Identifying boundaries that enhance system resilience in an integrated FRM project

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ABSTRACT

Traditionally, flood risk management (FRM) has relied on engineered structures to prevent floods. However, this strategy does not enhance system resilience as it only reduces the probability of flooding, focusing on the capacity to resist floods and neglecting the absorptive capacity of a landscape. Therefore, there have been calls for more integrated FRM, where flood prevention is viewed as interdependent with other spatial challenges. However, considering system interdependencies is complex. To manage this complexity, system boundaries have to be drawn. Setting boundaries is a balancing act; both too tight and too wide boundaries may cause problems. This study, therefore, asks: *To what extent do boundaries applied in FRM projects contribute to or hinder system resilience?* To analyse these boundaries and their impact on resilience, we combine insights about system and resilience thinking with insights from the literature on forward-looking decision-making. The latter allows us to account for the temporal aspects of resilience, which is key in FRM projects, given their high uncertainty and infrastructure systems with long lifespans. We developed a conceptualisation of boundaries that distinguishes between spatial, domain, hazard, participation, and temporal boundaries. We apply this conceptual framework to a project that aimed to reduce flood risks while improving spatial quality in the Netherlands. In this case, most boundaries were neither tight nor wide. As such, the project balanced between complexity and manageability. One boundary that was drawn notably tight concerns hazards, focusing solely on resilience to flooding without considering other disturbances. The participation boundary was relatively wide, encompassing diverse stakeholders, multiple levels, and various types. This research provides a practical framework for boundaries to consider in integrated FRM projects, acknowledging the need to balance complexity by drawing boundaries that are manageable yet supportive of system resilience.

KEYWORDS: Flood risk management, system thinking, flood resilience, spatial planning, system boundaries

1 INTRODUCTION

For several decades, flood risk management (FRM) in the Netherlands has relied on engineered structures that reduce the probability of flooding (Tempels & Hartmann, 2014; Verweij et al., 2021). Notable examples include the Dutch Delta Works, constructed after the 1953 storm surge that affected major parts of the Netherlands. This prevention-based FRM strategy is an illustrative example of the Netherlands' century-long fight against water. However, climate change is increasingly impacting urban and rural areas, intensifying extreme weather events and sea-level rise and increasing flood risks. The expected increase in both flood frequency and severity, coupled with spatial challenges such as urbanisation, suggests that an FRM strategy relying solely on engineered structures is unlikely to be the remedy to future flooding (IPCC, 2023; Van Buuren et al., 2016). Around the world, policies reflect a growing awareness of shifting towards innovative, more integrated FRM concepts. This shift is also referred to as the diversification of FRM strategies, in which flood resilience is enhanced not only by resisting to floods, but also by enabling the capacity to absorb, recover, transform and adapt to them (Hegger et al., 2016). Despite existing international and national policies on integrated FRM, the implementation of integrated FRM – which would generally enhance resilience – remains challenging (Bosoni et al., 2023; Hartmann & Spit, 2016).

An underlying factor is the complexity involved in enhancing system resilience. Thinking in terms of system resilience often implies taking a holistic view, acknowledging interdependencies between and within system elements (Helfgott, 2018). This increases complexity and potentially leads to 'paralysis by analysis' as more and more elements and interconnections are taken into account (De Loë & Patterson, 2017). Therefore, when considering resilience, one is always drawing boundaries regarding resilience of what, to what, for whom and over what timeframe (Helfgott, 2018). Resilience thinking, therefore, involves balancing boundaries and acknowledging the difficulty of fully understanding all interdependencies within an entire system.

In response to calls for integrated FRM, which requires actors to collaborate across more and diverse domains (Willems et al., 2022), and which spans a longer time frame (Pot et al., 2019), this study highlights the importance of balancing system boundaries that enhance resilience. We consider that integrated FRM has a pivotal role in enhancing resilience (Doornkamp et al., 2024) and that its implementation requires making forward-looking decisions to address uncertainty. However, the extent to which boundaries in integrated FRM enhance resilience, and whether these boundaries support forward-looking decisions, remains understudied. To address this knowledge gap, we address the following question: *To what extent do boundaries applied in FRM projects contribute to or hinder system resilience?* To answer this question, we develop and apply a framework to assess boundaries in integrated FRM projects. Empirically, we focus on a regional project in the Netherlands that integrated two objectives: ensuring flood safety and enhancing spatial quality. Based on the analysis of the implemented Polder Project, we identify the extent to which boundaries are supportive or restrictive of contributing to system resilience. Consequently, this research offers guidance on balancing boundaries to enhance flood resilience.

