesproken met papieren controles. Heel zwart wit gezegd, natuurlijke materialen scoren dan slechter omdat de kwaliteit erg berust op vakmanschap. Als je iemand hebt die altijd houten sluisdeuren maakt gaat het goed, krijg je een of andere beunhaas, dan houdt de deur het geen 1.5 jaar uit.

Het zijn de praktische zaken waar je tegenaan loopt wanneer je toch kiest voor hout. Het is een aantrekkelijke keuze vanwege het natuurlijke materiaal, de LCA doet het goed, kosten verhogen niet drastisch, maar het zorgt er wel voor dat het werkproces deels aangepast moet worden. Het is een keuze die RWS als organisatie moet maken of ze het proces aan willen passen. Het is dan ook maar de vraag of waterschappen ook bij hun werkprocessen aanpassingen wil én kan maken.

**Kolk**: Terug komend op je statement dat iedereen voor standaardisatie is totdat het niet de eigen standaard is, en dat dat intern erg merkbaar is, heb je hier een voorbeeld van?

**De Graaf**: Weer terugkomend op het voorbeeld van bewegingswerken. Je hebt de elektromechanische spindel en de hydraulische spindel. Beide scholen zijn voorstander van standaardisatie, zolang hun mechanisme wordt gekozen. Wanneer dit niet het geval is, komt er weerstand. RWS lijkt nu richting de elektromechanische spindel lijkt te gaan, aangezien dit bepaalde voordelen heeft. De voorstanders van de hydraulische spindel komen nu met bepaalde kanttekeningen zoals dat we de aanvaar niet goed hebben meegenomen en hydraulisch zou daar beter scoren door een ontsnappingsprofiel. Of dat het onderhoud geschat is op 20 jaar voor elektromechanisch, terwijl het eigenlijk 15 is waardoor de kosten omhoog gaan en hierdoor hydraulisch toch beter scoort.

**Kolk**: Dus als je standaardisatie toe wilt passen, moet je bepaalde voordelen opgeven van andere opties.

**De Graaf**: Inderdaad, je moet altijd bepaalde voordelen opgeven. In Duitsland hebben ze deze discussie opgelost door om een tafel te gaan zitten en als ze er niet uitkwamen te stemmen tot een keuze. In Nederland zijn soms rapporten van 40 of 50 pagina's over welke kant gekozen is met welke redenen. In Duitsland is het een klein stukje tekst met welke keuze het is geworden. Zoals bij bewegingswerken zou de tekst luiden: 'Het is de elektromechanische spindel geworden in plaats van hydraulisch, omdat wij geen hydraulische leidingen of bewegende deeltjes willen bij de sluisdeuren, daarom zullen wij bij nivelleer schuiven altijd spindels gebruiken.' Meer wordt er niet over geschreven, en als je het er niet mee eens bent ga maar naar hogerop, en die kapt het af.

**Kolk**: Is het probleem bij RWS dan dat er te veel partijen zijn, of te veel mooie ideeën?

**De Graaf**: Nee, het is meer het proces dat te langzaam is. Bij RWS is er veel oplossingsruimte gegeven waardoor er soms gaten ontstaan. Er zijn ook veel voordelen aan veel ruimte, en we hebben besloten standaardisatie te willen, alleen het duurt even.

**Kolk**: Wat denk je dat grote leerpunten zijn geweest tijdens het project?

**De Graaf**: Een groot leerpunt is dat uitvoering een grote rol speelt. Hiermee bedoel ik de mensen die dagelijks in aanraking komen met de objecten. Zeker bij waterschappen zijn er nog veel mensen die elke dag de objecten bedienen, zolang zij niet geloven in een bepaalde oplossingsrichting is de kans op succes klein. Als tweede is het belangrijk om te weten wat jouw rol als organisatie is in de markt. Met andere woorden, hoe belangrijk jij als speler bent. Bij RWS denken we vaak dat wij een bepalende factor zijn want we hebben 120 of 140 sluizen. Terwijl als je gaat kijken naar stalen damwanden of bewegingswerken, zijn wij helemaal niet zo groot. De leveranciers hiervoor zijn wereldwijd, en onze standaard moet aansluiten op die van de leverancier. RWS kan kiezen of dit product 1 of product 2 wordt, maar voor iets totaal nieuws moet de afname groot genoeg zijn, wat vaak niet het geval is. Dit zal hetzelfde zijn voor waterschappen.

Daarnaast is het definiëren van de afwegingscriteria belangrijk. Bijvoorbeeld het stukje duurzaamheid ten opzichte van beschikbaarheid en betrouwbaarheid. Een optie zal beter op het eerste scoren, een ander op het tweede. Het is zelden dat één optie op alle vlakken het hoogst scoort. Als je van tevoren het gewicht van de criteria duidelijk hebt, scheelt dat veel discussie. Want wat ik persoonlijk vaak gemerkt heb, is dat als een product het lijkt te worden, gaan tegenstanders dat ene punt waar het lager scoort omhoog brengen. Bij de gewichtsverdeling is vaak 80 procent de prijs.

**Kolk**: Jij zegt dat prijs vaak leidinggevend is?

**De Graaf**: Het kan ook zijn dat je volledig voor duurzaamheid kiest. Verwacht ik niet helemaal, want prijs is belangrijk, maar het kan.

**Kolk**: Kun je verder toelichten wat voor vooruitgang er is bij het maken van vraagspecificaties?

**De Graaf**: Voor bewegingswerken zijn we een stuk verder, zoals op het gebied van ijsbestrijding. Er waren vier mogelijke systemen om ervoor te zorgen dat er geen ijs tegen de sluisdeuren aan komt. Door een data analyse kwamen wij tot de conclusie dat één bepaald systeem veel beter presteert dan de andere. Nu dit duidelijk is, gaan we niet meer elk project opnieuw aan de markt vragen om te bewijzen welke het beste is. Alleen deze ene specifieke wordt nog gekozen.

Iets wat ik heb gemerkt, is dat ook veel kennis niet bij de ingenieursbureaus zit. Als je gaat kijken naar specifieke kennis, dan zit deze vaak bij de leveranciers. Ook ingenieursbureaus vragen bij leveranciers wat de beschikbaarheid en betrouwbaarheid, en nog andere kennis.

**Kolk**: Dus leveranciers spelen een grotere rol bij standaardisatie dan men origineel zou denken?

**De Graaf**: Ja zeker, hierbij heb ik ook wel een grappig voorbeeld. Voor het stukje spindels en bijbehorende zaken heb ik met een leverancier gesproken die ook aan waterschappen levert. Bij RWS hebben we de ROK, Richtlijn Ontwerpen Kunstwerken, en daarin wordt gemeld dat elk object standaard CC3 moet zijn. Hierin kun je van mening verschillen, omdat over het algemeen CC3 redelijk zwaar is. Een ziekenhuis is bijvoorbeeld CC2. Toch hanteert RWS CC3 omdat wij vinden dat er anders een te groot risico met te veel schade kan voorkomen, omdat RWS de infrastructuur van Nederland regelt. Nou hebben de waterschappen ervoor gekozen om ook de ROK te hanteren, omdat zij willen rusten op de mankracht en capaciteit van RWS om deze afweging te maken. Dit zorgt ervoor dat voor een klein object in een boerensloot ook CC3 aangenomen wordt. Stel je zou het via STOWA bepalen, dan zou CC2 ook voldoen voor veel gevallen.

Daarnaast leidt het ook tot onmogelijke eisen. Bijvoorbeeld, als je een onderdeel in PVC wilt uitvoeren, is dat nooit CC3. Dit stellen van onmogelijke eisen was ook een reden waarom de ontwerpruimte aan de markt werd gegeven. Als jij als organisatie van tevoren alle eisen vast hebt staan, dan komt de aannemer terug om te vragen om meer budget omdat onmogelijke eisen worden gesteld. Zoals: de standaard kiest een bepaalde type aandrijving, maar deze is te licht voor dit project, dus zijn er toch aanpassingen nodig.

**Kolk**: Denk je dan dat door standaardisatie snel overgedimensioneerd zou worden om dat risico te verminderen?

**De Graaf**: Niet perse snel overdimensioneren. Je kunt tijd besparen met standaardiseren, maar je moet wel na blijven denken of elke keuze opgaat voor dit specifieke project. Je moet niet blind zeggen dat de standaard in elk contract toegepast kan worden.

**Kolk**: De ROK als voorbeeld genomen, denk je dat er delen van de standaardisatie die RWS toepast, niet toepasbaar zijn voor waterschappen?

**De Graaf**: Ik denk dat een groot gedeelte te zwaar gaat zijn voor de eisen van een waterschap. Sommige waterschappen hebben wel objecten met primaire functie, maar de grote massa zit naar mijn inzicht bij de regionale keringen. Dus als je de normen van RWS gaat toepassen, zal een groot gedeelte overgedimensioneerd zijn.

**Kolk**: Zijn er oplosrichtingen of ideeën achterwege gelaten bij RWS omdat de objecten te belangrijk waren die misschien wel zouden werken voor de objecten van een waterschap?

**De Graaf**: RWS beheert objecten die maar in beperkte aantallen voorkomen, en al helemaal weinig objecten die dezelfde afmetingen hebben. Bij een waterschap zijn er veel meer gelijkenissen. Hierdoor is een bepaalde mate van bijvoorbeeld een voorraad mogelijk, of andere zaken die een waterschap sneller voor elkaar krijgt omdat ze kleinere objecten hebben. Ik denk dat daar zeker veel voordeel uit te halen valt.

Toch denk ik dat een waterschap al een semi standaard heeft liggen voor bepaalde objecten, waarin ze alleen de getallen hoeven aan te passen.

**Kolk**: Zijn dat niet vaak standaarden voor een nieuw object ontwerpen, en niet voor vervangen en renoveren? Als het meerdere nieuwe objecten zijn kun je makkelijker uniformiteit creëren maar bij vervangen en renoveren heb je al veel randvoorwaarden van objecten die er al staan. Ook is er veel complexe kennis nodig om deze objecten te gebruiken. Zou standaardisatie een oplossing kunnen zijn om dit meer behapbaar te maken?

**De Graaf**: Ik vraag mij af hoe makkelijk het is om dit te standaardiseren. Je moet bepalen hoeveel aanpassingen je wil of kan doen en tot wel niveau je wilt standaardiseren. Bijvoorbeeld alleen in de aangrijpingspunten of ook in het tussenstuk. Het voelt bijna als 'We hebben veel auto's die tussen 1910 en 1950 zijn gebouwd die allemaal gerepareerd moeten worden. Hoe kunnen we zonder veel onderzoek een standaard manier vinden om te bepalen hoe de motor moet worden aangepast en hoe we er tegelijk een nieuwe motor in kunnen stoppen'. Dat is een uitdaging.

**Kolk**: Zeker waar. Zijn er dan oplossingen die niet, of juist wel, op de grote schaal van RWS werken die op een kleinere schaal, zoals een waterschap, zouden werken. Ik kan mij voorstellen dat de condities per object van RWS erg verschillen.

**De Graaf**: Zodra gewapend beton aangepast moet worden, is het vaak goedkoper om van de standaard af te wijken. Standaardiseren wil je bij onderdelen van staal of andere onderdelen waar het makkelijk is om een kleine aanpassing te doen, zoals het lassen van een oogje.

De grootste faalkans zit bij de bediening en besturing, dus daar is de grootste winst te halen. Hier is dan ook de meeste vooruitgang in. Ik kan mij voorstellen dat dat ook het geval is voor waterschappen. Zolang je verzekerd bent dat de aanpassingen ook uitvoerbaar zijn.

Dus het stukje bediening besturing, elektrotechniek en werktuigbouwkunde zijn te doen. Ga je naar beton en staal kijken, dan heb je specifieke oplossingen en wordt het snel heel duur om er iets aan te verbouwen omdat het erg locatie gebonden is. Bij RWS zijn het verval van water, de ondergrond en de aanwezigheid van kwelschermen verschillend per object, dus met standaarden ga je snel overdimensioneren en dat is het niet waard.

**Kolk**: Je zei eerder dat er wel gekeken is naar het standaardiseren van sluisdeuren.

**De Graaf**: Klopt, maar op dit moment vinden wij de levensduur zo lang en uitwisselbaarheid erg laag, waardoor standaardisatie niet gaat werken. We kunnen kijken naar een voorraad maken, altijd 1 sluisdeur bijvoorbeeld, maar ook daarvoor zijn de sluizen te verschillend. We hebben wel ervoor gekozen het materiaal van de deuren te standaardiseren, hout voor kleine sluizen en staal voor grote. Dus de methode wel standaardiseren, maar de sluisdeur zelf niet.

In het kort, onderdelen met een kortere levensduur standaardiseren creëert eenheid in het areaal. Maar met een sluisdeur van 50 jaar krijg je geen eenheid. Bewegingswerken die 25 jaar meegaan standaardiseren werkt al beter, maar bediening en besturing wat 10 jaar mee gaat heeft de grootste win kansen.

**Kolk**: Eerder zei je al dat het doel van standaardisatie bij jullie de bediening en besturing makkelijker maken is.

**De Graaf**: Sneller, eenduidiger en minder fouten, daar zit het meeste voordeel. Daarna zijn de meeste kansen bij de werktuigbouwkunde. Op civiel technisch gebied is het lastiger, omdat er zo veel omgeving specifieke randvoorwaarden zijn waar je rekening mee moet houden. Hierom is het vaak de moeite waard om vanaf het begin engineering toe te passen in plaats van een standaard die je toch weer aan moet passen.

**Kolk**: Terug komend op het MWW project, ik hoorde dat er twee MWW sluizen gebouwd waren. Kun je dat verder toelichten?

**De Graaf**: We zijn bij beide uiteindelijk anders gaan werken. Bij de Marijkesluizen hebben we gekeken naar standaardisatie, maar vanuit kosten werd het moeilijk en ook de vraag verscheen of iets wat nog voldoet vervangen moet worden omdat we naar één standaard willen. Bij Tilburg 3 hebben we nu een sluisdeur van vezel versterkt kunststof toegepast.

Bij RWS willen we nu per project voor één onderdeel een standaard hebben. Voordeel hiervan is dat een project een deadline en geld heeft. Ik zou deze werkwijze ook aanraden aan het waterschap. Als ze bijvoorbeeld een gemaal willen vervangen, dan eerst bepalen welk onderdeel binnen het project gestandaardiseerd kan worden en later kijken of dit ook bij andere gemalen toegepast kan worden. Dit kost eventueel extra capaciteit en geld, maar op deze manier boek je vooruitgang.

**Kolk**: Dus eigenlijk per casus kijken wat er gestandaardiseerd kan worden en is het later ook bruikbaar bij andere projecten?

**De Graaf**: Bij een casus waar sowieso al iets vervangen moet worden, de opdracht verbreden om te kijken met welke aanpassingen het eventueel ook bij een volgende opdracht gebruikt kan worden. We merken dat dit veel beter werkt dan een onderdeel los te bekijken. Je kan niet testen of je een goede standaard hebt, totdat het ergens gebouwd is. Zo kom je er achter waar je tegen aan loopt, wat werkt en wat niet werkt.

