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Fast-tracking the Collaboration and Comprehension of Civil Engineering Structures within the Dutch Flood Protection Programme

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ABSTRACT

In the past years, much effort has been undertaken to gain further insight in the scope of the civil engineering structures, as part of the Dutch Flood Protection Programme (DFPP). In an innovative project, we shifted from aa flood defmount of structures to the required total investment cost to meet the statutory standards. The investment costs are considerably lower than originally thought. Here, the regional water authorities, Rijkswaterstaat, the Dutch Flood Protection Programme, research institutes and the consultancy firms joint forces. In the first phase we (1) developed a civil engineering roadmap, highlighting the different steps during the life cycle of a structure in a primary flood defence, and (2) used a framework to help identify the critical success factors.

For the second phase, allowing knowledge to flow was key. Therefore, we held several interviews to collect the available knowledge differentiating for the three phases of the hydraulic roadmap, namely (a) asset management, (b) portfolio management and (c) reinforcement projects. In our paper, we highlight the gained insights for each phase, with examples from the Dutch practice. As knowledge is situated and socially constructed, this knowledge has been actively shared and restated after each change in the group of participants.

There are two main reasons why collaboration in the civil engineering structures assignment is necessary. The limited capacity and expertise in the market requires smart and efficient cooperation. Besides this, the changing physical environment is an important reason for collaboration: climate change, technological developments and other societal challenges are the main reasons to work over one's organizational boundaries. This further enhances the collaboration between the regional water authorities and Rijkswaterstaat to ensure that their task is finished before 2050 and enhances the knowledge transfer and uptake within the triple helix.

KEYWORDS: Civil-engineering structures; flood risk management; innovation; knowledge management; Dutch Flood Protection Programme.

1 INTRODUCTION

For centuries, the Netherlands is battling with water. Approximately two-thirds of the country lies below current sea level. In recent years, the Dutch national government shifted from a reactive to a proactive approach (Delta Commission, 2008). This shift incorporates long term uncertainties—including climate change and land subsidence—into planning and policy in order to ensure the sustainable protection of the country (Most et al., 2014). The resulting risk based approach reflects new insights into the reliability of dikes and the consequences of major flooding resulting from the failure of dikes or associated structures. Protection standards are now determined by both the probability and potential impact of flooding in 2050, taking climate and socio economic developments into account. The Dutch Environment Act establishes statutory safety standards for flood protection infrastructure, including dikes, dams, and other hydraulic structures. Every twelve years, regional water authorities (RWAs) are required to assess the condition and performance of these flood defences to verify compliance with the prescribed standards. If deficiencies are identified, the responsible authority may apply for funding through the Dutch Flood Protection Programme (DFPP) (Jorissen et al., 2017; Tromp et al., 2025). Jonkman et al. (2018) identify two major challenges in this context: first, the renewal, adaptation, or upgrading of hydraulic structures in light of evolving safety standards and functional demands (e.g., increased shipping traffic); and second, the ongoing management and maintenance of existing structures.

In 2018, representatives of Rijkswaterstaat, RWAs, knowledge institutes, and consultancy organisations jointly emphasised the need for an innovation initiative addressing the civil engineering structures that form part of the primary flood defence system (DFPP, 2018). These structures include locks, sluices, culverts, pumping stations, and storm surge barriers (Figure 1). In 2021, the regional water authority Hollands Noorderkwartier (HHNK) initiated the innovation project Working Jointly on Hydraulic Structures. Until that point, hydraulic structures had received relatively limited attention, and no systematic national approach existed. In Tromp et al. (2024), the main author presented the findings from the project's first phase, which revealed that more than 400 hydraulic structures were listed within the DFPP portfolio—implying that, on average, one structure would need strengthening every three weeks.

