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Beyond the dikes: an institutional perspective on governing flood resilience at the Port of Rotterdam

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Abstract

Seaports, infrastructural nodes in global supply chains and production processes, are vulnerable to flood risks: they are crisis-prone critical infrastructure (CI) systems. However, the governance of their flood resilience involves many different private and public actors in a complex institutional environment and there is no scholarly consensus about how resilience can be successfully governed. We investigate the governance of flood resilience at the Port of Rotterdam (PoR) from an institutional perspective, by studying institutional arrangements for flood resilience within and across vertical, horizontal and territorial dimensions to elucidate the strengths and ongoing challenges of shaping the port's flood resilience. We conducted semi-structured expert interviews ($n = 17$) and an analysis of policy documents and legislation ($n = 33$) relating to flood risk management and CI protection. We find that the institutional design for flood resilience in the Netherlands consists of a complex matrix of responsibilities, capacities and plans. While coordination is visible in the shared visions and strategies for flood resilience developed at different policy levels and domains, we find fragmentation and persisting institutional challenges, including siloed governance approaches, knowledge gaps and blurred distribution of responsibilities; these are significant barriers to enhancing flood resilience for CIs and port–city relationships.

Keywords Flood resilience · Seaport · Governance challenges · Institutionalisation · Critical infrastructures

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1 Introduction

Seaports are at the heart of international trade as locations where transport modes intersect and economic activities take place (Becker et al. 2013). Given their role as critical links in global supply chains and production processes, their infrastructure needs to remain functional even during disruptions. However, seaports are vulnerable to flooding due to their coastal location. Furthermore, the access of ports to the open sea creates areas unprotected by flood defence infrastructures such as dams, flood barriers or dikes. Because of this vulnerability to floods and their role as critical infrastructures (CIs), seaports are expected to be resilient, responsive and adaptive to disturbances. In academia and policy, flood resilience has attracted attention as an approach that can enhance the capacity of ports to respond to flood disturbances (Hegger et al. 2016).

Studies on flood resilience have emphasised that containment of flood risks is not primarily a technical issue but it also requires successful governance (Hegger et al. 2016; Dieperink et al. 2016). However, governing flood resilience in ports is complex, because it involves many different actors and institutions across policy levels, policy fields, infrastructure domains and territories. The close connection between ports, cities and their regions through proximity, exchange of resources and layering of institutional arrangements contributes to this complexity (van den Berghe et al. 2018). Additionally, there are no integrated flood risk policies for CIs (de Bruijn et al. 2019) or for areas unprotected by flood defence infrastructure (van Buuren et al. 2016; Kaufmann et al. 2018). As a result, there is a limited sense of collective responsibility to deal with flood risks in ports. There is no consensus in the scholarly literature about how flood resilience for seaports can be successfully governed (Huck et al. 2021).

To address this research gap, we investigate the governance of flood resilience from an institutional perspective, taking the Port of Rotterdam (PoR) as a case study. We examine the institutional arrangements shaping coordination across relevant policy levels (*vertical coordination*), policy fields and infrastructure domains (*horizontal coordination*) and territories (*territorial coordination*). Since seaports are located in and connected to larger port city regions, we not only studied the governance of flood resilience at the port, but also the regional embeddedness of the port and port–city relations. The questions addressed are: *How is the implementation of flood resilience in the Netherlands coordinated horizontally, vertically and territorially and how does this shape the governance of flood resilience at the Port of Rotterdam?* This study is based on the analysis of semi-structured interviews ($n = 17$) and policy documents and legislation ($n = 33$) relating to Dutch flood resilience and CI protection.

The following section presents the conceptual framework explaining the relationship between vulnerability and resilience in the three dimensions (vertical, horizontal and territorial) across which the governance of flood resilience can be analysed. The third section describes the methodology. Our case study, the PoR, is introduced in the fourth section and an inventory is presented of governance challenges and opportunities emerging in the pursuit of flood resilience at the

PoR. The final section concludes by highlighting how flood resilience at seaports can be governed.

2 An institutional perspective on the governance of flood resilience

Seaports are vulnerable to flooding because they are located in coastal zones where flood probabilities are high (Becker et al. 2013). Vulnerability refers to the degree to which a system is susceptible to, and unable to cope with, hazards (Adger 2006; Cardona et al. 2012). The key parameters of vulnerability are the stress to which a system is exposed, its susceptibility and its adaptive capacity (Adger 2006). Exposure refers to the degree to which a system experiences stress (Adger 2006). The coastal location of seaports is a potentially dangerous setting, prone to flooding (Cardona et al. 2012). Furthermore, the open access to the sea that ports require to function as trans-modal hubs increases their exposure to floods (Mangan et al. 2008) because of the *unembanked areas* situated between the source of floods and a flood defence structure (Kaufmann et al. 2018). Ports' role as CI systems increases their susceptibility to disruptions (i.e. the likelihood of a system to be affected by exposure to stress) (Cardona et al. 2012). Seaports are CI systems in several respects. First, their primary function as trans-modal hubs means they are critical logistical nodes in global supply chains (Becker et al. 2013; Chhetri et al. 2015). Second, they are spatial conglomerations of logistics-related businesses and industries, performing essential functions, like freight consolidation, industrial pre-processing and assembly (Chhetri et al. 2015). Third, ports are dependent on underlying CI systems, including transport and energy infrastructures, electricity grids and ICTs (Tsavdaroglou et al. 2018). Ports thus resemble heterogeneous 'nested CI systems' (Monstadt and Coutard 2019), meaning that they are embedded in larger systems and intersect and interact with other CI systems (Teisman et al. 2009). This implies that disruption in one infrastructure may trigger cascading effects that propagate through the network and cause disruptions in other infrastructures, thus making the whole system more susceptible to disruptions (Rinaldi et al. 2001).