2 THEORY

In this section, we further explore the concept of system boundaries, which addresses the ever-increasing complexity of interdependent systems, and explain resilience and forward-looking decisions in relation to these boundaries. We conclude with a conceptualisation of boundaries in integrated FRM.

2.1 Balancing boundaries in flood risk management

Although integrating a wide range of environmental challenges brings co-benefits (Bakhanova et al., 2025), involving more domains, expanding the scope, and extending the time horizon generally also increases complexity. To manage the growing interdependence and complexity within and between systems, practitioners, experts, researchers, and individuals tend to draw – sometimes explicitly but oftentimes implicitly – system boundaries, to reduce complexity (Meadows, 2009). These boundaries typically reflect different transition zones. In the social sphere, boundaries may refer to the need to bridge between differing values and perspectives among individuals, organisations, or domains. Boundaries can also be physical, for example, marking transitions in land use, ecosystems, or hydrological systems (Van den Brink et al., 2022).

These system boundaries may be drawn rather tightly or too widely. Tight boundaries oversee potential adverse outcomes in adjacent systems, which are on 'the other side' of the boundary but enable more manageable analysis and demand fewer resources from actors. On the other hand, wider boundaries increase complexity as they may overwhelm system analysts by complicating the analysis of numerous potential interdependencies, while still allowing for system interconnections (De Loë & Patterson, 2017; Meadows, 2009). For FRM, boundaries were rather clear, as the focus was on engineered and sectoral solutions to flooding (Van Buuren et al., 2016). However, interdependent climate and spatial challenges emphasise the need for more integrative FRM that enhances flood resilience, for example, by acknowledging the need to address the consequences of flooding in spatial planning. The boundaries in FRM are therefore broadening, as flood solutions are increasingly considered as an interdependent social, ecological, and technological system (Markolf et al., 2018). This calls for more balanced boundaries that recognise increasing complexity, without simplifying the challenges at hand.

Various studies show that in FRM and the water sector in general, system boundaries are often defined quite tightly (De Loë & Patterson, 2017; Van Meerkerk et al., 2013; Vinke-de Kruijf et al., 2024). Previous research in the Netherlands, which conceptualises boundary judgements as the explicit and implicit decisions made about who and what to include in FRM projects, confirms this. It shows that regional water authorities, accustomed to making decisions independently, tend to draw tight boundaries, hindering cross-sectoral collaboration, reducing participation, limiting the scope, and lacking adaptability (Van Meerkerk et al., 2013; Vinke-de Kruijf et al., 2024). Other studies employ the concept of boundaries differently, emphasising the inherently subjective and value-laden character of boundary judgements, which arises when analysing the roles of specific actors. For example, Van den Brink et al. (2019) emphasise the crucial role of actors in integrated FRM: the earlier actors are involved, the more crucial their role is in spanning boundaries and converging values and perspectives within integrated FRM.

2.2 Resilience and forward-looking system boundaries

Resilience thinking is generally characterised by a holistic philosophy that considers everything within and between systems (Helfgott, 2018). To analyse system resilience and make it more manageable and less complex, system boundaries are drawn. This also applies to the context of FRM, where we acknowledge the need to balance boundaries to enhance flood resilience. This is often associated with the alignment of three capacities of a system to 1) resist floods, 2) absorb and recover from floods, and 3) transform and adapt to floods (Hegger et al., 2016). This view necessitates a comprehensive systemic perspective, wherein resistance-oriented structures, such as dikes, throughout the entire flood-prone area are considered alongside required institutional changes to transform and adapt to future floods (ibid.). However, adopting this perspective not only requires drawing boundaries related to geographic scale or the involvement of various domains in integrated FRM (Willems et al., 2022), but also to temporal boundaries.

In times of great uncertainty, making forward-looking decisions is crucially important. Such decisions consider adaptability (Pot et al., 2018) but also consider future developments. As such, they enable the selection of adaptive alternatives that are suited to changing circumstances (Pot et al., 2019). We further build on the *forward-looking* element of integrated FRM projects, since integrated FRM generally encompasses a longer time frame compared to traditional FRM (Pot et al., 2019). We build upon the forward-looking decision framework to analyse the extent to which integrated FRM is forward-looking. This framework considers whether the problem at hand, the proposed solution, and the justification are forward-looking (Pot et al., 2018).

