Institutional dimension of flood risk

Understanding institutional complexity in Flood Risk Management for the case of St Maarten

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Summary

As extreme weather events increase both in frequency and magnitude (IPCC, 2012, 2014), and considering that over 60% of the world population lives in coastal areas (UNEP, 2016) flood risk is increasing. Hereby, the need to address Flood Risk Management (FRM) becomes evident. Especially on small island the need for adequate FRM is apparent: "relative to other areas, small islands are disproportionately affected by current hydro-meteorological extreme events, both in terms of the population affected and losses as a percentage of GDP" (Anthoff et al., 2010).

In the young research field of socio-hydrology, the dynamic interactions between human systems and water systems are studied more integrated (Sivapalan et al., 2012). Socio-hydrology aims to gain a better understanding of the entanglement of human and flood systems in general. The institutional dimension has been studied with relatively little detail within socio-hydrology and Integrated Water Resource Management (Baldassarre et al., 2014; Brown and Damery, 2002; Gober & Weather, 2014; Manuta and Label, 2005; Naess et al., 2005).

Therefore, this research focuses on the institutional dimension of FRM, on the rules, norms, and shared strategies that guide decision making behaviour in flood risk response, recovery, mitigation and preparation. Institutional statements are defined as "shared linguistic constraint or opportunity that prescribes, permits, or advises actions or outcomes for actors ... [they] are spoken, written, or tacitly understood in a form intelligible to actors in an empirical setting" (Crawford & Ostrom, 1995).

The main research question is formulated as "what is the effect of interdependencies and connectivity between institutions on FRM, for the case of St Maarten?". First, I address how interdependencies and connectivity between institutions can be studied. Secondly, this methodology will be tested on a case study. Third of all, I discuss how insights in the connections between institutions can be translated to better FRM.

The Caribbean island St Maarten was chosen as a case study, as floods are the primary natural hazard on island (Sommers, 2015). The focus on economic development on the island increases vulnerability and exposure to floods, requiring adequate institutions to manage flood risk. Moreover, within the European PEARL research project, St Maarten was chosen as one of the case studies, which has led to the development of a knowledge base on FRM on the island and data availability.

Socio-hydrology is used as a theoretical framework of this research. The integrated approach of human-water coupled systems is central in this research. The Institutional Analysis and Dynamics (IAD) framework by Ostrom forms the framework to further address the institutional dimension of human-water coupled flood systems. Institutions in flood systems are researched using the FRM cycle. Within the institutional dimension, we focus on interdependencies and connectivity between institutions, by taking a network perspective towards institutions.

Institutional Network Analysis

To study interdependencies and connectivity between institutions, no methodology was found in existing literature. Therefore, I developed a new methodology: Institutional Network Analysis (INA). This methodology was created, based on four criteria:

1. Meaningful translation of institutions into networks; finding a way of representing the institutional reality as nodes and links that adds to our understanding of the human-water coupled flood system;
2. Show materialization of institutions; institutions are mental constructs – in order to understand their effect on FRM, the link between actor, action, decision making and institutions should be addressed;
3. Trade-off between complexity and insightfulness; we want to capture institutional complexity, but we want the results to be explainable to non-scholars as well;
4. Translatable to Agent-Based Modelling; to include institutional change over time, we want our 'snapshot' of the institutional network to be translatable into a dynamic model.

INA builds on the institutional grammar ADICO, developed by Crawford and Ostrom (1995). ADICO subdivides all institutional statements in Attribute (decision maker), Deontic (may, must, must not), aIm (what and how of the action), Condition (when does the institutional statement apply), and Or else (sanction). Rules consist of all five ADICO components, norms lack a formal sanction (ADIC), and shared strategies lack a formal sanction and a deontic (AIC).

To arrive at ADICO statements (INA research step 3), data is collected through desk research and stakeholder interviews, that are guided by the four FRM phases (INA research step 1), and by defining action arenas by coding and clustering the collected data (INA research step 2).

The action arenas and corresponding institutional statements are used as input to draw Institutional Network Diagrams (INDs), that are a graphical representation of the institutions guiding decision makers within action arenas, based on the four FRM stages. We chose to represent attributes/actors and outcomes as nodes, as they are the physical materialization of institutions. Institutions are mental constructs, that guide decision making towards a certain outcome, only when applied by an actor. Nodes are linked by the institutional deontic, aim and conditions. For a step-by-step explanation of how to draw an IND, please refer to table 4.1.