Seaports' vulnerability to floods may also be associated with a lack of resilience to cope with and adapt to hazards (Cardona et al. 2012). Resilience can be understood as the capacity of a system to resist, absorb, recover and adapt to disturbances (Hegger et al. 2016; Huck et al. 2021). A resilient system is one that can cope with and tolerate disturbances through these capacities (Wardekker et al. 2010). All three capacities (i.e., resistance, absorption/recovery, adaptation) are needed to reach the desired outcome of a 'resilient system'. However, adequate capacities or strategies need to be specified and balanced in each case (Liao 2012). While the concept of flood resilience has recently received much scholarly attention (Hegger et al. 2016; Driessen et al. 2018; Wardekker et al. 2010), the effects of floods on CIs are often not included (de Bruijn et al. 2019; Fekete 2019). Yet, understanding CI vulnerability is crucial for understanding the disruptiveness of a flood event for seaports.

Flood resilience has become increasingly debated by scholars and policymakers since the emergence of a risk-oriented approach in flood risk management (FRM; Fekete et al. 2020; Hegger et al. 2016). This approach accepts that 'floods cannot be

defended through technically-oriented measures alone and absolute protection cannot be provided' (Snel et al. 2020, p. 3) which has led to the diversification of FRM strategies as well as the changing governance of flood risks (Snel et al. 2020). FRM is no longer primarily focused on flood defence measures but also on flood mitigation measures, poldering, building removable and temporary structures that can be easily adapted to floods, or creating institutional learning mechanisms about how to anticipate and prepare for future disruptive floods (Hegger et al. 2016; Liao 2012). Furthermore, FRM is not only the domain of dedicated governmental authorities: non-governmental stakeholders and other governmental authorities are increasingly involved (Snel et al. 2020). Seaports are coupled to their host cities and surroundings through institutional coupling mechanisms, such as temporary coalitions, institutional arrangements and regulatory regimes, which further increases the number of actors and institutions involved in FRM in seaports (van den Berghe et al., 2018). This coupling is visible through the facilitation of start-ups located in the port–city interface by municipalities (Witte et al. 2018), or the CityPorts project in which city planning departments and the PoR authority redeveloped old port sites close to the Rotterdam city centre (van Gils et al. 2009). The task of creating 'resilient seaports' requires coordinated action across actors spanning a variety of territories, policy levels, infrastructure domains and policy fields. Van Tulder and Pfisterer (2013) argue that coordination between these actors takes place in a shared space created by the bundling of complementary competencies. Hereby, the coordination of individuals and organisations within this shared space is shaped by institutions, understood here as formal and informal rule systems (Helmke and Levitsky 2004). Flood resilience at seaports is governed within institutional arrangements: constellations of rights, values, rules, decision-making procedures (e.g., laws, regulations, planning instruments) and standardised operation procedures (Moss 2007; Ostrom 2011; Young 1999). These arrangements enable or constrain the actions and interaction of different actors (Ostrom 2011).

Due to the complexity of governing flood resilience in seaports, critical questions arise about how institutional arrangements support or constrain the pursuit of flood resilience (Alexander et al. 2016). Research suggests that institutional arrangements are often fragmented and too poorly coordinated to deal with the increasing interconnectedness of CIs (de Bruijne and van Eeten 2007). According to Young (1999, p. 49) 'the effectiveness of specific institutions depends not only on their features but also on their interactions with other institutions'. Therefore, in line with Huck et al (2021), to assess how flood resilience is governed in seaports we differentiate among three dimensions across which we can analyse how institutions interact and are coordinated.