In the subsequent section, we conceptualise system boundaries in integrated FRM in relation to resilience and forward-looking decision-making.

2.3 Conceptualising boundaries in integrated FRM

To operationalise boundaries that enhance system resilience in FRM, we use the four framing questions identified by Helfgott (2018) which specify resilience *of what*, *to what*, *for whom*, and *over what timeframe.* We enrich this framework with criteria for making forward-looking decisions (Pot et al., 2018). In the context of FRM, we further build on boundary typologies identified in adaptive water governance and integrated FRM projects (Van Meerkerk et al., 2013; Vinke-de Kruijf et al., 2024) and distinguish five system boundaries: spatial, domain, hazard, participation, and temporal (Table 1).

Spatial scale refers to '*resilience of what*' and concerns which geographical boundaries of the system are of interest. This indicates whether the geographical system boundaries are tight or wide. For instance, do boundaries reflect the hydrological properties and dike trajectory alongside the river, the potentially affected flood-prone area, or an entire catchment?

The **domain** boundary, considers the extent to which multiple domains are involved (Vinke-de Kruijf et al., 2024), which also relates to '*resilience of what*'. We use 'domain' instead of sector, as the former is broader and also refers to expertise and knowledge, while sectors are mainly considered as a specific subset of a larger system or economy. For this conceptualisation, we ask whether only the flood protection domain is involved, or whether broader water-related domains or adjacent areas such as housing or agriculture are also considered.

We define a **hazard** boundary considering the '*resilience to what*' disturbance. To make forward-looking decisions, a problem definition should include consideration of future challenges to which resilience is enhanced (Pot et al., 2018). We assess where boundaries are drawn and which challenges are considered. For instance, does the integrated FRM project include flood-related disturbances only, or does it also address drought or external disturbances (Van Meerkerk et al., 2013)?

The fourth boundary relates to stakeholder **participation**, focusing on '*resilience for whom*' and questioning the extent to which system features need to be preserved for whom. A tight boundary involves only one stakeholder group, such as experts, government organisations, and citizens (Vinke-de Kruijf et al., 2024). Expanding boundaries to include a broader and more diverse range of stakeholders, both horizontally and vertically, increases complexity but allows for a greater variety of perspectives to be heard.

The last boundary concerns '*resilience over what time frame*', addressing the often longer timespan of integrated FRM, and the necessity to take forward-looking decisions (Pot et al., 2018). The **temporal** boundary defines the time horizon considered, with tight boundaries representing a few years, and wider boundaries contributing to resilience that extend at least 100 years. (Vinke-de Kruijf et al., 2024). It also touched upon the adaptability of the solution over the considered time frame, i.e., can it be adapted to changing circumstances, and to what extent the decision-making process is adaptive (Pot et al., 2018). A rigid, less adaptable solution and process are less capable of dealing with changing circumstances.

Table 1: Five categories of system boundaries in integrated FRM.

Category	**Explanation**	**Resilience framing**
Spatial	Geographical scale of the implemented project.	*Resilience of what?*
Domain	Involved domains in the project.	*Resilience of what?*
Hazard	External disturbances considered.	*Resilience to what?*
Participation	Involved stakeholders in project phases.	*Resilience for whom?*
Temporal	Time horizon and adaptability of the solution and process.	*Resilience over what time frame?*

3 METHODOLOGY

To answer our research question, we use empirical evidence derived from a single case. Based on the distinction between system boundaries, we examine the extent to which these boundaries support or restrict system resilience in an integrated FRM project in the Netherlands. We first describe the Dutch context and our case. Finally, we elaborate on data collection and analysis.

3.1 Case description and context

We focus empirically on the Polder Project, where an existing dike protecting a low-lying polder was opened to allow water to flow freely in the event of high discharges in the surrounding rivers (Figure 1). This project was part of the Space for the River programme, which was initiated in response to the 1993 and 1995 extreme water levels in the major rivers in the Netherlands (Bosoni et al., 2023; Hegger et al., 2020; Pot et al., 2024). Compared to engineered FRM, which focuses on flood prevention by heightening dikes and resisting floods (Hegger et al., 2016), the Space for the River programme aimed to create more space for the river with two key objectives: flood safety and spatial quality (Van den Brink et al., 2019).