These network representations of action arenas can be analyzed on three levels: addressing institutional hierarchy, calculating network metrics and defining links between INDs (INA research step 5).

- The graphic representation of action arenas forces the researcher to address situations of institutional conflict: situations where two or more institutions with different outcomes guide actor behaviour. The researcher then needs to return to the raw data or even the data source to understand institutional hierarchy: what institution is followed over the other(s), under what circumstances?
- Network metrics, such as density, centrality and embeddedness can be calculated based on (a combination of) IND(s). These metrics impact the performance of a network and help the researcher understand the strengths and weaknesses of the current institutional reality. Translating insights from metric to learn how the networks may perform better is not straightforward. Low centrality, for example, results in networks that are robust to the removal of a node (advantage), but these networks are also inefficient and may lack control and accountability (disadvantage). By including the advantages and disadvantages of network structure, the researcher may suggest policy options to improve FRM by enhancing network performance.
- By linking INDs, either based on chronological order, while treating them as black boxes, or based on overlap in outcomes, the FRM system as a whole can be better understood. In this step, the researcher gains an understanding of the interdependencies and connectivity between INDs, instead of individual institutional statements.

Institutional Network Analysis of FRM on St Maarten

The case of St Maarten was studied as a first application of INA. Through desk research and by a total of 37 interviews, 36 rules, 9 norms and 30 shared strategies were defined and clustered in nine action arenas. Seven cases of institutional conflict have been identified. All cases shared one characteristic: they revolved around a rule installed by the government and a shared strategy that directly undermined this rule. Average network density was found to be low (0.290), indicating a large diversity in strategies, but also a limited spread of knowledge. Centrality was found to be low as well, only 27% of the 22 identified decision makers in FRM had a network position with a higher than average level of centrality, indicating a lack of robustness to the removal of a single actor and inefficiency. Average embeddedness was high, showing that the institutional processes are embedded within the field of actors. This means that the INDs are characterized by chains of decision makers, indicating checks and balances.

Recommendations stemming from these insights include the development of an infrastructure to share knowledge, enabling community action, and reviewing the efficiency and fairness of governmental processes within FRM. The INA shows the importance of better knowledge transfer and addressing the unequal distribution of power, based on the position of decision makers within the institutional network. Addressing the recommendations stemming from this research indicate that a change of culture is necessary to improve FRM on St Maarten. However, the existing power structures on the island are based on strong personal relations and corruption is a pressing problem (Transparency International, 2015). This analysis may however provide useful argumentations for stakeholders that are concerned about their safety from floods.

Institutional Network Analysis and better FRM

INA successfully addresses the four criteria developed for the methodology:

1. ADICO was used as a backbone to develop networks of institutional statements. This syntax helps to define the links between actors and hereby, institutional networks are an extension of traditional social networks.
2. By focussing on decision makers as nodes, the materialization of institutions lies at the basis of INA.

3. Although INDs may be more insightful than ADICO tables, reading and analyzing them still requires some background in institutional theory and Social Network Theory. Insights should therefore be translated into direct recommendations.
4. The translation of the INA research on FRM on St Maarten showed that the large number of decision-makers poses a challenge in defining agents in the ABM. However, the INDs provided to be useful in developing the model narrative. The implementation of institutional change over time was not done within this research and could be added in an ABM.

INA may add to better FRM on four levels. First of all, on a data level INA uses the FRM cycle to structure data collection. This framework provided to be useful to develop an understanding of the case study. Secondly, the INDs force the researcher to address gaps in the collected information. Third of all, they are more readable for non-scholars than large ADICO tables. By connecting the INDs, an overview of all action arenas within FRM is obtained. The network metrics provide a non-subjective way of addressing the institutional dimension and can be used to increase awareness and understanding of the problem amongst policy and decision makers.

Lastly, INA insights can be used to develop an Agent-Based Model, that helps address institutional change over time. By structuring the data, the researcher develops an understanding of system level problems, that arise through individual decision making behaviour in FRM. These problems can be studied by developing an ABM and experimenting with decision making behaviour. This can assist policy makers and decision makers in developing better FRM practices. Moreover, by combining the institutional dimension of FRM with a flood model, the relative impact of different policies can be addressed. For example, the effects of land use planning can be compared to the effects of structural FRM measures.