The first dimension, *vertical coordination*, results from interdependencies between institutions at different policy levels—municipal, regional, national or international. A more integrated approach to FRM in the Netherlands in recent years contributed to municipalities, safety regions (i.e., territories to facilitate regional cooperation for crisis management led by the mayor from the largest municipality), provinces and the European Union (EU) being involved, alongside primary national and regional water authorities, in FRM (Kaufmann 2018). This has resulted in responsibilities being distributed across policy levels. However, a lack of connective

capacities between different governmental authorities and the presence of strong boundaries between policy levels hampers a move towards a joint flood resilience strategy (Gersonius et al. 2016a). The second dimension, *horizontal coordination*, results from interdependencies between institutions at the same policy level. Actors' responsibilities for shaping flood resilience in seaports are distributed across policy fields, infrastructure domains, civil society and public and private actors suggesting a need to coordinate and align institutional arrangements. Policy fields and infrastructure domains contributing to flood resilience include spatial planning, crisis management, housing, and economic development, and infrastructures, include water, energy, transportation and digital telecommunication (Cumiskey et al. 2019). The third dimension, *territorial coordination*, relates to interdependencies across territories. Jointly developing an integrated flood resilience strategy for seaports necessitates sustained collaboration between different municipal and/or regional governmental authorities across territorial borders (Gersonius et al. 2016b). Huck et al. (2021) point out that territorial coordination is relevant for CIs because networks extend across territorial boundaries and failures could cascade between them, requiring action to be taken far from where the initial problem arose.

3 Methodology

Central to this study is an institutional analysis of the governance of flood resilience. Agreeing with Biesbroek et al. (2013) that institutional arrangements are context-specific, we adopted a case study design, a qualitative research methodology most suitable for comprehensively investigating a complex and context-specific issue (Harrison et al. 2017). Our case study, PoR, the largest seaport in Europe, has a sophisticated CI network and is vulnerable to floods due to its location in the Rhine–Meuse–Scheldt Delta. Since seaports are vulnerable to floods with potential severe implications for international trade (Becker et al. 2013), it is important to contextualise and compare the outcomes of this case study to international experiences. To analyse vertical, horizontal and territorial dimensions, we reviewed the most relevant institutional arrangements for the PoR. We analysed how these arrangements are coordinated and the opportunities, conflicts and governance challenges that arise between actors in shaping PoR's flood resilience.

To gain an understanding of flood resilience strategies and institutional arrangements in the PoR, we analysed legislation and the policy documents of municipalities, provinces, ministries and of the PoR Authority itself. The documents included the most recent National Delta Programme (2020), the Rotterdam Resilience Strategy (Municipality of Rotterdam 2016), adaptation strategies for port areas (2020, 2017, 2019, 2018) and national and international laws and regulations, such as the Port Security Law, Delta Law, Decree on the Risks of Serious Accidents, several municipal zoning plans (Municipality of Rotterdam 2018), and EU directives on the assessment and management of flood risks (Directive 2007/60/EC) and the identification and protection of European CIs (Directive 2008/114/EC) (EU 2007, 2008). Semi-structured interviews with actors provided insight into the institutional arrangements and the opportunities, conflicts and problems that arise in governing

flood resilience at seaports. Between January and October 2020, we interviewed 17 stakeholders from organisations such as the PoR Authority, the Municipality of Rotterdam, the Rotterdam–Rijnmond Safety Region, the Dutch Ministry of Infrastructure and Water Management (MI&W), and several CI providers ("Appendix"). We selected organisations that own, manage or use CIs connected to the PoR, are affiliated with flood resilience policy-making in Rotterdam—and more generally in the Netherlands—and are concerned with the protection of CIs. While acknowledging the wider connections of the port with the City of Rotterdam and in the region, when speaking of PoR we refer to the geographical perimeter of the port. In addition, when referring specifically to the position of the port in institutional arrangements, we refer to the PoR Authority (i.e. the landlord of the port responsible for its competitive, sustainable and safe development). We conducted a qualitative content analysis (Mayring 2000) to categorise and distil relevant information from the coded interview transcripts and the relevant documents.

4 Governing flood resilience at the Port of Rotterdam

The Netherlands is well-known for its elaborate FRM system and its history of flood protection. After the disastrous coastal flooding of 1953, a huge programme of structural measures was implemented to improve flood protection (van Koningsveld et al. 2008). This *Delta Project* introduced new and reinforced coastal defence structures and elaborate flood protection standards embedded in national law and regulations (van Buuren et al. 2016). The traditional flood protection approach is largely state-centred: only governmental institutions are responsible for flood protection (Wiering et al. 2015; Snel et al. 2020). According to van Buuren et al (2016) the strong institutional basis for flood protection is illustrated by legally anchored funding (*Deltafonds*), dedicated governmental organisations responsible for flood protection (*Rijkswaterstaat* and the regional water boards), an advisory board of flood protection experts (*Expertise Network for Flood Protection*) and statutory standards on how to maintain flood defences (*Wettelijk Toets Instrumentarium*).

Unembanked areas have generally been excluded from this approach (Kaufmann et al. 2018). They do not fall under the Dutch Water Embankment Act of 1995, which divided large parts of the Netherlands into dike-ring areas with a closed flood protection system of dikes and dams to protect the land from flooding (de Moel et al. 2014). As a result, there is no integrated policy for flood protection in unembanked areas (van Buuren et al. 2014). Yet these areas are at greater risk of flooding than dike-ring areas (de Moel et al. 2014). The PoR alongside residential unembanked areas in Rotterdam lie outside the protection of the flood defence system and thus are largely excluded from the dominant FRM approach (Fig. 1). The port has multiple CIs, including pipelines, inland waterways, railways, roads, telecommunication, electricity supply and port infrastructure (Tsavdaroglou et al. 2018). As these CIs are closely connected and interdependent, if one fails, others are likely to be disrupted (Rinaldi et al. 2001).