The DFPP continues to use the definition of hydraulic structures provided in the Dutch Environment Act (2016): a construction forming part of a flood defence that temporarily assumes the flood protection function over a limited length, but which is designed primarily to serve another utilitarian purpose crossing the flood defence (e.g., drainage or navigation). These structures typically include one or more movable components such as valves. For DFPP assessment, an additional requirement is applied: the flow area of the water retaining component must exceed 0.5 m² (DFPP, 2016). Four distinct failure mechanisms are used to assess water retaining structures: (1) Reliability of closure, expressed as the probability of non-closure per closure demand; (2) Insufficient height, expressed as the probability of excessive wave overtopping or overflow; (3) Piping, expressed as the probability of insufficient resistance to piping; and (4) Structural strength and stability, expressed as the probability of structural failure.

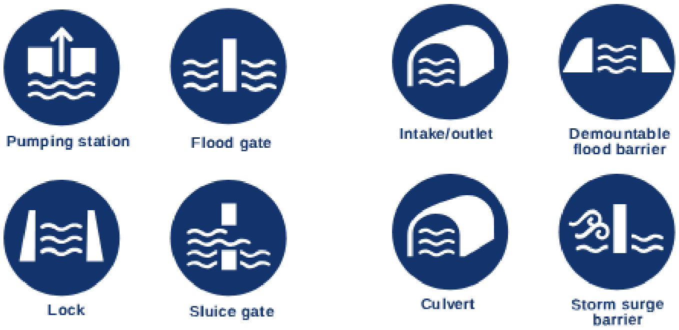

Figure 1: Hydraulic Structures within the primary flood defence of the Netherlands.

In this first phase (Tromp et al., 2024), the project team gained better understanding of the numerous obstacles that hamper the reinforcement of these civil engineering structures. To tackle these barriers, we developed a roadmap that gives more insight in the steps for strengthening these structures. Based on the first results of the statutory assessment, we updated the scope and numbers of the hydraulic structures as part of the DFPP. Phase 1, as shown in Tromp et al. (2024), concluded that a wealth of information and knowledge needs has been identified, but as knowledge is situated and socially constructed, this knowledge must be actively shared and restated after each change in the group of participants.

In this paper, we apply the learning-while-doing approach of the DFPP (Tromp et al., 2022) to these hydraulic structures and introduce the readers to our approach and experiences so far. Here, our focus lies primarily on the hydraulic structures that often consist of a location-specific combination of components and materials and are required to perform other functions too. For these structures, multiple parties, with their own individual interests and responsibilities, play a role, and they seek to minimise trade-offs. This complexity further emphasises the importance of knowledge management and continuous learning around these structures. The paper is structured as follows: Section 2 presents the methods, looking at the Dutch Flood Protection Programme and specifically to the hydraulic structures, followed by a description of the methodology used in our study; in Section 3, we describe what insights were gained and what the lessons learned are from the second phase of the innovation project. Finally, Section 4 presents the discussion and conclusions of this paper.

2 METHODS

As phase 1 showed that knowledge transfer and uptake was key, our aim was to actively gather and share knowledge, such that project teams now and in the future will benefit from this. To acquire a better understanding of how knowledge transfer and uptake takes place in the design processes of flood defences, the first author (Tromp, 2019, Tromp et al, 2022) developed and validated a conceptual framework called the Framework for Observing, Diagnosing and Intervening in Knowledge Interaction moments (acronym: FODIKI), as depicted in Figure 2. Drawing on Vlachos (1977), we conceptualise knowledge transfer and uptake as an interaction between a knowledge supplier and knowledge user, with knowledge (K) flowing from sender (S) to receiver (R). This model retains the possibility of failure, such as semantic distortion caused by cognitive barriers. When transfer succeeds, K becomes available to R, who may then apply it. We define uptake following Knott and Wildavsky's (1980) seven-stage utilisation scale, ranging from reception and cognition to adoption, implementation, and impact.