**Kolk**: Hoe werkt dat dan binnen MWW?

**De Graaf**: Standaardiseren is daarom een onderdeel van het project MWW. Bij de Marijkesluizen is ervoor gekozen om een andere werkwijze te gebruiken door de kosten en doorlooptijd. Bij duurzaamheid is het ook altijd de vraag hoeveel budget er voor is.

**Kolk**: Is duurzaamheid vaak een vast percentage van je budget?

**De Graaf**: Ja, orde grote 40/60 procent wordt door kwaliteit bepaald en de rest door geld, en van het deel kwaliteit moet minstens 1/3e deel weer duurzaamheid zijn.

**Kolk**: Wat zijn voorbeelden van meer duurzaamheid doorwerken in een ontwerp?

**De Graaf**: Het is belangrijk om te weten waarop je stuurt. Zoals weten wat eigenlijk voor grote milieulasten zorgt. Is het de elektriciteit die je gebruikt, of het materiaal om iets te maken. Een voorbeeld is een groot panama wiel. Er is veel materiaal nodig om het wiel te maken, en daarna nog extra beton er omheen. Alleen, zodra het werkt is het een efficiënt systeem met een klein elektromotortje wat door middel van armwerking alles kan aandrijven. Je kan ook kiezen voor een hydraulische cilinder, dit is een stuk compacter, maar er zit wel olie in. De spindel gebruikt meer elektriciteit maar nauwelijks olie. Je moet dan een bepalen welke van de olie, het extra materiaal, of de elektriciteit de meest duurzame keuze is.

Om een ander voorbeeld te geven: oeverbescherming. Een optie is stenen plaatsen op een filterlaag om te zorgen dat zand er niet doorheen kan. Daarnaast is nog geotextiel, maar daar zit plastic in. Wij hebben een gekeken of we voor het granulaire filter gaan, of voor het geotextiel. Voor het geotextiel moet je wel bijvoorbeeld juten aanvoeren. Juten bleek alleen redelijk vervuilend te zijn, omdat het op dit moment in India wordt verbouwd met veel bestrijdingsmiddelen. In Nederland zou het al een stuk minder vervuilend zijn geweest. Het grind voor een filterlaag was gevoelsmatig beter voor het milieu, maar het bleek dat je hiervoor veel extra grond moest verzetten, het opblazen van een berg kost ook veel energie en het vervoer met steenkolen is niet veel beter. Uiteindelijk bleek het geotextiel daarom het meest duurzame alternatief te zijn, ondanks het voorgevoel.

Met sluisdeuren hebben we ook gekeken naar het meest duurzame alternatief. Het bleek al snel een stalen sluisdeur te zijn aan gezien grote bomen uit Afrika importeren ook niet duurzaam is. Vezel versterkt kunststof is een nieuw materiaal en kan veel, het wordt al sinds de 70e jaren voor windmolens gebruikt. Echter, een kanttekening is het hergebruik. Bij een wedstrijd van Arcadis kwam als beste optie een pingpongtafel, dus om nu te zeggen dat over 50 jaar vezel versterkt kunststof het ei van Columbus gaat zijn is nog onduidelijk.

**Kolk**: Wat denk jij dat binnen de komende 50 jaar grote stappen gaan zijn binnen MWW of RWS op het gebied van standaardisatie?

**De Graaf**: Bij bediening en besturing gaat de meeste winst zijn. Ook juist omdat er een omslag gaat zijn van handmatig alles programmeren naar meer system based engineering, dus dat de computer de code voor jou genereert als jij de randvoorwaarden geeft. Dit zorgt voor reproduceerbaarheid en wordt het minder foutgevoelig, wat winstgevend is. Ik denk ook dat bij werktuigbouwontwikkelingen gaan zijn op dezelfde manier. Het uitwisselbaar maken van objecten verwacht ik minder vooruitgang. RWS is niet groot genoeg om altijd een reserve onderdeel op voorraad te hebben. Sluizen zijn daarvoor net te divers. Misschien kunnen er een paar bij de fabrikanten liggen, gewoon een soort standaard gedeelte. Het standaardiseren van kolkafmetingen gaat niet gebeuren. Dit met de simpele reden dat er al een sluis bestaat, en deze afbreken en een nieuwe maken erg kostbaar is. Ook door logistiek is het niet mogelijk, een grote vaarweg afsluiten is hetzelfde als de A2 voor een jaar dichtgooien om te standaardiseren.

**Kolk**: Dat is toch ook vaak de reden dat er een nieuwe sluis naast de oude wordt gebouwd, als daar ruimte voor is?

**De Graaf**: Ja en je ziet ook vaak dat het achterland is ingericht op die al bestaande sluisafmetingen. Een kleine afwijking groter kan vaak wel, kleiner gaat niet gebeuren. De bestaande sluis is ontworpen voor bepaalde schepen die er net inpassen. De verwachting is niet dat deze binnenkort gaan veranderen. Veranderingen in de sluisdeuren zullen ook meevallen omdat deze een levensduur van 50 jaar of langer hebben. Echter, onderdelen van sluisdeuren zoals nivelleringskleppen zie ik zeker wel meer standaard worden. Voor zaken als bodembescherming gaan vooral de rekenmethoden gestandaardiseerd worden, zoals de kwaliteitscontrole. Maar ook bodembescherming gaat 100 jaar mee, dus het is nog maar de vraag of verdere standaardisatie nut heeft. Op het gebied van engineering zijn we al een heel eind met standaardisatie, zoals normen voor beton en staal die al erg ver zijn. Overal waar er interactie is met de omgeving die heel belangrijk en dynamisch is in Nederland zal niet snel gestandaardiseerd worden.

De kleinere onderdelen die veel voorkomen en engineering niet uit kan, daar wordt gestandaardiseerd. Dit geldt vooral voor een waterschap. Om je een idee te geven, ik heb gewerkt aan de nieuwe sluizen Tilburg, waar het budget richting de 80 miljoen gaat. Daar durf je snel wat engineering toe te laten. Een gemaal in IJmuiden wat wij hebben pompt 260 $m^3$ per seconde, terwijl een waterschap spreekt over een groot gemaal als deze 30 $m^3$ per seconde pompt. Voor een gemaal van een waterschap is minder budget voor engineering, daar kan wel gekozen worden voor een meer standaard oplossing want het maakt toch niet uit als er 10% extra capaciteit is. Bij RWS worden dit soort zaken speciaal voor RWS gemaakt, zoals bij de Afsluitdijk.

**Kolk**: Een ander soort vraag. Kijkend naar klimaatverandering, zie je dit terug in ontwerpen bij vervanging en renovatie?

**De Graaf**: Afhankelijk van welk waterschap je naar kijkt, maar clusterbuien zijn vaak belangrijk. Voor RWS is zoet-zout water erg belangrijk en een probleem op dit moment. Als je praat over klimaat adaptief, dat klinkt altijd leuk, maar het meest effectieve wat ik persoonlijk heb gezien is overdimensioneren. Weer omdat beton en staal duur zijn, dus het is het meest effectief om gelijk meer te gebruiken dan iets te slopen en opnieuw te maken. Beide zijn ook niet duurzaam. Het is de vraag wat je wilt. Een pomp vervangen is ook makkelijker gezegd dan gedaan want er komt veel civiel werk bij kijken. Dus voor waterschappen: zet grotere pompen neer zodat er gelijk een overcapaciteit is.

**Kolk**: En op gebied van functionele eisen? Zoals grotere schepen door toenemende vraag naar transport, overdimensioneren jullie daar ook al voor?

**De Graaf**: Nee, er zijn standaard vaarwegcorridors, bepaald door richtlijn vaarwegen. Dat zijn de schepen die over die vaarweg kunnen varen. In de praktijk vragen schepen of ze ook met net grotere schepen gebruik mogen maken. Als je gaat kijken naar klimaatadaptieve vaarwegen, dan heb je bijvoorbeeld de Waal die langzaam een regenrivier begint te worden. Dat betekent dat er meer stuwen moeten komen, wat erg vervelend is omdat dan ook sluizen moeten komen met als gevolg veel schutverlies. Ook de haven van Rotterdam heeft dan een sluis nodig bijvoorbeeld. Ik weet niet of schepen per definitie groter worden. De reden daarvoor zou zijn dat personeelskosten te duur worden. Je hebt ook een andere denkschool die zegt dat we naar autonoom bestuurbare schepen gaan, misschien zijn juist dan kleinere schepen die rechtstreeks naar hun doel varen effectiever. Klimaatadaptief zit je nu eerder te denken aan extra sluis of andere toevoegingen, dan je huidige objecten meer robuust maken voor de toekomst.

Bij RWS zijn vooral zoetzout water en periodes van droogte een probleem. Voor dat laatste moeten er manieren gevonden worden om water eventueel vast te houden. We hebben nu stuwen in de Maas die te veel lekverlies hebben voor die droge jaren. Voor het zoetzout water probleem, ben ik nu betrokken bij een project in IJmuiden die bezig is met een zoetzout dam, zodat vooral zoutwater in plaats van zoetwater afgevoerd wordt. Dit soort maatregelen gaan we steeds meer krijgen.

# B. Interviews at Waternet

## B.1. Asset Manager

Datum: 17 oktober 2023
Locatie: Online via Teams
Aanwezig: Pieter Rinia van Nauta (Waternet), Iris Kolk

**Kolk**: Kun je jouw rol en functie bij Waternet toelichten?

**Rinia van Nauta**: Mijn functie is asset manager en ik ben betrokken bij het maken van plannen met betrekking tot beleid en assets van het watersysteem. Mijn huidige rol bestaat voornamelijk uit het adviseren van opdrachtgevers bij de realisatie van nieuwbouw en renovatie van gemalen, bruggen en sluizen.

**Kolk**: Op wat voor manier krijg jij nu met standaardisatie te maken in je werk en waar in het proces kom je het tegen?

**Rinia van Nauta**: Ik kom standaardisatie tegen bij het invullen van het Programma van Eisen. Daar komen vaak standaard stukken tekst in terug. Kijkend naar de assets zelf, kom ik het vooral tegen bij de proces automatisering van de installaties en bij elektrische installaties want die lenen zich het meest voor standaardisatie. Het standaardiseren van pompen en dergelijke is nog niet gedaan. Voor de kleinere installaties zou je ook een standaard kunnen ontwerpen omdat die relatief overzichtelijk zijn. Meestal nemen we het voorgaande project als voorbeeld, en passen we hier en daar wat zaken aan om het passend te maken.

**Kolk**: Het overnemen van delen van het vorige project is voornamelijk voor het vergemakkelijken van het proces aangezien er zo minder nagedacht hoeft te worden bij elke nieuwe opdracht. Bevalt deze werkwijze en wordt hij veel toegepast of moeten er veel aanpassingen gedaan worden?

**Rinia van Nauta**: Op dit moment zie ik het nog onvoldoende terug, dat komt doordat er op dit moment een grote wisseling van de wacht is en dus mensen de standaard niet meer kennen. Bij een project team waar je al meerdere gemalen mee hebt gebouwd, dan weet je 'we gaan het zo doen', maar waar nieuwe mensen aansluiten moet het eerst worden toegelicht.

**Kolk**: Wat zijn zaken die niet bekend zijn en daarom opnieuw uitgezocht worden waarvan jij vond dat ze juist heel goed werkten?

**Rinia van Nauta**: Dat kom je op bijna alle vlakken wel tegen, zoals welke spant moet je toepassen of welke pomp heeft veel of weinig onderhoud.

Daarom proberen we nu het standaard te maken om aan het begin van het project goed en kort te overleggen over de uitgangspunten, zoals wat is het nut en de noodzaak van de nieuwe installatie. Door dit te doen met een klein clubje, scheelt dat veel overleg en uitzoekwerk.

**Kolk**: Is onduidelijke communicatie een oorzaak van standaarden die niet gebruikt worden en op welk gebied dan voornamelijk?

**Rinia van Nauta**: Er worden allerlei onderzoeken gestart op zoek naar de beste oplossing, terwijl met een kort overleg met de belanghebbenden ook afgesproken kan worden hoe het gedaan gaat worden. Zonder die enorme studie daar aan te wijden.

**Kolk**: Denk je dat er nu informatie mist, die het makkelijker zou maken voor kleine groepjes om die keuzes te maken?

**Rinia van Nauta**: Ik denk dat het vooral het organiseren van het geheel is. Er zijn een aantal mensen die nog genoeg kennis hebben van hoe de standaarden werken, maar dit wordt nog te weinig overgebracht naar de nieuwe collega's. Je zal meer moeten doen aan kennisborging.

**Kolk**: Waar denk jij dat er nog veel potentie ligt voor standaardisatie, en hoe zouden deze vertaald kunnen worden in concrete maatregelen.

**Rinia van Nauta**: Het Programma van Eisen is al redelijk gestandaardiseerd. Dit moet wel bij elk project goed doorgenomen worden of de juiste dingen er in staan. Alleen het organiseren van het proces daaromheen en de standaarden de juiste plek geven in het project is het probleem. Weten mensen wat de standaarden zijn, waar ze staan en wat een standaard inhoud. Hebben ze daar voldoende ervaring mee of moeten ze daarbij ondersteund worden.

**Rinia van Nauta**: De potentie zit vooral in het kopiëren van installaties die we al eerder gebouwd hebben, en daar de juiste dingen uit halen. We hebben een dermate grote project organisatie waar vaak dingen opnieuw ontworpen worden terwijl er goede voorbeelden van vorige installaties te kopiëren zijn.

**Kolk**: Met welk doel willen jullie voornamelijk standaardiseren?

**Rinia van Nauta**: Wat mij betreft is het doel van standaardisatie het beperken van de ontwerpvrijheid. Mijn belangrijkste idee daarbij is dat je door ontwerpmogelijkheden te beperken, je minder tijd nodig hebt om een ontwerp te maken. Daar kun je winst in kan halen.

**Kolk**: Bij projecten kunnen nieuwe oplossingen ook positieve neven effecten hebben zoals een duurzamer ontwerp of meer controle over het hele systeem. Nemen jullie de winst die deze neven effecten kunnen hebben ook mee bij de ontwerpkeuzes?

**Rinia van Nauta**: Ja, met name duurzaamheid is een zaak die nu veel aandacht krijgt. Als je daar goed over nadenkt in een standaardoplossing, dan heb je daar eenmalig veel energie in gestoken maar dan heb je ook een goed resultaat. Als je dat steeds opnieuw doet dan ben je elke keer veel tijd kwijt en kun je je afvragen of dat de oplossing oplevert.

**Kolk**: Stel je hebt twee standaardisatie maatregelen bedacht die hetzelfde positieve effect op het budget en de planning hebben, wat voor neven effecten kunnen je dan toch overtuigen om een van de twee te verkiezen boven de ander?

**Rinia van Nauta**: Waar het beheer en onderhoud het meest verbeterd. Bijvoorbeeld, als je op een onverwacht moment wordt geroepen door een storing bij een standaard installatie, dan weet je hoe deze in elkaar zit want die heb je al veel vaker gezien. Dan hoef je niet eerst alle elektrotechnische schema's door te nemen om te onderzoeken wat voor installatie het is en hoe deze werkt. Dat scheelt daarnaast ook bij regulier onderhoud. Als je dezelfde machine vaker moet onderhouden weet je hoe het werkt en gaat het sneller. Onderdelen op voorraad kunnen hebben scheelt ook. Dat zie ik met name bij PLC's (de computers in gemalen). Als die standaard zijn, zijn onderdelen makkelijk uit te wisselen, en hoef je niet te wachten op de reserve onderdelen en je hoeft niet zoveel verschillende onderdelen op voorraad te hebben.