The Netherlands has started to implement a more integrated approach to water problems, paying attention to resilient FRM strategies (van Buuren et al. 2016;

Fig. 1 Rotterdam–Rijnmond region. *Source* the authors

van Koningsveld et al. 2008; Driessen et al. 2018). The approach has become more risk-oriented, as shown by the launch of the *Room for the River* Programme in 2000 (which designated areas for so-called "calamity polders" that were to be evacuated and inundated in case of floods), the 2007 European Flood Directive (2007/60/EC) (which stimulated member states to move towards a flood-risk-based approach that explicitly considers potential consequences), the introduction of a similar approach in the National Water Plan (2009) and the institutionalisation of the National Delta Programme in 2012 (van Buuren et al. 2016; de Moel et al. 2014). According to van Buuren et al. (2016), these policy changes reflect a growing awareness of the need to enhance flood resilience. Waterfront revitalization projects or port areas could benefit from these policy changes, as this approach also considers the flood-prone areas beyond the dikes or floodwalls (Snel et al. 2020). In Rotterdam, the municipality launched the 'Adaptive strategies for the Rotterdam unembanked area' plan in 2010, to rethink flood risk approaches for unembanked areas (van Veelen 2013). They argued that promoting flood resilient architecture and local adaptive measures in flood-prone areas can reduce the consequences of inundation. These measures are less expensive and more effective than elevating land for new building projects in unembanked areas (de Moel et al. 2014). The greater awareness of the importance of flood resilience for unembanked areas has led to the Rotterdam Resilience Strategy (Municipality of Rotterdam 2016), the Strategic Adaptation Agenda for areas outside the dikes (Municipality of Rotterdam 2017), and flood resilience strategies for unembanked port areas, thanks to collaboration between the PoR Authority, Rotterdam Municipality, CI providers and regional governing bodies (2020, 2017, 2019, 2018).

The growing interest from policy makers in enhancing flood resilience, especially in unembanked areas, has not yet translated into institutional adjustments. According to van Buuren et al. (2016), the current system of FRM remains focused on flood protection and so the distribution of roles, responsibilities, formal rules and funding remain unchanged. Moreover, the implementation of resilient flood measures is left entirely to the voluntary collaboration of governmental authorities and other stakeholders. van Buuren et al. (2014) suggest that this results in a lack of urgency and commitment and a limited sense of collective responsibility for flood resilience. In the next sections, we address the coordination challenges actors face in enhancing flood resilience.

4.1 Vertical coordination: knowledge gaps at decentralised policy levels

Coordination across European, national, regional and local policy levels has become increasingly necessary to enhance flood resilience. From the outset, the Dutch FRM approach has been characterised by the dominance of dedicated governmental organisations responsible for flood protection. At national level, Rijkswaterstaat is responsible for constructing primary flood defences; at regional level, water boards are responsible for their management and maintenance (Kaufmann 2018). The allocation of responsibilities and funds remain with these organisations (van Buuren et al. 2016). However, since the 1990s, this approach has gradually been complemented by a risk-oriented approach to FRM, in which other governmental authorities have become involved, such as the EU, safety regions, municipalities, provinces and non-governmental stakeholders. Figure 2 provides an overview of the responsibilities of the different governmental and non-governmental organisations in this new approach to FRM. The more prominent role of the EU, municipalities and provinces in FRM was institutionalised in the Water Assessment (*Watertoets*) of 2006 (a formal procedural instrument specifying how spatial planning authorities should consult regional water authorities when drafting land-use plans) and in the European Flood Directive (2007/EC/60) (Kaufmann 2018). Additionally, safety regions were tasked with facilitating regional cooperation for dealing with flood-related crises. Municipalities, safety regions and provinces have also become voluntarily involved in the National Delta Programme to explore opportunities for, and barriers to, achieving flood resilience (van Buuren et al. 2016). The National Delta Programme was set up in 2010 aimed at developing new flood protection standards, improving the availability and quality of fresh water, and making spatial planning climate-proof and water-robust. By involving municipalities, safety regions and provinces on a voluntary basis, the programme has contributed to a shared vision of flood resilience across all levels of government. The stakeholders we interviewed saw the existence of the National Delta Programme as a positive development and as an initiative for coordination between national, regional and local levels. In part, vertical coordination is incentivised top-down by the creation of a shared vision on FRM at the national level, which is presented and updated annually; but bottom-up initiatives in the form of pilot studies were also perceived to contribute to the exploration of flood resilience measures.