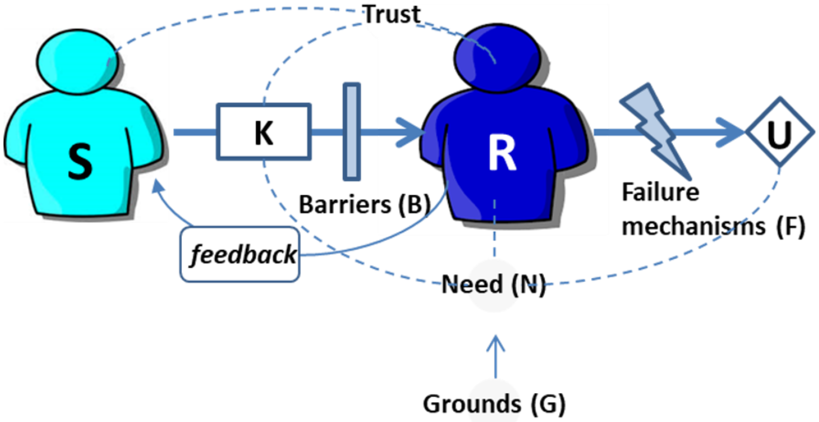

Figure 2: A sender–receiver framework for knowledge transfer and uptake (Tromp, 2019)

We identify three types of social mechanisms influencing successful transfer and uptake: preconditions, barriers, and failure mechanisms. Preconditions include a need for knowledge and mutual trust, with R trusting S's competence and intentions, and S trusting R to use K appropriately. Barriers may be: Transmission-related (e.g., physical obstacles, weak communication),Cognitive (misinterpretation of K), or Psychological (value or practice conflicts on the part of R). Even when barriers are absent or resolved, uptake can still falter through failure mechanisms, such as incorrect use (misapplication of K), diffidence (third party disqualification of K), or lack of relay (R failing to pass K to end users). We also reintroduce feedback (fb), recognising that S and R are aware of their roles and knowledge gaps. Through feedback, R can signal understanding issues or emerging barriers, enabling S to adjust the transfer process..

We applied the FODIKI Framework during the second phase of the project to systematically collect and disseminate the knowledge acquired regarding the hydraulic framework (see Figure 2). This framework, developed in the initial project phase (Tromp et al., 2024), delineates the three principal phases in the life cycle of a hydraulic structure within a primary flood defence system. These phases comprise: (1) Asset management, involving the statutory obligation to perform routine care and maintenance. When a structure no longer meets legal performance standards, the process transitions to (2) Portfolio management, during which planning and decision-making for necessary upgrades are initiated; followed by (3) Reinforcement projects, a multistep process aimed at strengthening the hydraulic structure. Upon completion of the reinforcement phase, the life cycle returns to the asset management phase, thereby continuing the cyclical process of maintenance and renewal.

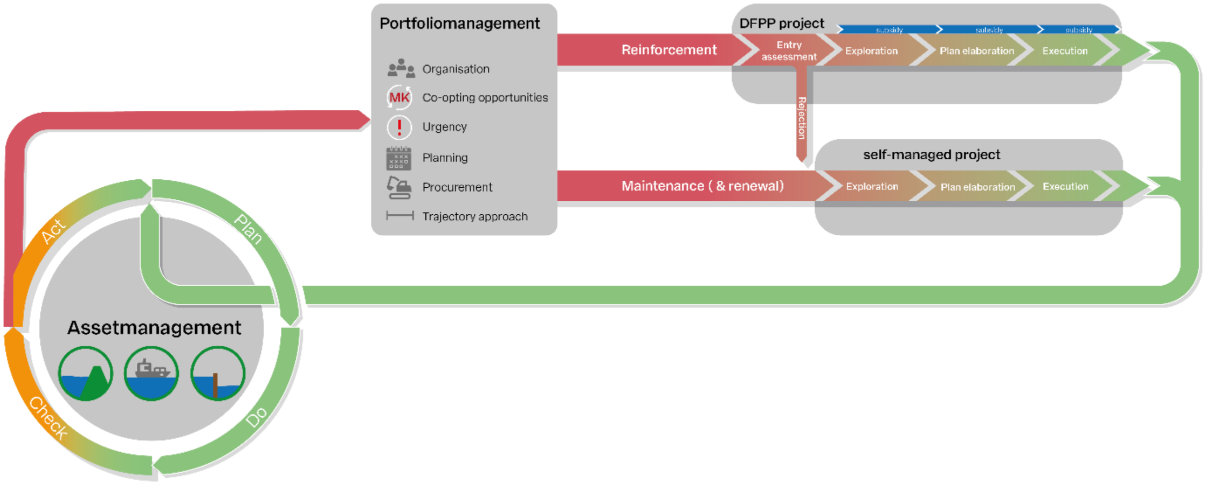

Figure 3: The Hydraulic Structures Roadmap highlighting the different phases during the life cycle of a structure in a primary flood defence.