**Kolk**: Wat zijn de negatieve kanten van standaardiseren. Overdimensioneren wordt vaak genoemd, heb je nog meer voorbeelden?

**Rinia van Nauta**: Gekeken naar pompen van gemalen is overdimensioneren een aspect, maar je kunt ook een paar pomptypes kiezen met meerdere ranges. Dan heb je inderdaad op bepaalde plekken een te krachtige pomp waar je meer geld aan uitgeeft dan normaal nodig zou zijn geweest, maar daar staat tegenover dat je veel minder tijd en geld kwijt bent aan engineering en overleggen over ontwerpkeuzes.

Een reden om niet te standaardiseren is dat er te weinig zicht is op de beperkingen van de standaard ten opzichte van waar je hem toepast. Het zou zo kunnen zijn dat een standaard niet past omdat de situatie om andere oplossingen vraagt. Je kunt dan denken aan vispasseerbaarheid. Dat wordt nu redelijk gestandaardiseerd, nu moeten alle gemalen vispasseerbaar zijn, vroeger was dat niet zo.

**Kolk**: Wat zijn de obstakels en nadelen van standaardisatie toe willen passen.

**Rinia van Nauta**: Een obstakel is het reorganiseren van het ontwerpproces waar de standaard in moet passen en wat de standaard voor zou moeten schrijven. Mensen krijgen nu nog te veel vrijheid om hun eigen ontwerp te maken en zijn onvoldoende bekend met de standaarden. Een nadeel is dat je een standaard moet onderhouden. Toen ik bij Waternet kwam werken, hadden we voor de rioolgemalen zes standaarden, van kleine gemalen tot grote, met vier ertussen. Elk jaar gingen we ze onderhouden en reviseren, waar we veel tijd aan kwijt waren. Voornamelijk de grote gemalen, dan gingen we elk jaar het standaard aanpassen, maar dan bouwden we maar eens in de vijf jaar een groot gemaal. Dan schiet de standaard zijn doel voorbij.

**Kolk**: Het is dus belangrijk dat een standaard actueel blijft, maar door deze actueel te maken verandert hij van de standaard die actief was op vorige projecten én kost het ook veel tijd om het actueel te houden?

**Rinia van Nauta**: Daarom ben ik voorstander van het vorige project er bij pakken en die als standaard te gebruiken en aan te passen op de nieuwe situatie. Dan zouden alsnog gemalen steeds meer op elkaar moeten gaan lijken.

**Kolk**: Zou het dan een oplossing zijn om voor de komende vijf jaar één project als referentie project te nemen en aan te passen voor nieuwe projecten. Zodat je niet alsnog te veel optimalisaties toepast en gemaal 1 en 10 nog steeds niet op elkaar lijken.

**Rinia van Nauta**: Het blijft belangrijk om actuele veranderingen mee te nemen, zoals vis, CO2 neutraal bouwen en biodiversiteit. Als je nu één standaard neemt maar steeds nieuwe ambities er tussendoor komen, bijvoorbeeld op het gebied van vis of klimaatneutraal. Dan kun je beter het vorige project, die al deels deze actualiteiten heeft meegenomen, pakken en dan de nieuwe ambities ook meenemen.

**Kolk**: Wat is daarnaast belangrijk voor specifiek het standaardiseren van gemalen?

**Rinia van Nauta**: De locatie is belangrijk, want zit er een lange persleiding achter, dan heb je al heel snel weerstand in de leiding en gaat de opvoerhoogte omhoog dus heb je een hele andere pomp nodig dan in de situatie met een korte persleiding. Dit vraagt dan weer om een heel andere oplossing.

Het gaat ook vooral om de capaciteit, oftewel de bestaande vermogens zijn een leidraad net als de motoren en hoe zwaar zijn die en dan kijken of deze te vergelijken zijn.

**Kolk**: Wat voor praktische problemen doen zich voor bij het toepassen van standaardisatie?

**Rinia van Nauta**: Er is een groot onderscheid tussen nieuwbouw en renovatie. Bij renovatie moet je in een bestaande situatie gaan kijken wat er nu zit en wat ga je er weer terug bouwen. Dan is het standaardiseren van proces automatisering en elektrotechniek redelijk eenvoudig. Zoals de schakelkast gaat er uit en de nieuwe standaard schakelkast gaat er in. Maar als je een pomp wilt vervangen door je standaard, zit je toch vast aan een bouwkundig omhulsel wat er al staat. Renovatie vraagt altijd om maatwerk, maar je kan nog steeds een standaard gebruiken hiervoor en dat scheelt ook werk. Dus door te kijken naar het vorige project kan dit al deels. Het is afhankelijk van welke installatie je aanpakt, een groot gemaal heeft pompen die erg project specifiek zijn.

**Kolk**: Wanneer denk jij dat standaardisatie loont? Met hoeveel procent moeten de kosten afnemen en hoeveel tijd moet er bespaard worden?

**Rinia van Nauta**: Het is met name waardevol wanneer het effect heeft op de bedrijfsvoering na de oplevering, wanneer het project richting beheer en onderhoud gaat en hij bedient wordt. Belangrijkste daarbij is de proces automatisering, die al gestandaardiseerd is, omdat hij anders niet kan praten met de rest van het systeem. Elektrotechnische installaties standaardiseren scheelt ontwerptijd maar ook in beheer en onderhoud, met name ook qua veiligheid. Want men weet hoe je een installatie moet veilig stellen omdat dit altijd hetzelfde is.

Verder, blijft het denk ik toch heel veel passen en meten zodra je gaat renoveren. Maar het standaardisatie loont wanneer je meer dan 20 procent op de ontwerpkosten bespaart. Want die pomp er in passen, dat is het werk wat je moet doen en dat blijft zo. Maar welke pomp je kiest kun je lang over discussiëren en dat standaardiseren zou veel tijd schelen voor overleg en discussie.

Dus op het gebied van tijd, elke maand van de voorbereiding die je er af kan halen is pure winst. Alle tijd die je wint is fijn. Ik denk zelf dat standaardisatie de ontwerptijd met een aantal weken kan verminderen.

**Kolk**: Wat denk jij dat nu nog nodig kan zijn om dit mogelijk te maken?

**Rinia van Nauta**: Een opdrachtgever die aangeeft waar de standaarden staan en afdwingt welke standaarden gevolgd moeten worden, daar begint het mee.

## B.2. Official client (ambtelijk opdrachtgever)

Datum: 26 oktober 2023
Locatie: Waternet, Amsterdam
Aanwezig: Remco Vogelezang-Havers (Waternet), Marco Versluis (Witteveen + Bos), Iris Kolk

**Kolk**: Kun je jouw rol en functie bij Waternet toelichten?

**Vogelezang-Havers**: Ik ben ambtelijk opdrachtgever van projecten dus daarmee krijg ik van de asset manager het verzoek om voor een asset een project uit te voeren en dat kan renovatie zijn, groot onderhoud, nieuwbouw of verbouw en daarmee ben ik, als het goed is, de schakel tussen de projectmanager en de bestuurders voor die projecten.

**Kolk**: Hoe krijg jij op dit moment al te maken met standaardisatie?

**Vogelezang-Havers**: Standaardisatie is een hot topic op dit moment binnen Waternet vanuit AGV. Vanuit de wetenschap dat de vervangings- en investeringsopgave die we hebben de komende jaren alleen maar groter wordt, is men hier intern op zoek naar alle mogelijke manieren om daar in sneller te opereren of meer realisatiekracht te organiseren. Omdat we simpelweg met dezelfde mensen meer werk moeten verzetten.

Ondanks dat we ook in het nieuws zijn dat het financieel slecht gaat met AGV, maar dat is een hele andere situatie want dat gaat over of we in staat zijn onze belastingen op te halen en is het vooral ook een korte termijn probleem, gaat dit (vervang- en renovatie opgave oplossen) over of we voldoende ruimte hebben om te investeren. Als je dan kijkt naar de ambities van ons bestuur, zit ik er financieel wat laconieker in dan sommige andere collega's. Die horen of lezen alle media aandacht dat het financieel slecht gaat en denken dat we moeten bezuinigen. Terwijl tegelijkertijd het bestuur nog steeds zegt dat ze gewoon de komende tijd de investeringsopgave willen verdubbelen. Dan ga ik ervan uit dat ze ook snappen dat als je de investeringsopgave verdubbelt, dat je ook de uitgaven verdubbeld dus dat je het geld wel moet hebben. Ik merk ook dat de ambities van het bestuur hier totaal niet getemperd worden. Integendeel, de ambities worden alleen maar hoger als het gaat om meekoppelkansen en zorgen dat we maatschappelijke meerwaarde creëren en dat kost ook altijd geld. Als het goed is zet je maatschappelijke meerwaarde tegenover maatschappelijke kosten en als dat uit kan dan moet je het doen. De vraag is dan alleen wie kan de rekening nou daadwerkelijk betalen. Dat is één deel, maar vooral dus de opgave is meer doen met evenveel mensen in kortere tijd, want de afgelopen jaren duren onze projecten gewoon te lang als je ze vergelijkt met andere waterschappen. Ik rol nu projecten uit die gestart zijn in 2014, en dat zijn geen wereldschokkende projecten zoals de Betuwelijn maar dat zijn gemalen van een van 6 á 7 miljoen en renovatie. Dat moet je gewoon in 5 of 6 jaar kunnen afronden, dus de start, oplevering en overdracht. Eigenlijk als je je best doet dan moet het nog sneller kunnen.

**Kolk**: Je noemt dat de projecten te lang duren, welke rol speelt standaardisatie hier dan tot nu toe in?

**Vogelezang-Havers**: Nu denkt men hier intern dat standaardisatie de heilige graal is, dat we vooral moeten standaardiseren en dat we daar heel veel winst mee gaan boeken. Je hoort al aan mij op de manier waarop ik dat zeg, dat ik daar wat anders in zit. We hebben al te maken met wat standaardisaties en daar heb ik ook eerlijk gezegd niet altijd positieve ervaring mee. Als je kijkt naar onze procesautomatisering met name, dan hebben we daar al een heleboel in gestandaardiseerd. Dan is er gewoon voorgeschreven vanuit onze procesautomatiseringsclub wat voor switches, router, kasten en al dat soort dingen er toegepast moeten worden, er is geen keuze. Datzelfde geldt voor heel veel elektra, is ook gewoon gestandaardiseerd. Dus wat is er nog verder te standaardiseren?

Als je het echt over gemalen hebt en dan kijk naar de portefeuille die we op dit moment hebben en ook naar de gemalen die Witteveen+Bos voor ons heeft bekeken, dan is daar elke keer wat mee aan de hand. Het is een monument of het dreigt een monument te worden, neem het gemaal Krommemijdrecht, wat Witteveen+Bos voor ons heeft gedaan. Dat staat solitair in het landschap, is een markant ding en een gecombineerd object met eigenlijk twee gemalen in één huis met enorme vijzels. Het grappige is dat als je naar de buitenkant kijkt dan zijn dat van die grijze beton stenen. We hebben meer van dat soort gemalen die in die stijl zijn uitgevoerd, dus daar is toen wel een keer een slag geweest dat dezelfde architect dat heeft ontworpen. Maar om nou te zeggen dat je Krommemijdrecht kan standaardiseren, het is maar de vraag wat kan je daar verder op kan standaardiseren. Daarin staat ook dat in mijn beleving voor dat soort grotere objecten het ook direct op gespannen voet met de bestuurlijke ambities staat.

Als het gaat om het stimuleren van biodiversiteit, het stimuleren van recreatieve voorzieningen en het stimuleren van waterbewustzijn. Zeker die laatste twee, stimuleren van recreatie en stimuleren van waterbewust zijn, zijn zeer locatie afhankelijk of dat überhaupt zin heeft, dus daar kan je niks op stimuleren. Je kan op biodiversiteit en op duurzaamheid wel wat standaardiseren in mijn beleving. Je kan zeggen dat bepaalde maatregelen altijd wel of altijd niet toegepast worden. Hoe kleiner de gemalen worden hoe makkelijker het volgens mij wordt om te standaardiseren, omdat je dan makkelijker de afweging kan maken of er wat afgedaan wordt aan de functionaliteit of aan de prestaties, of dat je met grover geschut gaat werken. Bijvoorbeeld, als we gaan rekenen aan het watersysteem hebben we 11.2 kuub per minuut nodig, dan ga je niet precies 11.2 kuub bouwen. Dan zou het wat mij betreft heel goed zijn als we met elkaar kunnen afspreken dat we voortaan of 10 kuub of 15 kuub bouwen. Nog slimmer, we kijken naar de markt wat de standaard pompen zijn en daarop gaan we zitten.

**Versluis**: Dat is een beetje de werkhypothese die Kolk nu in het technische gedeelte heeft. Kleine gemalen hebben het meest potentieel en een vijzelgemaal ligt het meestal voor de hand, en probeer daar nou dezelfde diameter of iets dergelijks aan te houden.

**Vogelezang-Havers**: Dan wordt het interessant, want dan kan je ook in je onderhoud wellicht de keuze gaan maken. Want je zet gewoon één standaard vijzel in de opslag als reserve en dan kun je dus ook alle gemalen afstemmen op onderhoudsniveau. Op het moment dat hij in de soep draait, mag hij toch een paar dagen uitvallen.

Voor de standaardisatie hier intern moet echt van de grond komen dat we alle gemalen die kleiner zijn dan de mobiele pomp, dat we daar nul redundantie meer in uitvoeren. Er is hier een tijd geweest dat we achter drinkwater aanliepen en zij zeiden N+1, oftewel niet een pomp maar altijd het aantal pompen dat je nodig hebt plus 1, dan kun je er altijd eentje uit bedrijf nemen. Dat is voor drinkwatervoorziening heel erg logisch want daar heb je een hele hoge eis als het gaat om leveringszekerheid maar wat kan het nou schelen en dat een gemaaltje van 10, 15 of 20 kuub een paar dagen eruit ligt. Alleen als het met bakken uit de hemel komt moet je dan iets doen en dan heb je in een paar uur gewoon een trekker pomp er heen gereden. Nou die nuchterheid en simpelheid die komt nu gelukkig hier intern wel een beetje van de grond. Als je dat doet en je hebt daarnaast een standaard pomp ter vervanging, of het nou een pomp is, een vijzel of wat dan ook, en je kan de pomp binnen een week vervangen als hij kapot gaat, dan is standaardisatie goud waard.

Blijft wel staan dat we vanuit de historie ook allerlei andere gemaaltjes hebben die soms ook monumentaal zijn, die ingepast zijn in een bepaalde omgeving, en waarbij het maar de vraag is of je die standaard vijzel of die standaard pomp daar ook daadwerkelijk kwijt kan.