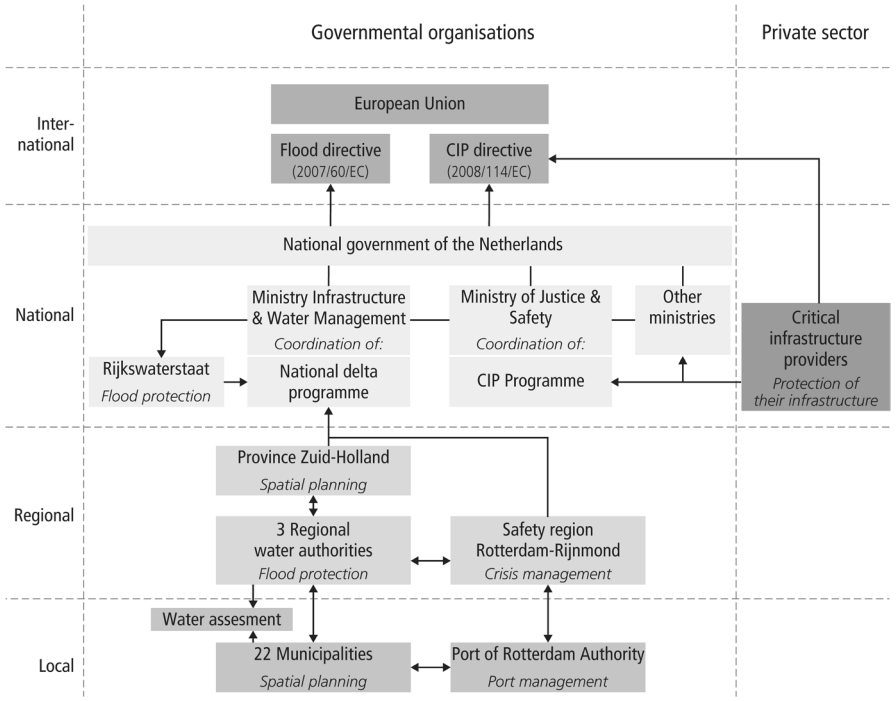

Fig. 2 Overview of responsibilities of different organisations in FRM in the Netherlands. *Source* the authors

On closer examination, we found that the multi-level relationships in Dutch FRM reflect intricate arrangements of responsibilities, power asymmetries and coordination problems that hinder the governance of flood resilience for CIs at the PoR. We revealed coordination problems in the governance of flood resilience in three areas: between the European and Dutch approaches to FRM; within unembanked areas; and across CI domains. First, the European Floods Directive (2007/EC/60) has enabled mainstreaming of risk-based thinking in EU Member States and has led to a centrally coordinated reporting mechanism that requires member states to report to the EU areas at significant risk of flooding and their progress in implementing the directive (Hartmann and Jüpner 2020). Dutch policymakers have adopted the terminology and risk assessment methods proposed by the EU, but have not adopted the processes regarding reporting and evaluation, arguing that the way of goal-setting is based on the achievability of safety levels and implies an unacceptable diminishing of the longstanding Dutch aspiration to advance flood protection. In practice, this has resulted in the Dutch playing along with the EU reporting and evaluation rounds but refraining from genuine policy benchmarking at the European level (Paul et al. 2016). The vertical coordination between the European approach to FRM and the Dutch approach is thus only partial and flood protection is still the dominant approach for dealing with flood risks in the Netherlands.

Second, our analysis revealed that there is a limited sense of responsibility in dealing with flood resilience in unembanked areas and that the division of responsibilities between parties is not always clear-cut—particularly regarding the division of responsibility between governmental authorities at different policy levels and between public and private parties (van Ledden and van de Visch 2017; MI&W 2020). National and regional water authorities have the knowledge and capacity to organise resilient FRM in unembanked areas, but have no statutory responsibility under national law (*Waterwet*) to do so (van Buuren et al. 2014, 2016). Furthermore, at the local level, the City of Rotterdam and the PoR Authority are formally responsible for deciding whether and under what conditions spatial development is allowed in these areas and they acknowledge that promoting flood resilience in these areas is important. Yet any measures are achieved through voluntary agreements in shared governance arrangements between the port and the city (I2, I10), while binding regulations by the national government are largely absent (I8, I12).

Third, vertical coordination of flood resilience for CIs is a challenge because there is a separate CI protection programme at national level coordinated jointly by the Ministry of Justice and Safety and the CI providers in parallel to the national programme on FRM that is the primary responsibility of the MI&W together with local and regional government authorities (see Fig. 2). In the national CI protection programme, CI providers are primarily responsible for protecting their CI, while the different departments from the national government establish general frameworks in policy, legislation or regulation for the infrastructure sectors that are their responsibility (I16). Our interviewees explained that as a result of this parallel institutional setup of CI protection, the municipalities, safety regions and regional water authorities have insufficient knowledge about the flood resilience of CIs. At the local level, municipalities are left with several questions, including: 'At what water level do floods become a problem for CIs? What potential cascading CI failures might result from a flood? Which approaches have infrastructure providers taken to prevent or prepare for floods?' (I10). Similarly, the safety regions have insufficient insight into potential cascading CI failures, particularly for ICT infrastructure. They are left wondering 'Where the important infrastructure components are and how they are connected' (I7).