Completed in 2015, the Polder Project employed a co-creative design approach that involved extensive participation from local stakeholders. After involving local stakeholders, a design was proposed that protected inhabited areas in the polder with mounds, while transportation routes were elevated on smaller levees within the landscape. The project introduced a special programme structure that included a team focused specifically on spatial quality, ensuring that the double objective could be achieved (Berenschot, 2018).

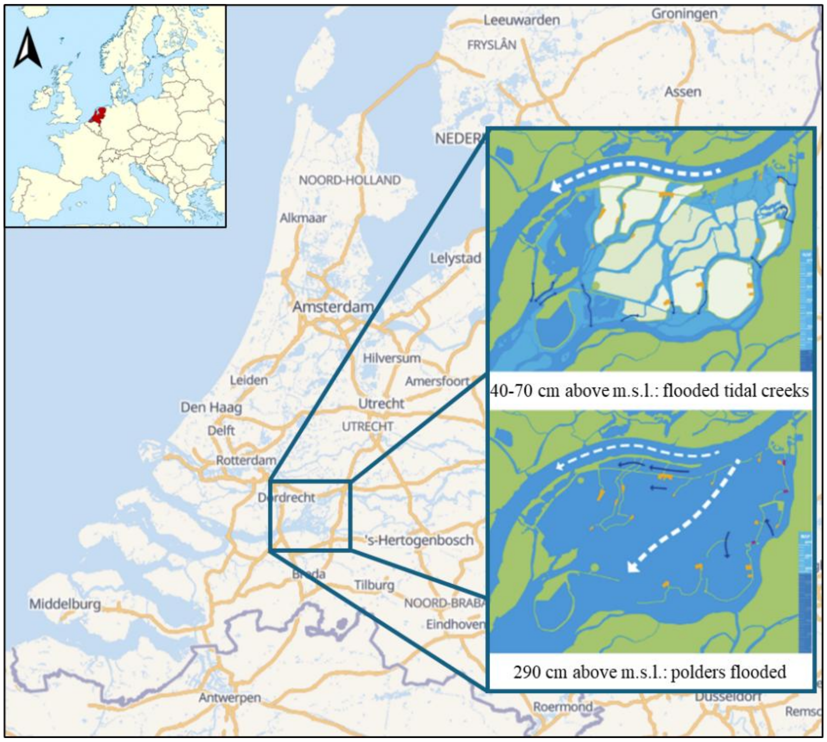

Figure 1: The Polder Project situated within the Netherlands, displaying a situation where the tidal creeks are flooded, and a situation where all polders, except the mounds and levees, are flooded (adapted from Bralts (2024)).

3.2 Data collection and operationalisation

Data were collected through document analysis and seven 90-minute-long semi-structured interviews (Bralts, 2024). The document analysis included action plans, policy and design documents, news articles and evaluations. The interviewees were selected based on their background, role, and expertise, and included representatives from governmental institutes, a research institute, and the Space for the River programme management. All interviews were recorded, fully transcribed, and the interviewees signed a consent form to inform them that they could withdraw at any time. The interviews were analysed in Atlas.ti using deductive thematic analysis with predefined codes related to, e.g., forward-looking decision-making.

Building on the distinction of system boundaries as presented in Table 2, we empirically identify the system boundaries of the implemented integrated FRM project. We use a three-point scale to assess whether system boundaries are tight, wide, or moderate, as shown in Table 2. In consideration of resilience thinking, which requires a holistic perspective, we regard wide boundaries as those that more accurately support system resilience. We associate tight boundaries with a sectoral, expert-centred and short-term approach.

Table 2: Assessment of system boundaries.

Category	**Tight**	**Moderate**	**Wide**
Spatial	Dike trajectory	Flood-prone area	River catchment
Domain	Flood protection	Water-related	Beyond the water domains
Hazard	Flood-related disturbance	Water-related disturbance	Water and external disturbances
Participation	Expert-centred stakeholder involvement	Horizontal **or** vertical involvement of diverse stakeholders	Horizontal **and** vertical involvement of diverse stakeholders
Temporal	Short-term (years) and rigid solutions and process	Medium-term (decades) and adaptable solution or process	Long-term (century) and adaptable solution and process

4 CASE STUDY RESULTS

This section presents the preliminary results of spatial, domain, hazard, participation, and temporal boundaries in the integrated FRM project and discusses the extent to which the drawn boundaries are supportive or restrictive to system resilience.