Further research on INA

One of the key limitations is that there is a certain level of subjectivity in collecting, coding and clustering data, and formalizing the insights into institutional statements. Within this research, the work on the St Maarten case could be scientifically improved if a team of researchers were to perform the first INA research steps. In formalizing institutional statements, I found it difficult to include interview insights that directed towards the cultural reality of the island (for example the limited trust in the national government). Further work on INA could address this issue.

INDs provide a static image of the institutional reality in FRM. Although they focus on dynamics, in a sense that they show how actions and actors are interdependent, they do not include the dynamics of institutional change. This may be tackled by developing an ABM, but an interesting line of further research may focus on how institutional change could be implemented in the INDs.

In addressing institutional hierarchy, it is difficult to gain an understanding of when and why a certain institution is preferred. This requires more in depth research than I have provided for the case of St Maarten. However, the advantage of an IND is that this research method visually indicates situations of institutional conflict and hereby 'forces' the researcher and stakeholders to address this issue.

To further address institutional complexity, it may be interesting to compare the network metrics for several FRM cases, rather than calculating them for one case study. This could add to our general understanding of the effect of institutional network structure on effective FRM.

Moreover, future research could focus on more formal linkage of institutional statements and/or INDs. Some INDs may be nested in other INDs, as Frantz (Frantz et al., 2013, 2015) showed for nested ADICO statements.

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Yared, even though we still haven't, it feels like we have visited St Maarten numerous times! Apart from your great knowledge on the case of St Maarten and ABM, you have offered me a lot of your effort and time to help me improve my work on St Maarten. Your eye for detail and your allergy to my somewhat careless use of scientific concepts in my writing have helped me improve my thesis a lot.

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Introduction

> "Despite the lack of understanding of the dynamic interactions between floods and societies and the associated feedback mechanisms, the topic remains largely unexplored."
>
> Baldassarre et al., 2013

Flood risk is increasing, due to climate change. Climate change evokes extreme weather events, that increase both in magnitude and number. Due to climate change, sea levels are rising and out of all natural disasters, coastal floods are one of the most dangerous and harmful disasters (IPCC, 2012, 2014). Since over half of the global population lives within 60 km of a sea coastline (UNEP, 2016), both coastal and hurricane-driven floods propose a serious and increasing threat to society.

A flood becomes a disaster, if the natural hazard intersects social processes, leading to losses and damages (Lane, 2014). A flood system is thus inherently an integrated human-water system. In order to take adequate action to respond to floods, the complexity of the flood system has to be taken into account. In 2012, Sivapalan et al. proposed a new field of science to learn to understand the dynamics and co-evolution of coupled human-water system. They named this field socio-hydrology, the science of people and water. The main addition of this field to existing research in Integrated Water Research Management (IWRM) is to focus more on the dynamics of the interaction between water and people. Goal is to understand patterns and dynamics of human-water systems (Blair & Buytaert, 2015). However, within this field little attention has been paid to the institutions that guide flood risk management.

In short, the problem this research addresses, consists of three main issues:

1	2	3
The natural flood hazard is increasing, due to climate change	*Vulnerability and exposure to floods are increasing, due to rising populations and levels of welfare*	*We lack sufficient knowledge on the institutional dimension of flood risk management*
Climate change evoked extreme weather events increase both in magnitude and number (IPCC, 2012, 2014).	Land use change due to economic development negatively impacts natural capacity of an ecosystem for water containment (IPCC, 2014).	In socio-hydrology, institutional complexity is currently underexposed in research.

Due to climate change and economic development, the flood hazard, vulnerability and exposure of humans and their built environment are increasing, hereby increasing flood risk on a global scale. Flood risk should be addressed with adequate preventive and risk reduction measures. However, we lack sufficient knowledge about the institutional dimension of flood risk management. Goal of this research is to first develop a methodology that helps untangle institutional complexity, and to apply this methodology to a case study: flood risk management on St Maarten.

This chapter will be structured as follows. First, I will define flood risk, institutional complexity and flood risk management. Secondly, I will introduce St Maarten, the case study area. In section 1.1, I will further define the research gap that I am addressing and propose the research questions in section 1.2.

Flood risk

Risk can be defined as the product of the natural hazard, exposure and vulnerability (see figure 1.1). The flood hazard depends on natural components: the source (rainfall, snow melt or storm surge) and the topography of an area (terrain, soil type), and human-related factors: availability and capacity of drainage systems, and flood protection sources.