We found that these governmental authorities did not have the answers to these questions because information about the protection of CIs is not shared with them. Municipalities, regional water authorities and safety regions admitted that they would benefit from knowing more about the implementation of concrete resilience measures for CIs (I7, I10, I12). Our interviewees explained that this problem is aggravated by an inadequate information flow from the national government towards local and regional government authorities. A regional water authority representative noted that 'the [national] state has given the wrong message by stating that they will take care of CI resilience, but instead, it is necessary to make a link between the approach at the national level, which so far has mainly focused on arrangements between CI sectors and responsible departments, and integrated regional area development' (I12). To successfully implement flood resilience, local or regional governmental authorities need guidance from the national government on what needs to be achieved (I12). Furthermore, our respondents contended that the disruption of CIs

often has a regional effect, thus transcending the municipal level and requiring coordination at regional level (I8, I13).

To improve vertical coordination, the initiators of pilot studies addressing the vulnerability and resilience of CIs want the MI&W to facilitate regional coordination (I2, I12). In response, the MI&W has proposed bringing the most relevant actors for each infrastructure domain together in a working group to enhance knowledge exchange and coordination at regional level (I8, I13). However, if there is an unwillingness to share detailed information on the vulnerabilities of CIs, these working groups might not contribute to closing the knowledge gap (I8).

These findings show that the vertical institutional design for flood resilience is a complex matrix of responsibilities, capacities and plans. The governance challenges are a knowledge gap of governmental authorities at local and regional policy levels, a lack of information exchange between policy levels and the unclear division of responsibility for unembanked areas. In line with the observation by Gersonius et al. (2016a) on flood resilience in general, it can be argued that fragmentation between policy levels hampers a move towards a joint flood resilience strategy for CIs at the PoR.

4.2 Horizontal coordination: a shared vision on flood resilience

The PoR Authority, the Municipality of Rotterdam, private terminal operators, CI providers, and nongovernment organisations are all involved in the governance of flood resilience at the PoR and the surrounding region (Municipality of Rotterdam, 2017). Additionally, many policy fields are involved in governing flood resilience. Responsibilities are thus distributed across public and private organisations as well as civil society, which suggests that horizontal coordination is necessary to ensure the port's flood resilience (van Tulder and Pfisterer 2013).

Several institutional arrangements regulate the resilience of CIs against flood risks at the PoR. For example, companies that store or transport hazardous goods need to comply with environmental regulations such as the Environmental Protection Act and the Decree on the Risks of Serious Accidents, which stipulates that companies of risk at the PoR need to report to the environmental service (*DCMR Rijnmond*) about their safety, regarding external hazards. The Port Security Act also applies to companies and CI providers, so risk assessments must be performed. Additionally, the PoR Authority plays a central role in enhancing horizontal coordination. As a landlord, the PoR Authority can include FRM as a topic in contracts with port companies (e.g., to create awareness), and it has taken the lead in setting up adaptation strategies (with measures to be taken in time) to cope with flood risks in collaboration with the Municipality of Rotterdam. The other collaborators in formulating the strategies were companies, CI providers, government authorities and knowledge institutions. Using the process of 'joint fact finding' in work sessions, actors analysed flood risks, their consequences and the possible countermeasures, before assessing potential adaptation strategies in terms of time, flexibility, effectiveness and feasibility. According to the different strategies for the port areas of Botlek (2017), Waal-Eemhaven (2018), Merwe-Vierhavens (2019), and Europoort (2020),

the strategies with most potential were: (1) 'keep the water out', which focuses on preventive measures such as elevating quays and strengthening flood defences; (2) 'live with water', which focuses on elevating newly developed areas and dry and wet proofing CIs; and (3) 'be prepared for a crisis', which includes drawing up crisis management and emergency plans or building emergency facilities. The first strategy enhances the capacity to resist, while the other two enhance the capacities to absorb, recover, transform and adapt (Hegger et al. 2016). Often, a combination of all three strategies was recommended to increase the port area's flood resilience. To augment these strategies, a general risk assessment framework was developed for floods in unembanked areas in the Rotterdam region.

Despite these efforts to create a shared flood resilience vision at the PoR, it remains challenging to implement cross-sectoral flood resilience measures, for five reasons. First, there is a lack of awareness among CI providers about their shared responsibility to ensure system-wide flood resilience at the PoR. Many companies and CI providers are aware of the potential disruptive effects of a flood for their own infrastructure (I6), but not all companies include flood risks in their risk assessments, or consider the potential cascading failures floods can trigger in other infrastructures, or in a port area (I12). A representative from the PoR Authority remarked, 'some companies expect that we [the PoR Authority] will protect the port against a flood' (I2). This is echoed by a representative from a pilot study of CIs in a port area of the Port of Amsterdam, Westpoort, in which 15 companies from 15 infrastructure domains were interviewed and it was found that 'companies feel safe and think the national state takes care of FRM' (I12). This finding also applies to the PoR. The PoR Authority and governmental organisations, such as the Municipality of Rotterdam or the national government are not primarily responsible for the protection of CIs in unembanked areas. Instead, all port users, companies and CI providers have a shared responsibility to invest in cross-sectoral flood resilience measures.