Dan kom je op de implementatie van standaardisatie. Is het wel de moeite waard om projecten uit te gaan voeren, waar we gaan renoveren én standaardiseren. Dan zit er eentje die wel benoemd wordt maar nog niet vertaald wordt in dit dossier: er wordt het hier wel gekapitteld af en toe door het afdelingshoofd beleid, de leidinggevenden van Rinia van Nauta. Hij vraagt zich af waarom we met allerlei projecten bezig zijn met duurzaamheid op de postzegel, terwijl we weten uit onze MKI voor heel Waternet dat op het watersysteem er eigenlijk maar twee dominante factoren zijn in onze CO2 voetprint, staal en beton. Hoe minder staal en beton we gebruiken hoe rapper onze CO2 voetprint naar beneden gaat en de hoeveelheid energie we verbruiken doet er eigenlijk niet eens toe. We zijn allerlei studies aan het doen hoe we de meeste energiezuinige pompen implementeren. Het standpunt van het afdelingshoofd is dat dat moet stoppen en er voor gezorgd moet worden dat we minder beton en staal gebruiken.

Ik denk zelf dat je allebei moeten doen. Ik zag laatst op LinkedIn een mooi plaatje waarbij ze de CO2 voetprint niet alleen in absolute aantallen per land hadden afgedrukt maar ook per hoofd van de bevolking en dan zie je in één keer dat er hele andere landen grootgebruiker zijn dan China en India, maar dat dan de Nederlandse Antillen als een hele grote naar boven komt. Want ze moeten alles importeren. Daarmee het pleidooi dat je zowel de grootgebruikers moet helpen omdat ze heel veel bevolking hebben die heel veel verbruiken als dat wij hier ook gewoon alles op alles moeten zetten. Het gaat ook om een mindset veranderen.

Dat is mijn visie daarop, maar ook zonder die visie, kan je je dus afvragen als je standaardisatie gaat implementeren moet je dan wel een bestaand gemaal gaan vervangen door een standaard gemaal want dan ben je beton en staal aan het weghalen en om daarna er iets nieuws in stoppen. Dat is qua duurzaamheid achteruit boeren en ten opzichte van die duurzaamheid voordelen die het heeft om bestaande infrastructuur gewoon te laten staan, mag je heel veel extra kosten maken zowel in CO2 als in euro's in efficiëntie in het beheer en onderhoud dat je niet gestandaardiseerd hebt en dat hebben we bij twee grote projecten ook ontdekt.

We hebben bij gemaal Middelpolder en bij gemaal de Ruit, daar ligt een openbaar stuk van besluitvorming met een multicriteria analyse met varianten studie. Vooral voor Middelpolder zijn 11 varianten gewogen, want we hadden oorspronkelijk tegen het bestuur gezegd al jaren terug dat we voor een renovatie zouden gaan want het is een gemeentelijk monument uit de 19e eeuw. Het bestuurt vroeg of er ook alternatieven afgewogen waren zoals misschien wel op een hele andere locatie een nieuw gemaal bouwen. Wat mij daarvan bij is gebleven, en diezelfde studie is ook gedaan voor gemaal de Ruiter dus de grotere gemalen uit ons gebied met 300 kuub of meer, dat duurzaamheid dominant is in de multi-criteria analyse. De CO2 voetprint, met daarin dominant dat elk ander alternatief dan renoveren betekent zoveel beton en staal extra dat je daar veel extra investeringen voor kan doen in een bestaande situatie en dat het dus altijd duurzamer is om iets wat beton en staal is, her te gebruiken.

Het is echt frappant hoe hoe dominant dat blijkt te zijn en dat heb ik daar wel aan overgehouden voor al mijn andere projecten. Je moet wel echt een verrekte goeie businesscase hebben wil je een bestaande situatie verlaten. Dan kan je nog steeds kijken naar allerlei standaardisaties, zoals als je toch aan het renoveren bent en je stopt er een andere pomp in en er kan de standaard pomp in, dan is het slim om dat te doen. Voor nieuwbouw moet je zeker over allerlei standaarden afspreken. Ik ben het met Rinia van Nauta hartstochtelijk eens dat we een aantal dingen met elkaar af moeten kaarten. Elke keer discussiëren over of we redundant moeten zijn met een of twee pompen. Dat kunnen we gewoon stoppen, ergens tussen de 60 en de 80 kuub kan je nog steeds met mobiele pompen heel veel doen. Dus het enige wat je moet regelen is een mobiele opstelplaats, dat je daar naartoe kan. Dan heb je helemaal geen redundantie meer nodig, en kan je ook in je bedrijfszekerheid kan je heel veel aftoeren, dus daar kun je hartstikke veel winnen. Het is geen standaardisatie maar wel winst.

Ik heb hier ook discussies met de watersysteembestuurders over krooshek reinigers, moeten we dat wel of niet doen. Als we geen automatische krooshek reiniger hebben dan moet er af en toe iemand langs om al dat vuil weg te halen. Nou als we er gewoon een breder rooster voor zetten duurt het langer voordat het verstopt is, als je er dan voor zorgt dat het breed genoeg is dat je maximaal eens per 3 dagen er langs moet gaan kan je het altijd over het weekend heen tillen en is er eigenlijk niks aan de hand. Dus dat kan je standaardiseren en niet elke keer opnieuw de discussie voeren moeten we wel of moeten we niet, nee standaard onder een bepaalde capaciteit doen we het gewoon niet. Nou die richtlijn is er al lang, vanuit de STOWA of het UNI verwant zijn er dat soort richtlijnen. Zodanig zijn er nog wel meer dingen te bedenken.

**Kolk**: Wat ik een beetje uit jouw verhaal is dat voor grote gemalen je eigenlijk niet kan gaan standaardiseren want het is allemaal zo uniek en zo projectlocatie gebonden dat je toch altijd weer bezig bent met de standaard aanpassen. Bijvoorbeeld, omdat het monumentaal is, de grond is anders, het water is anders maar dat bij kleine assets je veel potentie hebt maar dat ook veel kleine assets al gestandaardiseerd zijn. Maar ik ben inderdaad gaan focussen op middelgrote gemalen, maar waar ligt de grens? Hoeveel clusters moet/kun je maken voor één standaard?

**Vogelezang-Havers**: In mijn beleving, wat ik hier intern ook volhoud, die 60 tot 80 kuub is voor mij een grens want daarmee kan ik een heleboel oplossen met tijdelijke bemaling. Een 80 kuub mobiele pomp of 2 keer 30 en dan ga ik nog een beetje in het watersysteem de peil verlagen en dan heb ik wel opgelost. Op die manier kom je een heel eind. De andere kant van het spectrum is in ons geval de 24 grote gemalen van 300 kuub of meer. Die krijg je niet met mobiele pompen snel opgelost, dan kom je op op hele grote jongens die je van Rijkswaterstaat moet lenen. Daar wil je ook redundantie hebben en allerlei zekerheden in inbouwen. Die gemalen doen ook een heel groot gebied en het zijn ook hele kostbare gemalen als je ze moet bouwen of renoveren. Kans dat je weer zo een nieuw gemaal moet bouwen van die omvang is ook niet heel groot. Die categorie daartussen, dat is de moeilijke groep want daar kun je altijd wel iets met nood maling of met mobiele pompen en eventueel koppelen van gebieden aan elkaar en stuwen open als het fout gaat maar nooit helemaal. Het is altijd groter dan een simpel kastje in het veld. Je weet ook dat je er regelmatig onderhoud aan moet doen en dat je een hoog gebruikszekerheid wil hebben dus je zult ook iets aan voorzieningen moeten hebben. Het zal ook echt in een gebouwtje zijn, terwijl die kleinere gemalen zijn gewoon de kastjes in het veld.

Ik moet dan denken aan Delfland, als ik daar door het gebied heen rij. Als je dat zou doen en je hoeft niet eens ver Delft uit, richting Rotterdam - Schiedam staan er meerdere langs de Vliet met eigenlijk altijd hetzelfde ontwerp: een glazen pui met een sedum schuin dak en een krooshek reiniger wat aan het dak vast zit en eigenlijk elke keer dezelfde uitstraling. Dus in ieder geval aan de buitenkant zit de nodige standaardisatie. Schijnbaar hadden ze daar een keer de noodzaak dat ze in korte tijd een heleboel moesten renoveren of moesten nieuwbouwen en hebben ze daar dus de investering gedaan om eerst een standaard gemaal te bouwen en daar dan vervolgens dat toe te passen. De vraag is voor ons als AGV en Waternet, is hoe groot is die midden groep eigenlijk en hoeveel weegt het op om een keer te investeren in een standaardontwerp ten opzichte van elke keer apart. Dat durf ik niet te zeggen.

**Kolk**: Wat denk jij dan dat redenen zouden zijn waarom je alsnog wel veel in één keer zou investeren?

**Vogelezang-Havers**: Je kan er bedrijfseconomisch aan rekenen in theorie. Bijvoorbeeld, als ik weet dat ik de komende 5 jaar 30 gemalen moet vervangen in dat spectrum, dan kan ik het standaard gemaal ontwerpen. Daarna kan ik aan de voorkant ook in een scan doen of ik die standaard in 25 of 28 keer van de 30 daad werkelijk kan toepassen. Dan levert voordelen op zoals het aan de voorkant investeren in standaard ontwerpen, uitwerken van allerlei zaken en ook de opdracht op een andere manier in de markt zetten. Alleen, als ik er maar 10 te doen heb in de komende 5 jaar en ik heb ook nog een keer twijfel of ik dat ontwerp dan 10 keer kan toepassen, is het de vraag of het loont om goed te investeren in een standaard ontwerp, of dat je beter eerst op een andere manier de markt gaat benaderen. Wat in allebei de gevallen trouwens slim is.

Gelukkig is onze afdeling projecten ook veel meer op aan het oriënteren of we in plaats van elk individueel gemaal in de markt zetten met een met een renovatie opgave en een aannemer, met tenderkosten aan hun kant, uitvraagkosten aan onze kant en ontwerpkosten bij het ingenieursbureau. Of we in plaats daarvan één opgave maken voor 10 gemalen, waarvan we nog niet weten hoe dat er precies uit gaat zien, maar we willen in ieder geval de partijen aan boord hebben waarmee we dat samen kunnen gaan doen. Die uitvraag hebben andere waterschappen al lang op die manier gedaan en daarmee boeken ze zeker winst.

De vraag is of wij nu zelfs maar aan 10 van dat soort gemalen in 5 jaar tijd komen. Als ik kijk naar onze opgave van de komende 5 jaar dan zitten daar vooral die grote jongens in. We hebben ook een hele berg sluizen, dat zijn al helemaal unieke objecten die elke keer historisch zijn en een hele hoop gedoe mee is. Dat is voor ons techneuten hartstikke leuk, maar voor standaardisatie volstrekt ongeschikt. Er is ongetwijfeld ook nog meer winst te boeken dan alleen maar PA en Elektro standaardisatie. Wat ik net al zei, dat we alleen pompen van bepaalde capaciteitssprongen zouden gebruiken en niet alle tussenliggende, of bepaalde buis diameters van 600 tot 800 cm. Dat zijn ook de standaard maten die waarschijnlijk nu al op de markt zijn. Tegelijkertijd heb ik een tijdje geleden een gemaal gehad waarbij ze ontworpen hadden dat er in de uitstroomleiding een knik zat van 89 graden. Wie ontwerpt dat? Dan draai je toch het hele gemaal één graad zodat de hoek weer 90 graden is. Daar was de standaardisatie niet helemaal gelukt zo te zeggen.

**Versluis**: Onze hypothese is ook dat als we naar het areaal van Waternet kijken, de meeste potentie ligt op de middelgrote of de kleinere gemalen. Bruggen hebben jullie maar een beperkt aantal van en sluizen zijn erg divers. Rijkswaterstaat heeft heel erg geprobeerd sluizen te standaardiseren en die hebben nog vaak een kanaal wat een corridor is. Vroeger waren dit dezelfde sluizen, maar de een is een keer vervangen, de ander gebombardeerd, dus nu zijn het unieke ontwerpen. Ik denk dat dit bij het areaal van Waternet minder is omdat je de polder hebt en de boezem. Een standaard sluis zie ik niet bij jullie terug komen, herken je dit en zie je deze potentie wel voor gemalen of nog voor andere objecten?

**Vogelezang-Havers**: Bij gemalen is dat potentieel al een beetje verzilverd, alleen hebben we dat zelf niet door. Edwin van der Veen, die werkt bij projecten bij de kleinere en middel grote gemalen, zegt dat hij gewoon 3 standaard ontwerpen heeft. Ik heb nu een project met hem lopen, een gemaaltje van 13 kuub en aan de voorkant vroegen we of hij niet recent een gemaal had gebouwd dat ongeveer even groot was. Toen liet hij foto's zien, dus toen zei ik: Dit gemaal is een kopie van dat gemaaltje totdat het niet meer kan. Met bepaalde dingen kan dat niet, want bijvoorbeeld de afstand tussen de instroom en de uitstroom was twee keer zo groot dus daar zitten toch altijd nog wel wat ontwerp dingetjes maar je kan daar heel veel standaardiseren.

Terug naar de vraag of er nog potentie zit bij andere objecten. Stuwen, daar is zonder meer veel meer in te beleven en die zijn ook allemaal gestandaardiseerd. Ik zie in ieder geval potentie voor een heel nieuw soort asset wat wij nu hebben geïntroduceerd, het waterkwaliteitsscherm. Dan zie ik niet zozeer een potentie in echt een standaard ontwerp maar wel in een moeder onderwerp. Het verschil is dat je bij een moeder ontwerp hypothetisch een object bouwt waarmee ik alle aspecten heb en waarbij ik weet aan welke knoppen ik moet draaien om het passend te maken in de echte omstandigheden. Dat is ook een vorm van standaardisatie. Bij kwaliteitsscherm weet ik dat in het ene geval leg je hem in een in een vaarweg maar die kan erg verschillen,we hebben er net een gebouwd van 30 m breed, en ik heb er nu ook eentje in de in de KRW zitten en die moet in een waterweg van 10 m breed ofzo. Dus echt wel andere orde grootte maar tegelijkertijd zit je met dezelfde problematieken van bediening en veiligheid en hoe ga je daarmee om. Dan zou je daar best een paar standaarden voor het ontwerp kunnen maken.

Nog andere potentie, dat je het over waterschappen heen probeert te standaardiseren. Dat is echt een onmogelijke opgave haast maar zou wel degelijk potentie hebben. Daarnaast hebben we hier een heleboel BDO keringen, vanuit oudsher is dat ook redelijk standaard. Als je een beetje een civiel technische blik hebt dan zie je ze. Die hebben nog steeds de functie en je ziet ze vaak aan de dirk die er standaard staat. Dat is zo'n kraantje waarmee de schotbalken in twee sleuven gehesen kunnen worden en die zien er allemaal hetzelfde uit. Die zijn er allemaal al dus daar moet alleen maar onderhoud aan gepleegd worden en we bouwen ze niet nieuw.

Wij hebben hier weinig te maken met vaste bruggen, maar als je die veel zou hebben dan zit daar potentie in. Dammen en duikers, zijn al gestandaardiseerd. Er zijn vergunningen en meldingsplichten als het goed is, waar bij staat als je hem op een bepaalde manier bouwt is het alleen een meldingsplicht, dus iedereen bouwt hem op die manier. Dus daar hebben we het al verzilverd denk ik. Dan komen we op de natuurvriendelijke oevers, maar daar zit niet echt de opgave qua tijd en geld.