We held multiple semi-structured interviews with different projects for each phase of the hydraulic roadmap with representatives of the RWAs. Moreover, we had meetings with the RWAs on the results of the statutory assessments and collected additional information. The results were translated into, among other things, an adjusted scope for admission to the DFPP, and the experiences gained during the projects were recorded in a repository of knowledge. We also organised meetings to enable the active sharing of knowledge and experience. Particularly one of the dominant failure mechanisms in hydraulic structures generated a great degree of interest. The following section examines the results in greater detail.

3 RESULTS

Within the DFPP project ‘Working jointly together on hydraulic structures’, further insight into the scope of the task, a uniform approach and available knowledge has been obtained. In this section, we describe these results of the research.

3.1 Scope of the hydraulic structures within the DFPP

Our project team conducted interviews with all Dutch RWAs regarding their civil engineering assets. The findings differed from initial expectations for three main reasons.

First, the scope of the task proved smaller than anticipated. This discrepancy arose from differing interpretations of assessment results between the RWAs and the DFPP. The DFPP had not fully recognized that the large number of structures, classified as non-compliant, was primarily due to limited time and data availability. The RWAs were given only six years to implement the amended statutory assessment (the risk-based method as described in the introduction) and reassess all dike sections, including hydraulic structures. This major transition created time constraints, limiting opportunities to collect additional data for more accurate (and often safer) evaluations. Consequently, many structures were initially marked as non-compliant, even though the RWAs already were aware that most structures did not require reinforcement.

Second, the variety of reinforcement measures is considerable. The average cost per instance (financial ratio) did not provide a realistic picture of the task at hand (see Figure 4). Cost estimates for strengthening hydraulic structures were significantly overstated. In many cases, minor technical adjustments or even changes in procedures for operational closure were sufficient to restore compliance.

Third, several structures were reinforced as part of broader dike reinforcement programs, meaning they were addressed indirectly.

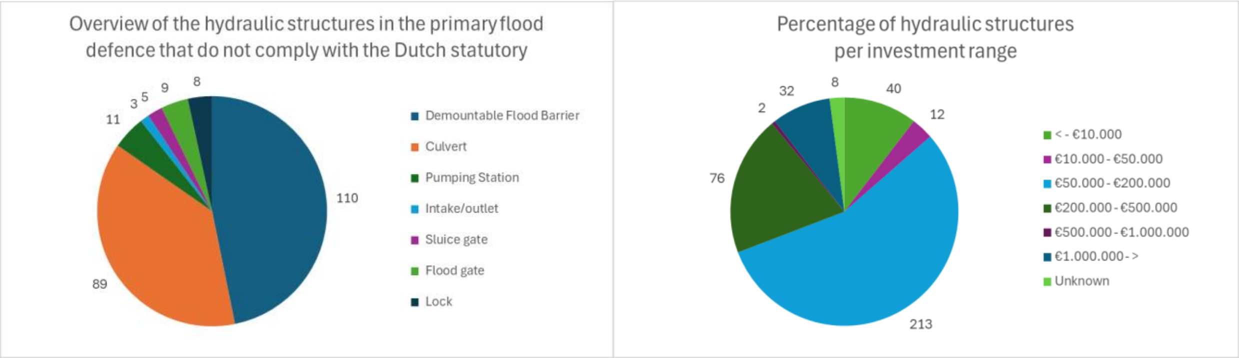

Figure 4: (a) Overview of the hydraulic structures in the primary flood defence that do not comply with the Dutch Statutory (Left). (b) Percentage of these hydraulic structures per investment range (Right).