Second, although the adaptation strategies of port areas have contributed to a shared vision of flood resilience at the PoR, the general lack of legally binding agreements and financial incentives to invest in flood resilience in unembanked areas means that implementation remains difficult (Gersonius et al. 2016b). As a result, horizontal coordination usually remains at the level of knowledge sharing: 'Everyone does everything neatly on paper, but at the same time this does not lead to concrete measures' (I6). Third, aligning flood resilience strategies across organisations remains challenging due to the differences in assessing flood risks or because data sharing can be sensitive (I6). Fourth, various interviewees indicated that individual institutional practices of government authorities challenge horizontal coordination. For example, because government budgets are allocated per department, cross-sectoral issues receive less attention and resources (I6, I10). This reinforces siloed thinking and contributes to challenges with policy implementation and with efforts to align departments and sectors (I10). Lastly, the parallel development of different urban, flood and CI resilience strategies, each with different approaches and at different policy levels, has further complicated coordination of flood resilience for CIs. For example, while the flood adaptation strategies from the PoR Authority and the urban resilience strategy from the Municipality of Rotterdam have both developed from the idea to position climate and flood adaptation challenges in a resilience

framework, and despite being both local initiatives (I2, I10), hardly any attention is paid to flood risks in the National Resilient CI Programme (I8, I16).

Our analysis revealed that there are regulatory frameworks in place to ensure port safety against floods and that the PoR Authority has a central position in coordinating efforts to enhance resilience across infrastructure domains, privatised port users and policy fields. The recently developed flood adaptation strategies for port areas have helped CI providers become more aware of their responsibility to strive for flood resilience. However, there is no financial incentive or legally binding agreement to encourage these private actors to invest in, or implement, cross-sectoral flood resilience measures. Furthermore, information sharing for CI providers can be sensitive. We have thus identified horizontal coordination challenges that suggest a degree of horizontal fragmentation is hampering a move from 'joint fact finding' to a shared implementation plan with formal commitments.

4.3 Territorial coordination: regionalisation of port operations

Containerisation, extended hinterlands and global supply chains have made it necessary for seaports to expand beyond the city and have led to the regionalisation of ports (Hall and Jacobs 2012). Inland ports are directly connected to seaports through transport infrastructure: rail, road or inland waterways (Witte et al. 2014). Van der Horst et al. (2019) observed a critical dependency between deep-sea terminal operators and hinterland transportation companies. Because of this, a flood can cause disruption throughout the supply chain of container transport. One interviewee recounted how in 2009 the PoR was temporarily unreachable for container transport via rail because of a train accident in Barendrecht, a municipality bordering the City of Rotterdam in the South-West, which created a train traffic jam across Europe (I7; see Fig. 1). Port infrastructures thus transcend the territorial boundaries of the port domain. Yet, as our analysis reveals, flood resilience strategies are often prepared for single territory rather than targeted at the transboundary character of infrastructure assets (I6). This raises the question of how the development of strategies for CI systems is coordinated across territories.

The following territorial contexts are relevant to flood resilience in the PoR: the port industrial complex and its hinterland; the Municipality of Rotterdam; the Rotterdam–Rijnmond safety region, which covers the territory of 15 municipalities; three regional water authorities (Waterschap Hollandse Delta, HHS van Delfland, Schieland & de Krimpenerwaard); and the river catchment area of the Rhine and Meuse (see Fig. 1). In some cases, institutional arrangements already exist and cross-territorial coordination occurs. For example, although crisis management was originally organised at municipal level, in 2010 the Rotterdam–Rijnmond safety region was created to bring together fragmented responsibilities for regional crisis management. A representative from the safety region noted, 'modern crises play out in an environment where responsibilities are intertwined. [It is important] to ensure that responsibilities are respected and that they do not interfere with the management of a regional crisis' (I17). Furthermore, the Delta Programme is perceived by interviewees as an initiative for territorial coordination of flood resilience in

the Rotterdam region, including the river catchment area. For example, a regional strategy for unembanked areas has recently been developed through the Delta Programme. The Delta Programme's role in enhancing regional cooperation was also emphasised by the municipality: 'There is a great deal of cooperation in the region and I must say that the Delta Programme has given this a strong boost. You see that the lines are shorter because we sit together and talk about the flood resilience of the region' (I10).

However, our interviewees also mentioned significant governance challenges. First, they exposed a lack of a dedicated budget for cross-territorial coordination (I6): CI providers do not always have the capacities and resources to participate in crisis exercises organised by the safety region or PoR Authority, or to invest in cross-territorial initiatives to improve flood resilience (I2, I17, I12). A regional water authority representative noted, 'cascading effects and interdependencies between infrastructures make it difficult to work collaboratively on flood resilience, because no one feels responsible for it. Companies are interested in reducing (climate) stress, related to their processes, but feel much less responsibility for the effects of (climate) stress on the interdependencies between different CI networks' (I12). Second, some interviewees voiced criticism that flood resilience strategies are often dedicated towards a specific territory, such as a neighbourhood, rather than to the transboundary character of infrastructure assets or the interconnections between CIs (I3, I6, I12). Parts of coupled infrastructure systems therefore remain unprotected against floods. Lastly, although the Delta Programme introduced regional councils to promote area- and topic-specific coordination and implementation, the most recent Delta Programme acknowledges that introducing these regional councils on top of existing institutional arrangements has contributed to further institutional fragmentation and even more administrative complexity (MI&W 2020).