We hebben wel een grote KRW opgave, daar hebben we defosfateringen te bouwen, dat wordt nog een grote klus. Daar zit ook nog echt een innovatieslag die we moeten maken, want we kennen de defosfateringen met de ijzerchloride toediening en eigenlijk heb ik de afgelopen jaren wel geleerd vanuit de specialisten dat die dingen in de afgelopen 10 jaar ook niet meer gebouwd zijn. want de techniek is komt te kort omdat je bij lagere concentraties fosfaten niet genoeg er uit krijgt met de bestaande techniek dus moet je ook een andere techniek toepassen om de rest eruit te halen. Op zich is dat goed nieuws want dat betekent dat je er al heel veel uit hebt maar er moet toch meer uit.

Dan kom je op zand bed filters en dat is allemaal redelijk zoeken. Dus voordat je naar standaardisatie bent zal die techniek eerst verder ontwikkeld moeten zijn en opgeschaald. Tegen die tijd hebben we de boel hopelijk schoon. Je hebt een onderverdelingen nog in de gemalen, je hebt de klassieke gemalen en de opvoer gemalen die niet voor de waterafvoer zijn maar voor de wateraanvoer. Die hebben nog lagere bedrijfszekerheid nodig en vaak ook nog lagere capaciteit.

**Kolk**: Naast te kijken waar potentie voor standaardisatie zit, wanneer denk jij dat het loont om standaardisatie toe te passen?

**Vogelezang-Havers**: Dat hangt per standaardisatie af. Als het standaardisatie is aan de binnenkant van een object is dan loont het denk ik al heel snel. Als het standaardisatie is aan de buitenkant, dan is het de vraag of je in een locatie- afhankelijkheden niet vastloopt.

Je kunt het bepalen met life cycle costing, dus als de LCC positief is. Je moet hier gewoon totale levenskosten benadering toepassen en daar is daar zijn wel mitsen en maren, maar daar kom ik zo op. Je kan dat zelfs SSK doen en zeggen dat je nu zoveel extra engineering kosten hebt, deze kosten maak je eenmalig, en dan kan je bepalen voor het aantal objecten hoeveel engineering kosten je bespaart, hoeveel extra onderhoudskosten er zijn door de standaard en of er extra energiekosten zijn door de minder efficiënte pomp. Als het lager uit komt, dan doen. Theoretisch is dat met een life cycle benadering te berekenen.

**Versluis**: Dus stel je voor je hebt optie A en Optie B en op 50 jaar op scheelt het 1000 euro, dan kun je toch voor de goedkoopste gaan, heel zakelijk.

**Vogelezang-Havers**: Ja, gister heb ik nog een hele lange sessie gehad voor gemaal Middelpolder waarbij gekozen moet worden of we kiezen voor schacht pompen, dompelpompen of voor de meer traditionele pomp. Ik zit dan gelijk tegen de innovatie aan en dat die dingen weinig verder hebben maar uit de LCC komt dat gewoon dat er een enorme besparing op zit op lange termijn, zowel in de investering als in het onderhoud. Zitten wel een paar nadelen aan, want het is nieuw in het beheer en onderhoud dus je moet een nieuw vakgebied leren. Het is onbekend terrein dus we hebben zorg om de bedrijfszekerheid en daar moet je ook een prijskaartje aan hangen en dat zijn dan de punten waarom je in de LCC tekort schiet. Kijk, bij twee pompen is het ongeveer evenveel staal en gebruiken ze ongeveer evenveel energie. Dus als je de milieukosten indicator gaat uitrekenen dan kom je ongeveer gelijk uit hebben we nu maar aangenomen omdat het anders nog ingewikkelder wordt.

Als je aan beton en staal gaat lopen standaardiseren, dan kom je aan je CO2 voetprint en dan wordt het interessant om dat het dan ook echt een politiek bestuurlijke afweging wordt. Want hoeveel geld heb je ervoor over om bij elk individueel gemaal toch nog meer engineering te doen, omdat je daarmee beton en staal kan uitsparen. Dan zit je op waarom ik wat tegengas geef tegen mijn collega's die roepen dat standaardisatie de heilige graal is. Als je alleen bedrijfseconomisch kijkt, moet je zoveel mogelijk standaardiseren want dat gaat je in beheer en onderhoud en in bedrijfszekerheid zo veel opleveren.

De vraag is of je daarmee niet op andere punten, en dan met name op het duurzaamheid, in efficiëntie verliest. Als ik standaard dus een vijzel installeer terwijl ik ook weet dat op sommige punten ik een opvoerhoogte heb van 5 m met een laag debiet, en dat dus eigenlijk een pomp een efficiëntere manier is dan een vijzel en gaan we naar pomp curves kijken. Dan krijgen we energiegebruik en dan vragen we hoeveel kilowattuur moet het opleveren voordat ik de engineering opnieuw ga doen en toch kies voor een pomp met een andere investering ook nog een keer.

Ik durf wel mee te gaan voor de kleine gemalen omdat die verschillen marginaal zijn en of je nou een kastje plaatst wat 10 cm groter is, die hoeveelheid staal op de totale levensduur doet er niet toe. Als je nog een klein beetje staal had kunnen besparen, jammer dan. Misschien als je engineering had toegepast, had je er net een kleinere pomp in kunnen zetten met een net iets kleiner kastje en met net iets minder elektronica, misschien net iets minder koper enzovoort. Bij een klein gemaal is dat verschil zoveel minder, maar of het zo weinig minder is dat de extra kosten die je moet maken in dat je weer mensen moet opleiden om een andere soort pomp te kunnen onderhouden met andere reserveonderdelen met andere leveranciers die ook weer met hun auto busjes moeten gaan rijden, als je daar de hele levenskosten op milieu kosten op gaat berekenen word je helemaal gek. Het is echt niet te stoppen maar juist voor die grote weten we zeker ga maar engineeren want zoals ik net zei bij gemaal Middelpolder komen die onderwater pompen dus handig uit financieel.

Bij de midden categorie, is het weer de vraag. Daarvoor voel ik wel mee met alles wat aan de binnenkant van het gebouwtje zitten en denk ik dat je vrij makkelijk is naar standaardisatie kan, PA en de E. Ik denk dat je ook wel kan kijken naar de opvoerhoogte, als die zich beweegt tussen twee waarden dan is een vijzel interessant, ga dan maar uit van een vijzel en als je in dit Oranje gebied komt, dan niet.

Dat is natuurlijk de oplossing voor al dit soort zaken, zeggen van 'Als je beweegt binnen deze parameters is standaardisatie een goed idee en als je buiten die parameters beweegt moet je er nog een keertje naar kijken'. Dan kom je op een beslissingsmodel. Bij pompen of vijzels kom je bij de ideale opvoerhoogte, of als je de vijzel hanteert dan moet je hem in een bepaalde hellingshoek doen, en zolang je de vijzel in die hellingshoek kan plaatsen moet je dat doen. Maar op het moment dat je de ruimte niet hebt om het op die helling te doen, dan heb je het over een alternatieve standaard voor bijvoorbeeld bedacht of je gaat engineeren.

In Nederland, als je echt een gebouw moet ontwerpen dan zit je met de welstand. Die is per gemeente verschillend dus succes met je standaardisatie. Wat tevens ook weer ruimtelijke kwaliteit is, want als we overal dezelfde blokkendozen neerzetten boeten we allemaal wel in de ruimtelijke kwaliteit.

**Kolk**: Heb jij nog verdere opmerkingen of meningen over standaardisatie en wat nodig zou zijn dat jij positiever in zou staan over standaardisatie.

**Vogelezang-Havers**: Het gaat om die beslisboom, waarom ik wat negatiever erin sta is dat het een dogma wordt waarbij je *penny wise, pound foolish* wordt. Dat je uitzichtloos alles standaardiseert, en dat je dan krijgt dat er niet mee te werken is. Een voorbeeld, als we iedereen in Nederland een Volkswagen golf station zouden geven om mee te rijden dan zou denk ik heel veel mensen dat prima vinden. Maar, monteurs komen dan dat ze een busje nodig hebben voor het gereedschap en de studenten dat ze het geld niet hebben voor de dure benzine en liever een de mini willen. Het antwoord daarop is natuurlijk dat we het beste toe kunnen met een paar varianten waarbij je voor lief kan nemen dat het soms ietsjes groter is dan dat strikt genomen noodzakelijk.

Bij een project hebben we 13 kuub per minuut nodig en de standaard pomp levert 14 kuub. Dat was overigens een groot probleem hier, we hadden de afspraak met Rijkswaterstaat en de andere waterschappen dat op de boezem van Amsterdam-Rijnkanaal en aanverwante een bepaalde hoeveelheid maximale capaciteit geïnstalleerd erop uit mag slaan, en dat mocht niet veranderd worden want daarop is IJmuiden uitgelegd. Dat is recent pas veranderd, nu mag je een hogere maximum capaciteit installeren als je het maar altijd kan afstellen tot waar je maximaal als waterschap recht op hebt. Als een ander waterschap minder doet dan het maximum mag je eventueel meer dus dat dat wordt veel meer slim watermanagement. Dit is pas sinds 1.5 jaar formeel vastgelegd en het gevolg is dat we nu eindelijk ook de standaardisatie hier doen dat we op al onze gemalen een FO installeren. Die hadden we helemaal niet en voor mij was het onbestaanbaar dat we gemalen hier bouwen met pompen zonder FO.

**Kolk**: Kun je uitleggen wat een FO is?

**Vogelezang-Havers**: Een FO is een frequentie omvormer, waarmee je het toerental van een gemaal kan regelen en dus de capaciteit kan tunen. Vroeger was het altijd een gemaal stond aan óf uit. Hier was de aanname intern, dat als je er een FO op zet dan vreet dat energie en dat daarmee de efficiëntie van de pomp afneemt. In de praktijk is dat maar één of twee procent. Ondertussen zijn die dingen hier ook heel veel verbeterd, want wij liepen hier gewoon achter op de techniek. Ik kom bij een ander waterschap vandaan waar het 15 jaar geleden al standaard was om overal een FO op te zetten, omdat je dan ook slimmer kan zijn met het stroomverbruik. Bijvoorbeeld, als ik mijn pomp nu niet op volle kracht laat draaien maar op halve kracht, en ik doe dat de hele nacht op goedkope stroom. Dan is dat goedkoper dan als ik hem op volle kracht in de max van zijn pompen curve laat draaien wat minder efficiënt is en ook nog eens een keer overdag op de dure stroom laat draaien. Tegenwoordig is het natuurlijk andersom met wind- en zonne-energie. Je kan ook veel beter in het optimale werkpunt van je pomp gaan zitten, als het tenminste qua neerslag niet in een maximum hoeft. Dus dat levert ook weer op. Dat complete rekensommetje hebben we nog niet gemaakt, maar ik weet wel dat dat voordelig is om altijd een FO er op te doen. Het maakt ook andere keuzes mogelijk, nu kan je ook makkelijker zeggen: wat maakt het nou uit dat we eigenlijk 16.2 kuub nodig hebben maar de standaard is 20 kuub? We zetten er een FO op en dan passen we het altijd aan op de weersomstandigheden op dat moment ideaal is.

**Versluis**: Je gaf aan dat je meer wilt doen met dezelfde mensen. Rijkswaterstaat doet de 'visie van de markt tenzij'. Ze hebben 10 sluizen allemaal verschillend, en hun beheersorganisatie wordt er gek van. Als je zegt dat je meer zelf gaat doen door een moeder ontwerp te ontwikkelen dan is dat ook weer extra effort voor de organisatie van het waterschap omdat mensen dan input moeten leveren, en als je een standaard hebt moet je die ook bijhouden anders loop je binnen 5 jaar achter de feiten aan.

**Vogelezang-Havers**: Dat moet met een andere contractvorming. Dan kom je op de vraag hoe kom je aan dat standaardontwerp.

Johan Gietman, teamleider van contract management, is betrokken geweest bij de implementatie van de contracten die WDODelta ook in de markt heeft gezet. Die hebben belachelijk veel gemalen in de markt gezet en niet een standaard ontwerp neergezet maar hebben gezegd: 'We gaan nu beginnen met deze eerste, daar leren we van, en daarna is is de volgende en die maken we elke keer beter. Zo komen we op uiteindelijk op een standaard.' Die hebben een enorme slag gemaakt in hoeveel gemalen ze in korte tijd kunnen verwerken. Daar zitten volgens mij veel meer mogelijkheden in, hoe doe je het samen met de markt.

**Versluis**: Dat je eigenlijk de markt de standaard laat ontwikkelen en beheren in plaats van dat je ze allemaal zelf gaat proberen te doen.

**Vogelezang-Havers**: Volgens mij hebben ze bij WDODelta drie clusters gemaakt met drie aannemers en drie ingenieursbureaus en daar waren een X aantal gemalen te doen waarbij ze niet alles op voorhand hadden verdeeld, maar de eerste partij die als eerste klaar was kreeg weer meer te doen dus meer omzet. Dus er zat ook echt een incentive om met elkaar heel snel en heel slim te zijn.

Dat zijn precies de afwegingen die je volgens mij moet maken: kan je het af met dezelfde soort aannemer, kan je het af met dezelfde soort ingenieursbureau en hoe doe je dat dat dan. Daar zit misschien wel veel meer winst nog dan in de technisch inhoudelijke standaardisatie en dan krijg je hierna de neiging dat we het allemaal zelf gaan verzinnen.

Wij hebben hier last van een kennisspel paradox. Wij hebben zo enorm veel kennis in huis, specialisten, dat het heel moeilijk is om nieuwe kennis naar binnen te krijgen. Want wij weten het goed, wij weten het beter, wij hebben altijd dit zo gedaan. Dus dan beleef je wat ik net vertelde over de FO: dat alle waterschappen in Nederlands zo ongeveer allang die dingen als standaard geïmplementeerd hebben, en hier nog een aantal specialisten zijn die vanouds hebben meegekregen dat het energie inefficiënt is en dus hebben we verkondigd dat we dat niet doen.

## B.3. Project preparer (werkvoorbereider)

Datum: 1 november 2023
Locatie: Online via Teams
Aanwezig: Menno Tonnon (Waternet), Iris Kolk

**Kolk**: Kun je jouw rol en functie binnen Waternet toelichten?

**Tonnon**: Ik zit in de werkvoorbereiding voor het hoofdzakelijke, de storingskant van de rioolgemalen en de oppervlaktewater gemalen en daar een ook nog beetje de brug en sluis bij.

**Kolk**: Op wat voor manier krijg jij nu al te maken met standaardisatie en waar zie je dit dan in terug?

**Tonnon**: Eigenlijk alleen met de nieuwbouw dat ik met standaardisatie te maken krijg. Kijk, we proberen natuurlijk wel zoveel mogelijk als we dingen vervangen dezelfde materialen te gebruiken. Zoals elektrische componenten zo, dat is altijd nog wel redelijk te doen.

Maar met pompen ligt het er aan wat voor pomp het is. Als er een nieuwe pomp zou moeten komen, dan moeten wij dat in aanbesteding doen dat kan er weer van alles komen wat we eigenlijk liever niet willen hebben.

Dus zeg maar, er zit nu een bepaald merk in en we willen eigenlijk dezelfde weer terug hebben maar dat gaat niet altijd. Omdat we daar een contract met een paar partijen voor moeten aanbesteden.

**Kolk**: Je noemde al pompen dat je daar een bepaald type hebt of een bepaald merk wat je graag terug wilt. Zijn hier ook standaarden in, of zoek je echt weer precies hetzelfde terug?