This leads to the recommendation for the DFPP to frame the scope of the hydraulic structure within the DFPP in terms of an investment sum rather than the number of structures. Accurate estimation of this sum requires close collaboration with the RWAs, which is only possible through a strong relationship of trust and regular interaction between the DFPP and the RWAs. Based on current insights, the investment needed to ensure all civil engineering structures in the Netherlands meet flood safety standards is approximately €250 million, with an uncertainty margin of 25% (excluding economic inflation and construction material cost escalation). Adopting an investment-based approach with the current quantity of reinforcements eliminates the need for a separate programmatic strategy for structures within the DFPP.

3.2 Hydraulic Structures roadmap: Lessons learned in uniform approach

In our project, we made several key results in establishing a uniform approach for reinforcing hydraulic structures, examples are the decisions on life-cycle reliability of flood defence systems and the Roadmap for Sustainable Hydraulic Structures. A uniform approach enhances efficiency, knowledge sharing and quality across all life-cycle phases of hydraulic structures (see Figure 3).

Portfolio management: decisions on life-cycle reliability and a programmatic approach on flood defence systems

Scope definition is essential for effective portfolio management. The method of optimal marginal safety gain, as developed by Klerk (2021 & 2022), optimizes investment decisions by comparing the cost-benefit ratio of measures, expressed as risk reduction per euro spent. Originally designed for dike reinforcements, the method was successfully applied to three sluices in dike trajectory 16-1. Key findings (Deltares, 2024) indicate that investments in hydraulic structures can significantly influence dike reinforcement strategies. This interaction depends primarily on (i) the initial failure probability of the structure relative to adjacent dike sections and (ii) the cost ratio between structural and dike measures. Timing is critical: postponing structural improvements increases total costs and flood risk, while coupling measures or advancing them can be cost-effective, especially when aligned with maintenance schedules. Importantly, optimization may deviate from strict design-level criteria, favouring solutions that balance compliance and cost-effectiveness, sometimes accepting slightly lower safety at substantially lower cost. This enables tailored strategies that reduce life-cycle costs while meeting trajectory-level standards.

Examples from Dutch RWAs have shown that adopting a programmatic approach to reinforcing hydraulic structures enhances efficiency through standardized processes, centralized design frameworks and integrated governance. For smaller portfolios, flood safety measures can be embedded within broader programs such as asset renovations or water system adaptations. Larger volumes of work strengthen collaboration with research institutes, authorities, and market partners by providing long-term visibility, which encourages investment and innovation, contributing to safer and more resilient infrastructure.

Reinforcement projects: lessons learned

Knowledge sharing between project teams is critical for improving efficiency and quality. Interviews with stakeholders revealed three key themes: technical, environmental, and contracting.

Technical**:** Early contractor involvement proved highly effective in the DFPP-project: 7 Hydraulic Structures by HHNK. Engaging the contractor during the exploration phase enabled proactive measures, such as early dewatering of sluices to assess structural condition and mitigate risks. This approach reduced uncertainty and has since been replicated in other projects, demonstrating the value of integrating contractor expertise from the outset.

Environmental**:** Reinforcement projects offer opportunities beyond local stakeholder management and cultural heritage preservation. They can contribute to (inter)national sustainability goals. The Roadmap for Sustainable Hydraulic Structures (Web-1) provides a structured framework for integrating sustainability throughout the project lifecycle. Key principles are: early scope definition to limit environmental impact, explicit governance structures with clearly defined roles and specialized expertise to ensure the translation of ambitions into concrete design criteria and the systematic embedding of sustainability in procurement and execution through functional requirements and performance indicators. Practical examples demonstrate these principles, including CO_2 reductions via optimized designs, electrification, and material reuse such as cement-free concrete and recycled steel gates.

Contracting**:** Combining hydraulic structure reinforcements together with dike projects can be efficient when the works are related to crest heights. The opposite was seen at a project in the southern part of the Netherlands (near Mook). Differences in contract forms and planning cycles often lead to misalignment. While dike projects typically require iterative detailing, reinforcement of structures is usually well-defined upfront, complicating integrated execution.

Good Conversation: empathy, respect, openness and vulnerability.