Our analysis reveals that the CIs supporting the functioning of the port and port infrastructures have grown and expanded beyond the municipality's traditional administrative boundaries, which suggests a need for cross-territorial coordination of institutional arrangements in the Rotterdam region. Although in some cases regional collaboration has contributed to addressing region-wide flood risks (for example through the introduction of safety regions and the development of a regional strategy for unembanked areas), it has also resulted in significant governance challenges across territories.

5 Conclusion

This article has explored the governance of flood resilience at the PoR from an institutional perspective, paying attention to the vertical, horizontal and territorial coordination in the governance of flood resilience of critical port infrastructures. We have argued that while resilience is attracting increasing attention, as an approach for ports to cope with flood risks, considerable challenges are involved in the institutionalisation of flood resilience efforts. Our analysis revealed that the Dutch institutional design for flood resilience consists of a complex matrix of responsibilities, capacities and plans. Although we

identified forms of coordination across all three dimensions (vertical, horizontal and territorial), we also found governance challenges related to institutional fragmentation.

We have identified gaps in local and regional governments' knowledge about the flood resilience of CIs; a lack of vertical information exchange; and an unclear division of responsibilities for unembanked areas. Horizontal coordination has been improved by developing a shared vision for the PoR's flood resilience jointly with different infrastructure domains and policy fields. Yet, we have also identified coordination challenges, including departmental budgeting and siloed thinking, indicating that horizontal fragmentation hampers effective flood resilience. Regarding territorial coordination, we found that the lack of cross-territorial institutional arrangements has been problematic when addressing region-wide problems and the cross-boundary character of CI systems, despite the existence of a regional unembanked area strategy.

We conclude that it is challenging to implement flood resilience for complex CI systems, under an institutional environment that remains dedicated to flood protection. Yet, we have also identified a growing awareness from public and private actors of the importance of integrating resilience capacities into FRM, especially in the case of CI systems and unembanked areas that are vulnerable to flood risks but fall outside the traditional scope of the flood protection regime. This growth in awareness is not only observed at the PoR, but can be seen as a global trend (Chhetri et al. 2015; Becker et al. 2013). To enhance the PoR's flood resilience, the current institutional environment should either be completely redesigned or a process of institutional experimentation and learning needs to be facilitated (Gersonius, Van Buuren, et al. 2016). It would seem unfeasible to completely change the institutional base for FRM in the Netherlands, especially since many stakeholders still consider the flood protection approach successful. Instead, legislation should be flexible, so that adequate resilience capacities or strategies can be specified in each case (Liao 2012). In this light, it might be helpful to identify contextualised, procedural standards that force local stakeholders to assess risks, develop and implement strategies, redistribute responsibilities and evaluate progress, given the institutional and geographical contexts (Monstadt and Schmidt 2019). Furthermore, it could be helpful to review the overlapping responsibilities, roles and actions of the actors involved in flood resilience to find the appropriate configuration of actors to govern flood risk most effectively and to enhance port–city symbiosis (van Tulder and Pfisterer 2013). This research contributes to the discourses on complex governance arrangements and port–city symbiosis by identifying coordination challenges in the shared governance of flood resilience at seaports. Future research is needed into which governance strategies, procedural standards and actor configurations are necessary for the successful implementation of flood resilience in seaports. Gaining insights into the enhancement of flood resilience of unembanked areas and the role of cascading effects in CI systems will be particularly important not only for guaranteeing the functioning of seaports but also for port–city regions.

Appendix: List of expert interviews

No	Position	Date	No	Position	Date
1	Independent Administrative Body: board member and research manager	23.06.2020	10	Municipality Rotterdam: strategic adviser	25.09.2020
2	Port of Rotterdam Authority: policy adviser	14.07.2020	11	Municipality Rotterdam: programme manager	25.09.2020
3	Knowledge Institute Mobility: researcher	27.07.2020	12	Regional Water Authority: strategic adviser	05.10.2020
4	Independent Administrative Body: researcher and programme coordinator	28.07.2020	13	South-Holland Province: programme manager	09.10.2020
5	Ministry of Infrastructure and Water (MI&W): programme manager	21.08.2020	14	Municipality Rotterdam: asset manager	09.10.2020
6	Critical Infrastructure Provider (Transport): senior adviser	21.09.2020	15	South-Holland Province: senior advisers (2)	14.10.2020
7	Safety Region: senior manager	22.09.2020	16	Ministry of Justice and Security: policymaker	15.10.2020
8	MI&W: senior adviser	22.09.2020	17	Safety Region: policy adviser	16.10.2020
9	Critical Infrastructure Provider (Transport): project managers (2)	25.09.2020			

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