4.1 Assessment of boundaries

In the Polder Project, the **spatial boundary** was **moderate**. The project extended beyond a traditional dike reinforcement project, involving the depoldering of an area of approximately 2,000 hectares. However, it did not evaluate the potentially affected land in the river catchment. Multiple alternatives were considered, starting with a side channel through the area. This solution was rather tight and lacked support from local stakeholders. This led to a broader scope, involving the replacement of dikes and depoldering the area.

The **domain boundary** was also **moderate**. Primarily, the flood protection domain was considered without accounting for droughts and sea level rise. Nevertheless, flood safety was integrated with spatial quality as part of the project's dual objective, which involved domains as diverse as archaeology and cultural history. Although the dual objective of the project led to the involvement of various disciplines, only flood protection was considered in relation to water.

The **hazard boundary** was **tight**, since boundaries were only drawn in relation to resilience to flooding, without considering other water-related or external disturbances explicitly. The primary focus of the Polder Project was on addressing flood-related disturbances associated with riverine discharges, while overlooking droughts, sea level rise, and other water-related disturbances. For the spatial quality objective, no long-term goals or other external disturbances were explicitly considered.

The **participation boundary** was **wide** due to the inclusion of a diverse range of stakeholders, both horizontally and vertically. The project involved experts, regional governments, and national government bodies, which covered most costs and risks, thereby promoting collaboration among various stakeholders. Additionally, inhabitants had an active say in the project, and responsibilities were distributed among multiple national ministries.

The **temporal boundary** was **moderate**. As a long-term problem, only potential increases in river discharges have been considered, without accounting for potential long-term sea-level rise. To evaluate the integrated FRM solution for extreme flood events, hydraulic models have been utilised to assess its long-term effectiveness. Long-term spatial design has not been developed, as land-use claims in the Netherlands are affected by the constantly changing political climate. Instead, improvements in spatial quality for the Polder Project have focused on the short and medium term, with the flexible development of biodiversity and nature explicitly considered for future development. While adaptability to future development is considered dual – both in terms of flood safety and spatial quality – the project structure no longer exists, hindering adaptation to future changes.

4.2 How boundaries contributed to or hindered resilience

In this paragraph, we briefly reflect on whether the applied boundaries were contributing to system resilience or not. First, we observe that regarding resilience '*of what*', relating to spatial scale and domain involvement, moderate boundaries were applied, indicating that complexity is balanced between adopting a holistic perspective and maintaining manageable analysis. Resilience '*to what*' is considered tight, encompassing only flood-related disturbances. Conversely, resilience '*to whom*' is assessed widely, reflecting the participation of a wide range of stakeholders both horizontally and vertically. Lastly, resilience '*over what time frame*' is assessed as moderate, since neither a long-term (century) perspective was incorporated into flood protection nor spatial planning. Despite the solution being adaptable, the programme structure has been abolished, thereby impeding an adaptive decision-making process should a river catchment-wide disturbance recur. When conceptualising resilience based on these four framing categories, we consider the boundaries drawn in the Polder Project to be rather diverse, balancing complexity in considering disturbances with a holistic perspective of stakeholder involvement.

5 CONCLUSION AND OUTLOOK

Bringing together insights from systems thinking, resilience, and forward-looking decision-making, this study designed a framework to evaluate the extent to which system boundaries contribute to or hinder system resilience within an integrated FRM project in the Netherlands. We operationalised five boundaries, each framed by questions that specify system resilience in distinct ways, with wider boundaries reflecting a more holistic view but also adding complexity. Overall, we observe that the boundaries drawn in the considered integrated FRM project are rather moderate or wide. Considering that thinking in terms of system resilience typically involves a holistic perspective, and given that only one boundary in the Polder Project was tightly defined, we conclude that the Polder Project may potentially contribute to resilience regarding flooding. Nevertheless, because the assessment of hazards was tight due to its primary emphasis on flood protection, further research is required to determine how the project enhances system resilience to other disturbances.

Looking ahead, we would like to discuss some future research considerations. Firstly, operationalising resilience and setting boundaries involve values, as organisations and individuals draw boundaries based on their own perspectives and values. Further research into how experts or institutions perceive resilience and boundaries could reveal important insights into the informal mechanisms behind system analysis. Secondly, we note that some boundaries overlap; for example, in our case, stakeholder involvement and domain inclusion coexist. Therefore, we recommend further research into how boundary categories interact, creating synergies or trade-offs. Finally, as the project relied heavily on informal citizen involvement to facilitate a spatial solution, we suggest further study into the importance of including informal relations that usually remain outside formal institutional frameworks.

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