The interviews with RWAs were crucial to the findings presented in this paper. Through open dialogue, information was clarified, deepened, and enriched, fostering curiosity-driven exchanges. These conversations resulted in greater insight, trust, and a sense of ownership among the authorities. Responsibility for the hydraulic structure program lies with them, while the "conversation partner" facilitates by sharing and connecting knowledge and experiences from peer organizations.

Maintaining this constructive dialogue is essential, as shown and analyse by the FODIKI framework. It creates connection in a safe and relaxed environment, prevents barriers and failure mechanisms, keeps the hydraulic structure program clearly in focus, and reduces unnecessary administrative burdens. In addition, this enhance the ownership of RWAs. For RWAs, engaging in this dialogue annually ensures that, at the alliance level (DFPP), a current and widely supported perspective emerges, one that accurately reflects the realities and priorities of the regional authorities

4 DISCUSSION AND CONCLUSIONS

In this paper, we stressed the importance of knowledge transfer and uptake. Despite all effort, the necessity of strengthening dikes is more top of mind at the RWAs than hydraulic structures. Luckily, the required measures in the primary flood defence system are less far-reaching as originally thought. The scope of the hydraulic structures was minimised due to efforts of the project team and the RWAs who took their role of ownership. The interviews with the RWAs reveal that the importance of knowledge uptake is acknowledged, but little action is there. As a result, project teams reinvent the wheel, leading to a low degree of efficiency. The scope in the regional water system for hydraulic structures in the Netherlands is a multitude, where the question arises whether some assets continue to play a role in the near future. Learning across projects is also recognized but this is not part of the task of project teams, hampering the knowledge transfer and uptake. From our interviews, we observed several barriers and failure mechanisms occurring in the knowledge transfer and uptake, predominantly due to lack of cognitive barriers, relay of knowledge and trust.

One of the barriers mentioned is the subsidy application process. The underlying reason is the extensive administrative effort required to comply with the DFPP subsidy scheme. The cost of meeting all requirements (approximately €200,000) makes it unattractive to apply for funding for relatively small reinforcement measures, even though RWAs are formally entitled to it. As a result, hydraulic structures are predominantly included in dike reinforcement projects (where subsidies are already being requested) or addressed through regular maintenance programs, which may result in inefficient strengthening. Although a Fastlane approach already exists (combining the phases of exploration, plan elaboration and/or execution) this process must be further simplified for small-scale reinforcement measures of civil engineering structures.

Although practitioners recognise the importance of knowledge transfer and uptake, the systematic exchange of knowledge with peers—both within and beyond the RWAs—remains insufficiently utilised. Strengthening learning processes between RWAs and project teams requires a more prominent role for boundary spanners. Boundary spanners are individuals who ‘proactively scan their organisational environment, engage in activities that bridge organisational or institutional boundaries, facilitate and mediate information flows, and coordinate interactions between their home organisation and its external environment’ (Van Meerkerk & Edelenbos, 2018). They contribute substantially to processes of sense-making and framing (Carlile, 2002; Williams, 2012). In practice, such roles are typically fulfilled by staff within RWAs as well as by members of the Dutch Flood Protection Programme (DFPP) Programme Board. Positioned between RWAs and their projects, and between policy and operational practice, the DFPP increasingly needs to function as a boundary organisation (Van Meerkerk & Edelenbos, 2018), as shown by Tromp (2019).

This paper has underscored the significance of effective knowledge transfer and uptake. The Hydraulic Structures Roadmap has demonstrated its value in clarifying the steps and considerations associated with each phase of the life cycle. RWAs now possess the necessary tools to access knowledge and instruments from their counterparts. However, knowledge transfer and uptake must become an integral component of every programme or project assignment, and RWAs must treat this as a strategic priority.

Current societal challenges—such as large-scale housing development, agricultural transition, and the energy transition—are driving widespread construction activities across the Netherlands. Limited market capacity and specialised expertise highlight the need for more efficient and coordinated collaboration. In addition, the rapidly changing physical environment, driven by climate change and technological developments, reinforces the necessity of working across organisational boundaries. This imperative strengthens cooperation between regional water authorities and Rijkswaterstaat and supports timely completion of their joint objectives before 2050, while also enhancing knowledge transfer and uptake within the broader triple-helix context.

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