**Tonnon**: In principe willen wij natuurlijk zoveel mogelijk één op één vervangen. Dus als het ene type pomp er uit gaat dan weer het zelfde type terug krijgen. Alleen sinds dit jaar moeten we dan bij een paar partijen gaan aanbesteden, en dan zeggen we alleen dat we alleen dit type pomp willen met zo veel debiet of zo'n zware motor moet er in zitten of wat dan ook en dan kunnen zij daar een pomp voor aanbieden.

Dat zijn dan wel de pompen die onder water zijn, dus de dompelpompen. De droog opgestelde pompen, die kunnen we natuurlijk wel nog één op één of een nieuw type voor vervangen. Dus voor de dompelpompen dus die onder water zitten allemaal, die moeten we aanbesteden. De pompen die gewoon droog opgesteld zijn, daar kunnen we inderdaad nog wel aangeven dat we daar hetzelfde met terug willen hebben maar dan het nieuwe type.

**Kolk**: Hoe denk jij dat dat standaardisatie jouw werk makkelijker zou kunnen maken?

**Tonnon**: Aan de ene kant wordt tegen ons gezegd dat we één op één moeten vervangen, maar door de contracten die afgesloten zijn kunnen we dat niet altijd doen. Dat werkt natuurlijk toch wel tegen, want dan krijgen we bij verschillende objecten allemaal pompen die we liever niet zouden hebben, omdat er een ander merk in komt of een ander type. Als je een twee pompen gemaaltje hebt, bij de ene heb je een merk A en daarnaast zit een merk B, terwijl je vroeger gewoon twee keer merk A of twee keer merk B had.

Standaardisatie zou dan handiger zijn omdat het dan allemaal standaard is, dan hebben we eigenlijk overal een beetje dezelfde pomp zouden kunnen krijgen.

**Kolk**: Je hebt dan wel het probleem dat je standaard af kan wijken van het type dat nu in het gemaal zit. Dus aan het begin moet je dan toch veel aanpassingen maken. Als je veel types A hebt, maar B wilt, dan moet je wel een keer B passend krijgen.

Denk je dat als je deze investering aan het begin maakt, dus nu al die moeite en tijd er in steken door onze standaard er in te krijgen, dat daarna beheer en onderhoud makkelijker wordt?

**Tonnon**: Ja, want ook qua onderdelen is het natuurlijk een stuk makkelijker als we overal dezelfde pompen zouden hebben.

**Kolk**: Naast de naast de pompen, wat zijn nog meer onderdelen die vaak moeilijk in te passen zijn omdat je dan wisselt van type bij een vervanging of renovatie opdracht.

**Tonnon**: We zijn natuurlijk heel vaak afhankelijk bij renovaties wat ze wat ze erin gebouwd hebben. Dat wordt natuurlijk meegenomen bij de projecten kant in één hap. De aannemer krijgt zo'n beetje de vrije hand om te bepalen wat hij inbouwt, dus hij zegt gewoon wat we inbouwen. Bij sommige dingen niet, dan wordt er wel aangegeven tevoren. Maar sommige componenten, die worden gewoon door de aannemer zelf gekozen.

Dat is een beetje vervelend soms, want je kan niet sturen op welk type of merk je specifiek er in wilt hebben.

**Kolk**: Ik haal hier uit dat het fijn zou zijn als waternet zou zeggen dat er drie opties zijn en dat één van die moet werken, dat dat veel zou helpen bij de werkvoorbereiding omdat je dan sowieso weet wat er in gaat, ook al weet je nog niet wat je hebt.

**Tonnon**: ja.

**Kolk**: Wat denk jij dat nog meer nodig kan zijn om het gebruik van standaardisatie makkelijker te maken naast de ontwerpvrijheid belemmeren van aannemers en ingenieursbureaus?

Zou je bijvoorbeeld meer informatie over bepaalde zaken willen of meer regels, om zo tot betere standaarden te komen.

**Tonnon**: Ik denk vooral in het voortraject, dat collega's dan mee worden genomen van om te bepalen hoe we dingen graag willen zien. Zoals wat voor materialen er gebruikt zouden kunnen worden. Dat gebeurt nu ook steeds meer, dat ook mensen van de onderhoudskant meegenomen worden in het hele project. Als onderhoud en beheerder heb je er natuurlijk het meeste last van als er veranderingen zijn, omdat je zo veel verschillende componenten hebt die niet meer standaard zijn met wat we normaal gebruiken.

**Kolk**: Hebben jullie al een overzicht van wat jullie standaard willen gebruiken?

**Tonnon**: Die zullen er wel zijn, want ze zijn bij ons ook bezig geweest om dingen te standaardiseren. Alleen op een gegeven moment is dat toch weer een beetje los gelaten.

Omdat vooral met renovaties, dan neemt de aannemer natuurlijk gewoon het hele pakketje aan. Elektrotechnisch en werktuigbouwkundig, en dan ben je eigenlijk afhankelijk van wat de aannemer erin bouwt. Die zegt tegen welke prijs hij het kan doen, en dan kan hij er ook goedkopere spullen erin zetten natuurlijk om toch de prijs te drukken.

**Kolk**: Met mijn onderzoek kijk ik nu of je bijvoorbeeld maar 3 verschillende types pompen kan gebruiken voor alle middelgrote gemalen, afhankelijk van het debiet. Dus als je bepaalde randvoorwaarden hebt, dan krijg je een bepaalde pomp ookal is de capaciteit iets te hoog of wordt het systeem iets minder efficiënt. In mijn ogen zou dat beheer en onderhoud veel makkelijker maken, zie jij dat ook? pompen kan kiezen die in elk gemaal toegepast moet worden. Onafhankelijk van de huidige contractvorming die het zou belemmeren, zie jij dit als een optie?

**Tonnon**: Ja dat zou wel moeten kunnen.

**Kolk**: Een iets ander punt, je noemde al dat standaardisatie positief zou zijn voor jou in beheer en onderhoud onder andere omdat de componenten hetzelfde zijn en dit handig is voor de reserve componenten. Zijn er nog meer van dat soort zaken waardoor jij wel, of juist niet, voor standaardisatie zou zijn?

**Tonnon**: Ik denk dat dat toch wel de grootste is, reserve onderdelen. Nu hebben we natuurlijk zo veel verschillende pompen, ook op de plank liggen, waarvoor we onderdelen voor aan moeten kopen. Dat is nog best wel een dingetje natuurlijk. Het maakt het een hoop makkelijker als je een hoop dezelfde onderdelen hebt.

**Kolk**: Hebben jullie nu een reserve opslag of bestellen jullie elke keer als een pomp kapot gaat de benodigde onderdelen?

**Tonnon**: Voor een hoop hebben we wel wat op voorraad. We hebben ook een tijd gehad dat we liever niks op de plank wouden hebben maar omdat tegenwoordig de levertijden heel erg lang zijn bestellen we soms nog wel eens wat extra mee zodat we toch wat op voorraad hebben.

**Kolk**: Wat zijn zaken waarom je niet zou willen standaardiseren?

**Tonnon**: Ik kan nu niks bedenken. Op de werkvloer zijn we natuurlijk sowieso voor dingen zo veel mogelijk standaard te krijgen. Het is niet altijd niet altijd mogelijk natuurlijk door omstandigheden.

**Kolk**: Wat zijn dan de grootste zaken die standaardisatie tegenhouden naast de aannemer?

**Tonnon**: Wat ik net zei, voor de dompelpompen zitten we natuurlijk vast aan een contract eigenlijk. Als dat contract er niet is, dan kunnen we al zeggen bij de leverancier zeggen welke pomp er nu in zit, dat we dezelfde pomp terug willen of vervangend oor een nieuw type en dan blijft het allemaal een beetje bij hetzelfde.

**Kolk**: Hoeveel denk je dat je kan winnen in tijd als je overal zou standaardiseren?

**Tonnon**: Ik weet niet of we daar tijd gaan besparen. Als de concretisering komt, dan is daar ook tijd voor nodig, of nou het ene type komt of het andere type. Dat maakt dan niet zo veel uit. Maar het is wel dat je dan natuurlijk sneller met je onderdelen zit en dat je al een reserve pomp misschien al hebt liggen. Daar win je natuurlijk wel tijd. Het is een beetje wisselend. Je kan er een op de plank hebben liggen, die omwisselen, en als het dan wat rustiger is die andere reviseren. Of je moet hem uit elkaar halen en wachten op onderdelen. Het is moeilijk in te schatten.

**Kolk**: Denk je dan dat er wel veel in te winnen is dat je altijd hetzelfde hebt, omdat je bijvoorbeeld mensen minder hoeft op te leiden met nieuwe soorten pompen?

**Tonnon**: We besteden steeds meer uit, we moeten dat steeds meer doen omdat de mensen die dat kunnen er ook niet meer zijn. Dus je bent afhankelijk van derden op een gegeven moment, met revisie werkzaamheden. Je kunt ze allemaal wel opleiden en aanleren maar dan moeten ze er wel zijn.

**Kolk**: Als je overal hetzelfde zou hebben dan hoef je niet iedereen steeds maar weer op te leiden, maar alleen voor één type pomp of drie. Dan ben je minder tijd kwijt aan elke nieuwe pomp leren.

**Tonnon**: Het is wel zo dat de collega's die de pompen nu nog zelf regisseren dat doen uit ervaring, die doen het al zo lang. Die zijn meegegroeid met de werkzaamheden. Als er iemand net van school komt, dan is het natuurlijk weer anders want die moet je aan het handje meenemen.

**Kolk**: Zijn er verder nog zaken rondom standaardisatie of rondom het vervangen van gemalen waarvan jij vindt dat ik er echt rekening mee moet houden?

**Tonnon**: Er zijn een heleboel dingen waar je rekening mee moet houden als je iets renoveert. Zoals we moeten er goed bij kunnen, je moet makkelijk kunnen sleutelen en het moet ook allemaal veilig zijn om daar mee te werken.

# C. Additional information Case study

## C.1. NEN-2767 Elaboration

In the Masterplan, the technical state of assets is expressed with a condition level ranging from 1 to 6. This follows the NEN-2767 method.

Insight into asset condition level is achieved through detailed inspections and expert judgement. If these are unavailable, the condition level is calculated based on years where large maintenance is executed.

**Table C.1:** Condition score Parameters according to NEN-2767-1:2017

| Parameters according to NEN2767 | | |
|---|---|---|
| **Condition level** | **Description** | **Elaboration** |
| 1 | Excellent condition | Occasional minor defects - Equivalent to new construction |
| 2 | Good condition | Occasional signs of aging |
| 3 | Fair condition | Locally visible signs of aging |
| 4 | Moderate condition | Functionality occasionally at risk |
| 5 | Poor condition | Aging is irreversible |
| 6 | Very poor condition | Technically ripe for demolition |

The condition is assessed in four categories: Civil Engineering (CIV), Mechanical Engineering (ME), Electrical Engineering (EE), and Proces Automatisation (PA). CIV is the construction of the object, e.g. the foundation, concrete work, walls and roof. ME includes the pump, hoisting installations, lock doors, moving parts of a bridge or weir, the drive (motor) and transmission, and gears. All installation parts that use or regulate electricity, are part of EE. Examples include the cabling and distribution of electricity, transformers or emergency power systems. At last, PA includes all installation parts that deal with control and (automatic) operation. This includes computers, software, routers and (digital) communication lines.

For assets where the condition level is calculated, the standard technical lifetime is taken, and the remaining technical lifetime is calculated based on the years where large maintenance is executed. The given standard technical lifetime per category as defined by Waternet is given in Table C.2.

**Table C.2:** Standard Technical Lifetime as defined by Waternet (AGV, 2022)

| Category | Standard Technical Lifetime |
|---|---|
| Civil Engineering | 50 years |
| Mechanical Engineering | 25 years |
| Electrical Engineering | 13 years |
| Proces Automatisation | 8 years |

A minimum required condition level is assigned based on the importance of the asset and NEN-2767. This is compared to the current condition level. As the score ranges from 1 (excellent) to 6 (very poor), the component fails if the current score is lower than the minimum score. For example, if the minimum required condition level is 4, and Civil Engineering has a score of 5, the risk of failur is higher than allowed.

The mean condition score is calculated by adding all four components and dividing by four, then rounding to the lower full number. For example, if the scores are: CIV 2, ME 3, EE 3, and PA 5, the mean is 3.3 which is rounded to a mean score of 3 (fair condition).

## C.2. Established Water Levels

**Table C.3:** Established water levels (Waternet, 2023a)

| KIN-number | From [m] | To [m] | Water Level Difference [m] |
|---|---|---|---|
| KGM00004 | | | Not determined |
| KGM00020 | | | Not determined |
| KGM00056 | | | Not determined |
| KGM00094 | | | Not determined |
| KGM00103 | | | Not determined |
| KGM00116 | | | Not determined |
| KGM00159 | | | Not determined |
| KGM00162 | | | Not determined |
| KGM00232 | | | Not determined |
| KGM00247 | | | Not determined |
| KGM00218 | | | Not determined |
| KGM00294 | | | Not determined |
| KGM00275 | -1.85 | -1.85 | 0 |
| KGM00239 | -2.16 | -2.1 | 0.06 |
| KGM00066 | -0.3 | -0.2 | 0.1 |
| KGM00452 | -0.4 | -0.3 | 0.1 |
| KGM00220 | -1.85 | -1.74 | 0.11 |
| KGM00351 | -2.3 | -2.1 | 0.2 |
| KGM00466 | -2 | -1.8 | 0.2 |
| KGM00126 | -0.4 | -0.2 | 0.2 |
| KGM00332 | -0.65 | -0.4 | 0.25 |
| KGM00509 | -1.3 | -1.05 | 0.25 |
| KGM00105 | -2.41 | -2.15 | 0.26 |
| KGM00065 | -1.72 | -1.38 | 0.34 |
| KGM00439 | -6.35 | -6 | 0.35 |
| KGM00281 | -0.75 | -0.4 | 0.35 |
| KGM00323 | -1.75 | -1.4 | 0.35 |
| KGM00049 | -6.55 | -6 | 0.55 |
| KGM00142 | -2.8 | -2.1 | 0.7 |
| KGM00235 | -1.2 | -0.4 | 0.8 |
| KGM00412 | -1.15 | -0.3 | 0.85 |
| KGM00059 | -1.41 | -0.3 | 1.11 |
| KGM00046 | -1.45 | -0.3 | 1.15 |
| KGM00072 | -1.55 | -0.4 | 1.15 |
| KGM00070 | -1.68 | -0.4 | 1.28 |
| KGM00479 | -1.7 | -0.4 | 1.3 |
| KGM00074 | -1.65 | -0.3 | 1.35 |
| KGM00320 | -1.95 | -0.4 | 1.55 |
| KGM00236 | -2.1 | -0.4 | 1.7 |
| KGM00063 | -2.05 | -0.3 | 1.75 |
| KGM00155 | -2.15 | -0.4 | 1.75 |
| KGM00358 | -2.49 | -0.4 | 2.09 |
| KGM00482 | -2.5 | -0.4 | 2.1 |

**Table C.4:** Continued: Esthablished upper and lower water levels (Waternet, 2023a)

| KIN-number | From [m] | To [m] | Head difference[m] |
|---|---|---|---|
| KGM00301 | -2.6 | -0.4 | 2.2 |
| KGM00474 | -2.69 | -0.4 | 2.29 |
| KGM00158 | -1.9 | 0.4 | 2.3 |
| KGM00106 | -2.85 | -0.4 | 2.45 |
| KGM00107 | -2.95 | -0.4 | 2.55 |
| KGM00356 | -2.96 | -0.4 | 2.56 |
| KGM00123 | -5 | -2.17 | 2.83 |
| KGM00111 | -5.55 | -2.15 | 3.4 |
| KGM00409 | -4.05 | -0.4 | 3.65 |
| KGM00227 | -4.45 | -0.4 | 4.05 |
| KGM00136 | -4.5 | -0.4 | 4.1 |
| KGM00307 | -4.67 | -0.4 | 4.27 |
| KGM00160 | -4.8 | -0.4 | 4.4 |

## C.3. Pump types and manufacturer

**Table C.5:** Pump types and manufacturer

| KIN-number | Specific type | Manufacturer |
|---|---|---|
| KGM00106 | Uncertain, type: HV | Landustrie |
| KGM00358 | No information available | Spaans Babcock |
| KGM00474 | No information available | Spaans Babcock |
| KGM00046 | ZG-300-A | VOPO |
| KGM00049 | ZG-300-C | VOPO |
| **KGM00070** | ZG-300-B | VOPO |
| KGM00236 | ZG-400 | VOPO |
| KGM00059 | L20-A-MD-LNVSC | Eekels Samson (hidrostal) |
| KGM00155 | No information available | No information available |
| KGM00235 | QV 400 | No information available |
| KGM00142 | 7045 | Flygt |
| KGM00158 | 7045 | Flygt |
| KGM00482 | 7045/600 | Flygt |
| KGM00063 | F10A-SS1 | Eekels Samson (hidrostal) |
| KGM00072 | I16A-MD | Eekels Samson (hidrostal) |
| KGM00074 | I16A-MD | Eekels Samson (hidrostal) |
| KGM00301 | I16A-HD1 | Eekels Samson (hidrostal) |
| KGM00320 | No information available | No information available |
| KGM00412 | No information available | No information available |
| KGM00479 | No information available | No information available |

## C.4. Normative water level differences

**Table C.6:** Normative water level differences

| KIN-number | 5th percentile | 95th percentile | (A) |
|---|---|---|---|
| | LWL [m+NAP] | UWL [m+NAP] | Normative water level difference |
| KGM00046 | -1.50 | -0.21 | 1.29 |
| KGM00049 | -6.6 | -5.91 | 0.69 |
| KGM00059 | -1.42 | -0.21 | 1.21 |
| KGM00063 | -2.12 | -0.21 | 1.91 |
| KGM00070 | -1.72 | -0.33 | 1.39 |
| KGM00072 | -1.59 | -0.33 | 1.26 |
| KGM00106 | -2.92 | -0.28 | 2.64 |
| KGM00142 | -2.84 | -2.03 | 0.81 |
| KGM00155 | -2.2 | -0.55 | 1.65 |
| KGM00158 | -1.95 | -0.59 | 1.36 |
| KGM00236 | -2.1 | -0.34 | 1.76 |
| KGM00301 | -2.63 | -0.32 | 2.31 |
| KGM00358 | -2.64 | -0.36 | 2.28 |
| KGM00474 | -2.8 | -0.3 | 2.5 |
| KGM00482 | -2.55 | -0.32 | 2.23 |

## C.5. Example calculation head loss due to in- and outflow and friction

As an example, the head loss due to in- and outflow and friction is determined for KGM00063.

- Length of the pipe = 20 m
- Starting number of pipes = 1
- Diameter of the pipe = 1.0 m
- Discharge $Q$ = 1674 $m^3/h$
- $K_{e-entrance}$ =0.5
- $K_{e-exit}$ =1.0
- g = 9.81 $m/s^2$
- The flow velocity must be below 1 to avoid bottom protection, in case $U_pipe > 1$, another pipeline is added

$$U = \frac{\frac{1}{N}Q}{A} = \frac{\frac{1}{1}1674/3600}{\frac{1}{4}\pi 1.0^2} = 1.86m/s > 1$$

  Another pipe is added

$$U = \frac{\frac{1}{2}1674/3600}{\frac{1}{4}\pi 1.0^2} = 0.93m/s < 1$$

- $H_{inoutflow}$ must be below 10 cm, if not: another pipe is added or D increased. $H_{inoutflow}$ is calculated as follows:

$$\Delta H_{inoutflow} = (K_{e-entrance} + K_{e-exit}) * \frac{U^2}{2g} = (1.5) * \frac{0.93^2}{2 * 9.81} = 0.07m < 0.10m \quad \text{(C.1)}$$

- $H_{friction}$ must be below 15 cm, if not: another pipe is added or D increased. $H_{friction}$ is calculated as follows:

$$H_{friction} = f\frac{L}{D}\frac{U^2}{2g} = 0.02\frac{20}{1.0}\frac{0.93^2}{2 * 9.81} = 0.02m < 0.15m \quad \text{(C.2)}$$

**Table C.7:** Overview of head losses due to a pipeline

| KIN-number | Pipeline required? | Length | N | D | B | C |
|---|---|---|---|---|---|---|
| | | | | | $H_{inoutflow}$ | $H_{friction}$ |
| KGM00046 | yes | 20 | 2 | 1 | 0.04 | 0.01 |
| KGM00049 | no | | | | | |
| KGM00059 | yes | 154 | 3 | 1.2 | 0.07 | 0 |
| KGM00063 | yes | 20 | 2 | 1 | 0.07 | 0.02 |
| KGM00070 | no | | | | | |
| KGM00072 | yes | 23.4 | 3 | 1 | 0.05 | 0.02 |
| KGM00106 | no | | | | | |
| KGM00142 | yes | 56.5 | 3 | 1 | 0.06 | 0.05 |
| KGM00155 | no | | | | | |
| KGM00158 | yes | 18 | 3 | 1 | 0.06 | 0.01 |
| KGM00236 | yes | 58.5 | 3 | 1 | 0.04 | 0.03 |
| KGM00301 | yes | 15.3 | 2 | 1 | 0.06 | 0.01 |
| KGM00358 | no | | | | | |
| KGM00474 | no | | | | | |
| KGM00482 | yes | 6 | 3 | 1 | 0.06 | 0 |

## C.6. Spaans Babcock Quick Selection

**Table C.8:** Spaans Babcock quick selection for Archimedean Screw Pumps (Spaans Babcock, 2017a)

| Outside Diameter | 30° | | 35° | | 38° | |
|---|---|---|---|---|---|---|
| | Q_cap_30 [l/s] | Lift CP-FP | Q_cap_35 [l/s] | Lift CP-FP | Q_cap_38 [l/s] | Lift CP-FP |
| 400 | 24 | 3,1 | 18 | 3,7 | 16 | 4,0 |
| 500 | 39 | 3,6 | 31 | 4,2 | 28 | 4,6 |
| 600 | 62 | 3,9 | 48 | 4,5 | 42 | 4,9 |
| 700 | 90 | 4,5 | 68 | 4,8 | 61 | 5,6 |
| 800 | 148 | 4,1 | 116 | 5,3 | 100 | 5,2 |
| 900 | 192 | 4,6 | 152 | 5,3 | 128 | 6,0 |
| 1000 | 250 | 4,6 | 195 | 6,0 | 166 | 5,7 |
| 1100 | 310 | 5,0 | 245 | 6,5 | 207 | 6,5 |
| **1200** | **380** | 5,5 | 300 | 7,4 | 250 | 7,0 |
| **1400** | **540** | 6,4 | 430 | 7,3 | 360 | 7,9 |
| **1600** | **745** | 6,3 | 586 | 7,7 | 500 | 7,7 |
| **1800** | **980** | 6,7 | 770 | 8,1 | 650 | 8,2 |
| **2000** | **1250** | 7,0 | 980 | 9,2 | 870 | 8,7 |
| 2200 | 1550 | 7,9 | 1200 | 9,5 | 1000 | 9,7 |
| 2400 | 1900 | 8,3 | 1500 | 9,2 | 1280 | 10,0 |
| 2600 | 2300 | 8,0 | 1800 | 9,6 | 1500 | 9,8 |
| 2800 | 2700 | 8,3 | 2100 | 9,9 | 1800 | 10,2 |
| 3000 | 3200 | 8,6 | 2500 | 10,3 | 2160 | 10,5 |
| 3200 | 3750 | 8,9 | 2950 | >10 | 2500 | >10 |
| 3400 | 4300 | 9,1 | 3350 | >10 | 2900 | >10 |
| 3600 | 4900 | 9,4 | 3900 | >10 | 3300 | >10 |
| 3800 | 5600 | 9,7 | 4400 | >10 | 3750 | >10 |
| 4000 | 6350 | 9,7 | 5000 | >10 | 4250 | >10 |
| 4500 | 8300 | >10 | 6500 | >10 | 5600 | >10 |
| 5000 | 10600 | >10 | 8300 | >10 | 7100 | >10 |

# D. Adapted steps after validation

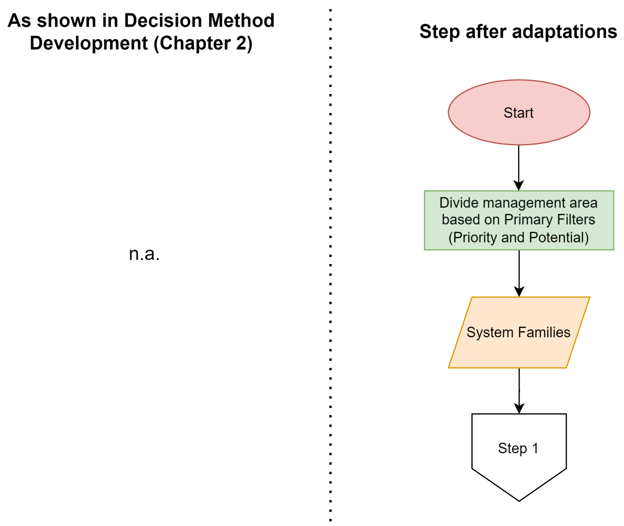



**Figure D.1:** Step 0 - Context Definition - After Validation

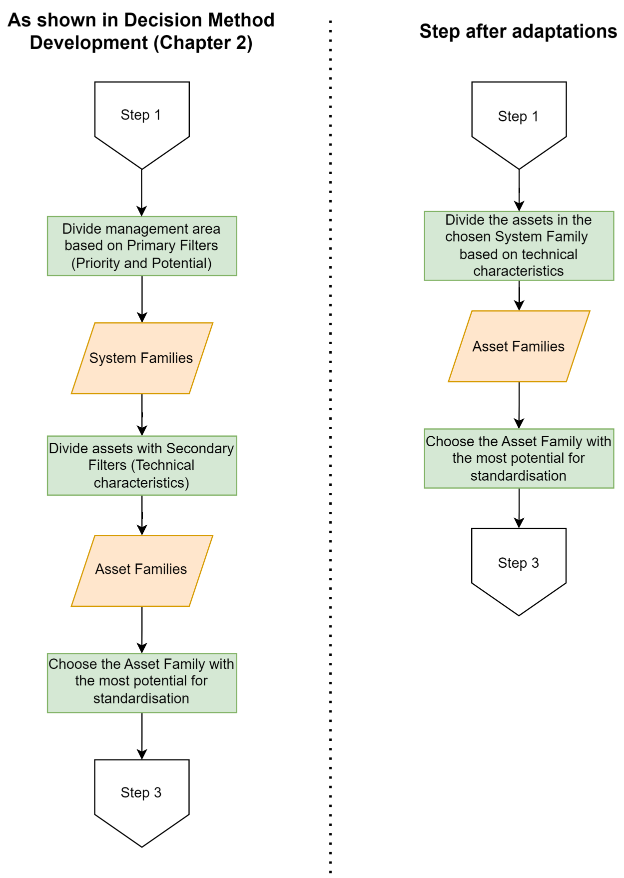



**Figure D.2:** Step 2 - Prioritisation of Assets - After Validation

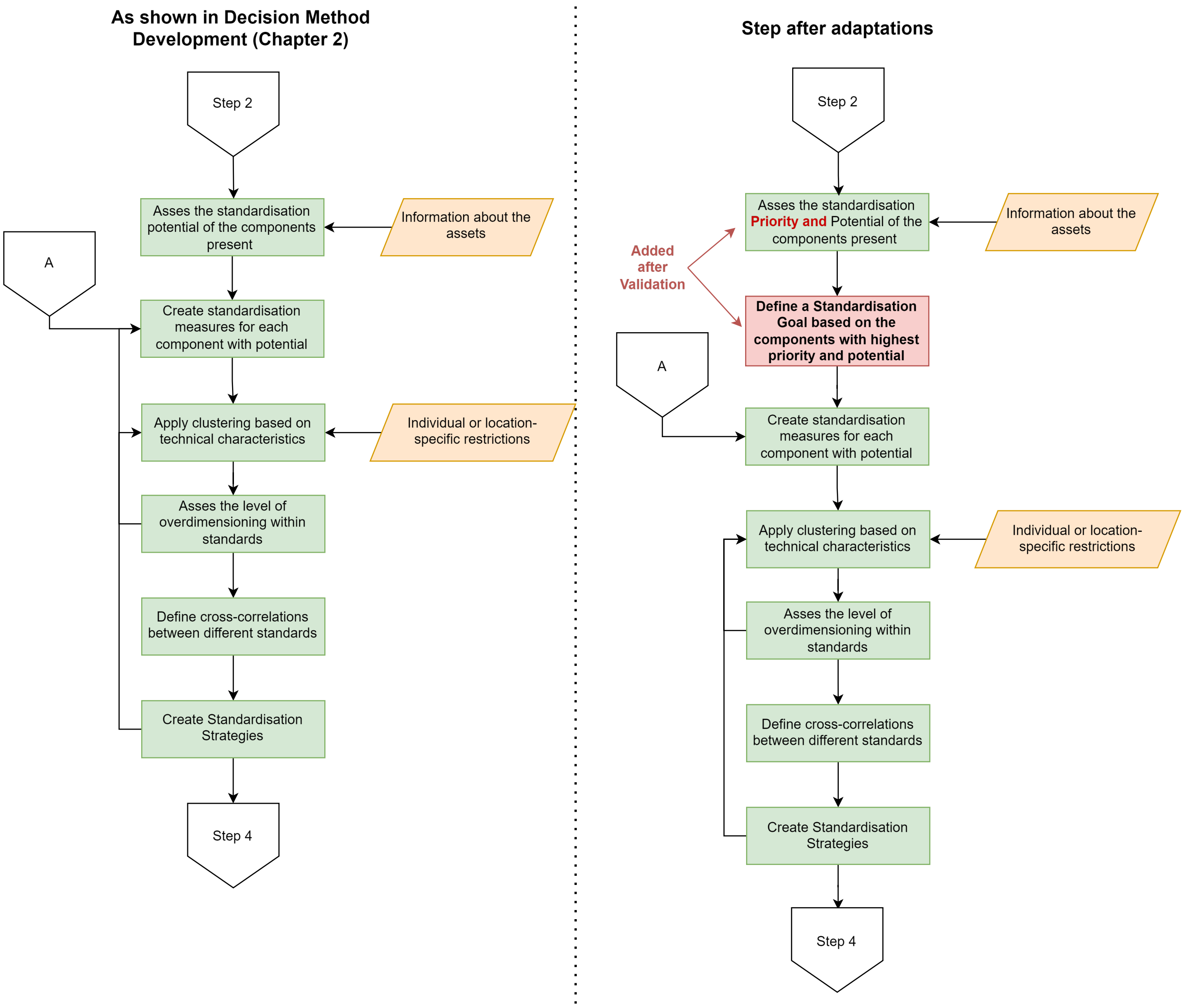



**Figure D.3:** Step 3 - Standard Development - After Validation

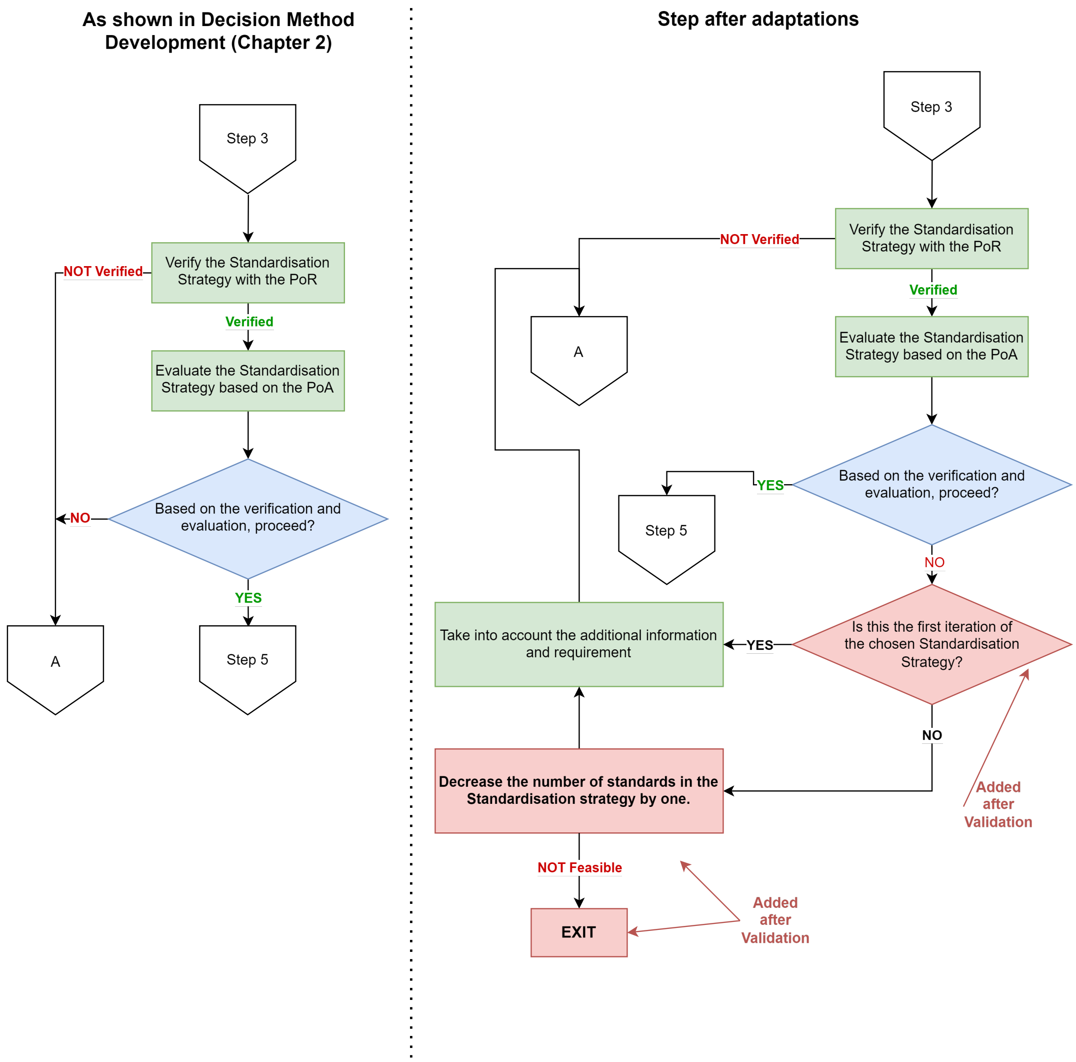



**Figure D.4:** Step 4 - Verification and Evaluation of Standards at System Level - After Validation

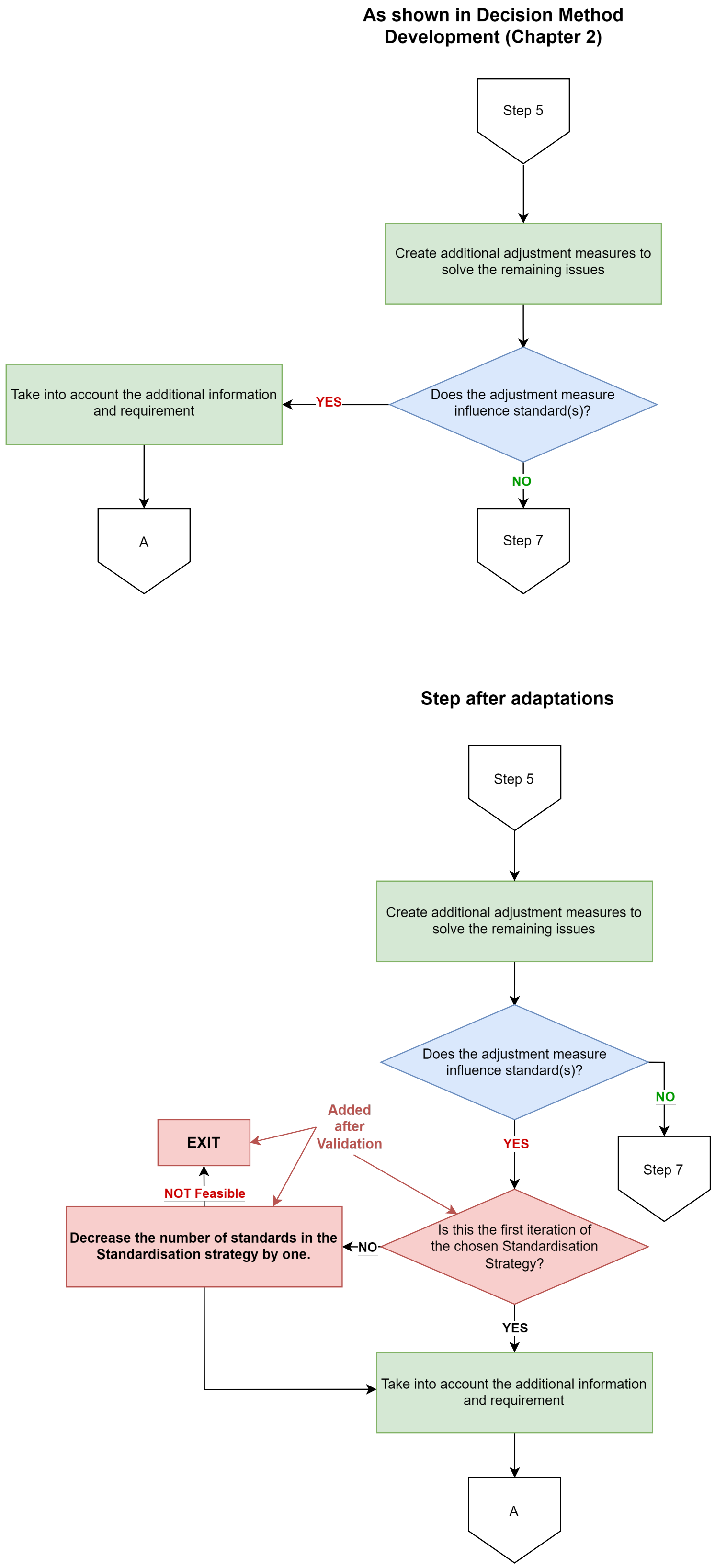
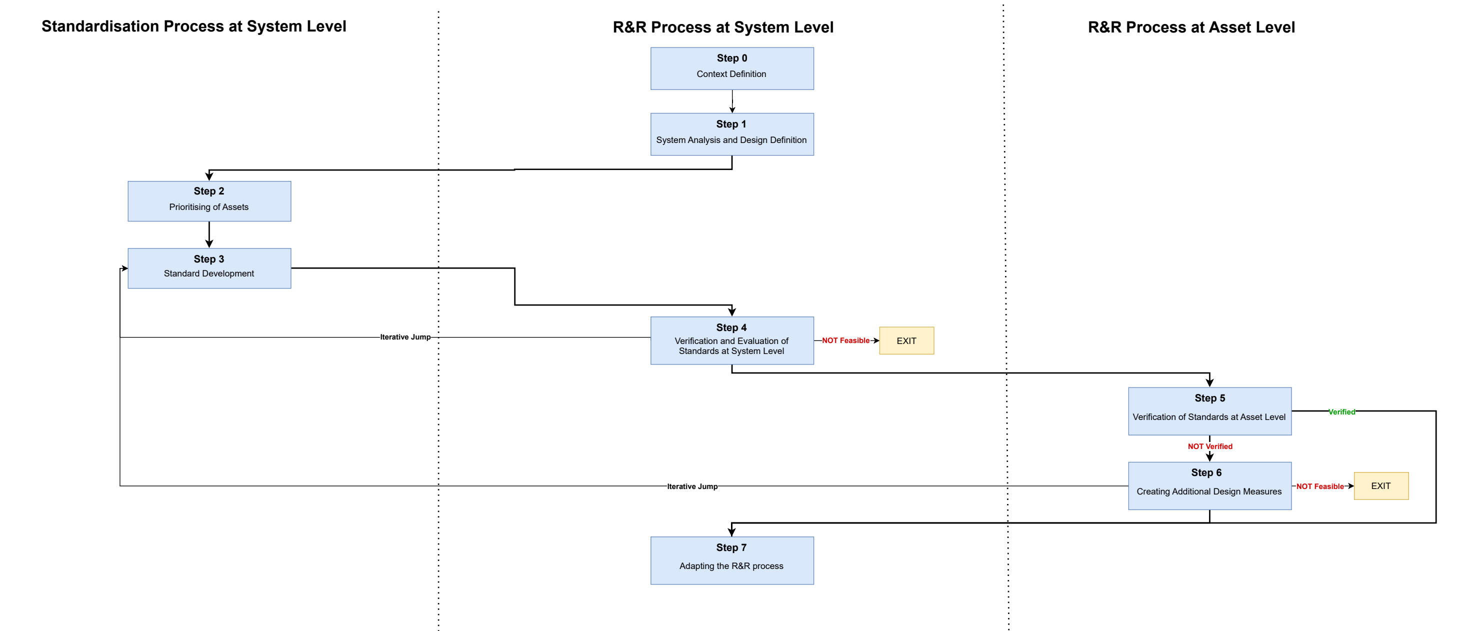



**Figure D.5:** Step 6 - Creating Additional Design Measures - After Validation

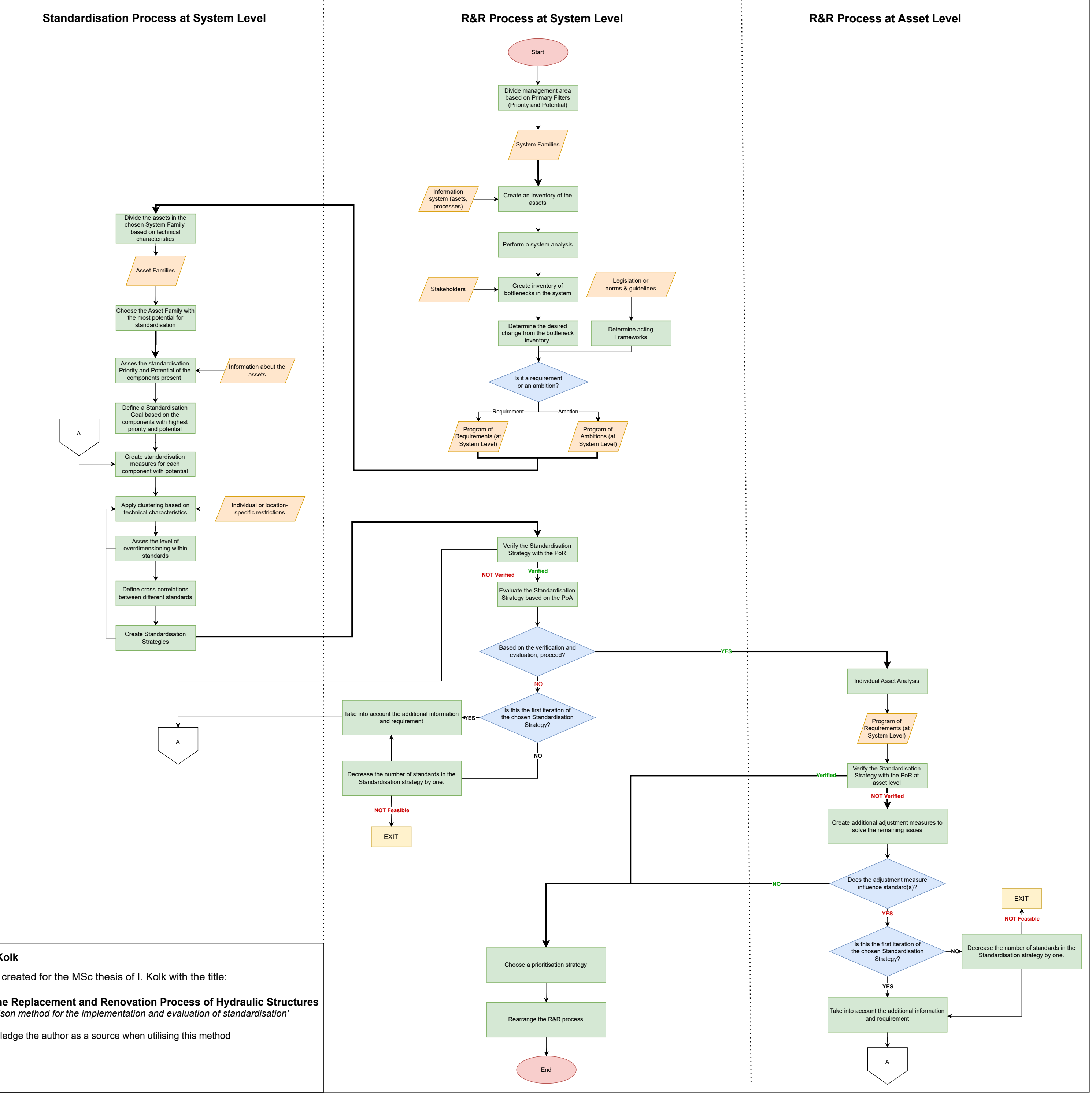
# E. Poster of the Decision Method

# A decision method for the implementation and evaluation of standardisation

## The General Decision Method




## The further developed Decision Mehtod





**Author: Iris Kolk**


This poster is created for the MSc thesis of I. Kolk with the title:

**'Improving the Replacement and Renovation Process of Hydraulic Structures**
*Creating a decison method for the implementation and evaluation of standardisation'*

Please acknowledge the author as a source when utilising this method