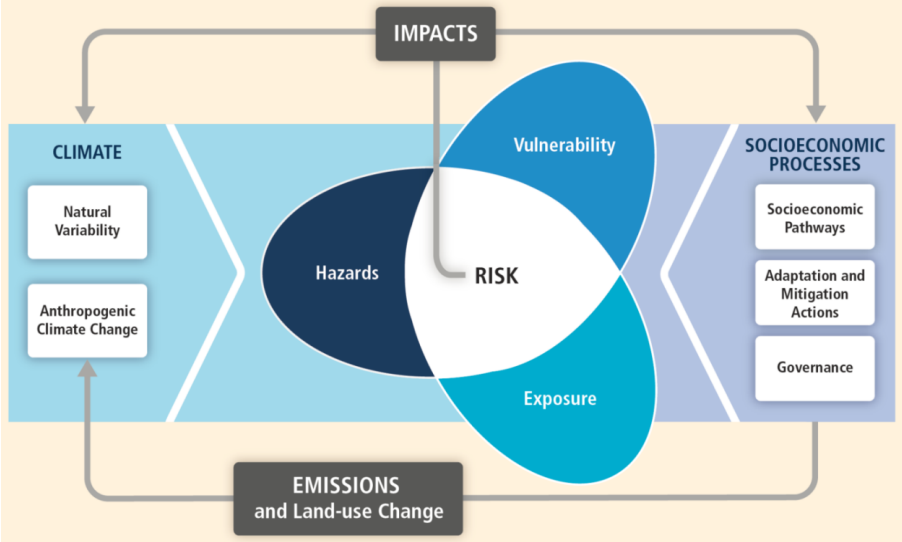


Fig 1.1: Schematic overview of risk and related concepts, source IPCC (2012)

The risk depends on the vulnerability of physical structures (houses, infrastructure) and people, and their exposure to flood hazard. Vulnerability could for example be decreased if people decide to elevate floor levels. Both vulnerability and exposure are shaped by socioeconomic processes, such as socioeconomic pathways, adaptation and mitigation actions and governance. These socioeconomic processes shape the anthropogenic climate change. The risk affects both the climate and the socioeconomic processes (IPCC, 2012). Communities under high risk, will generally speaking be more willing to pay for adaptation and mitigation actions (Marrero, 2008).

A flood disaster is the intersection of a hazard with social processes, leading to impact. Disasters influence political, socioeconomic and governance processes (IPCC, 2012). Before going into more detail on disaster management, I will introduce institutional complexity in the next paragraph.

Institutional complexity

In socio-hydrology flood systems are defined as a Complex-Adaptive Systems (CAS). In a CAS, relationships between natural processes, human action and technology development are self-organizing, non-linear, dynamic and emergent. Moreover, human actors adapt and learn as they interact with each other and their physical environment (Holland, 2005). Because of these characteristics, governing a CAS is a complex interplay of decision makers and stakeholders.

In order to manage a common interest, in this case security from floods, cooperating individuals develop institutions over time. Institutions are defined here as “the set of rules actually used by a set of (actors) to organize repetitive activities that produce outcomes affecting those (actors) and potentially affection others” (Ghorbani et al., 2013).

Crawford and Ostrom (1995) summarizes three ways of viewing institutions: as equilibrium behaviour or shared strategies (individuals change responses until no improvement can be obtained), as norms, or as rules. All these views start from social constructs that guide individual decisions and build social orders on a system level. In this research rules, norms and strategies are seen as institutions. Rules can

be distinguished from norms and shared strategies, as they lead to tangible sanctions. The effectiveness of rules is dependent on whether sufficient monitoring and sanctioning is available. Without explicit stating or a deontic (obligation, permission, prohibition), groups of individuals can internalize strategies to deal with flood risk. A shared strategy may for example be to elevate ground levels of houses, without a governmentally ordered, written rule that orders to do so (Crawford & Ostrom, 1995).

In this research, institutional complexity is defined as the dynamics between actors and institutions. How do institutions affect actor behaviour and how does individual behaviour affect behaviour of other actors? Institutional dynamics are thus explained as the interdependencies and connectivity between institutions, rather than the dynamic development of institutions.

Flood Risk Management

To deal with a disaster event, four phases of disaster management have to be addressed: preparation and mitigation (before a disaster event), and response and recovery (during and after a disaster event). This disaster management cycle (figure 1.2) can be used to categories and review all four disaster management phases. From now on, when referring to the combination of all governance activities regarding flood risk, I will use the term Flood Risk Management (FRM).

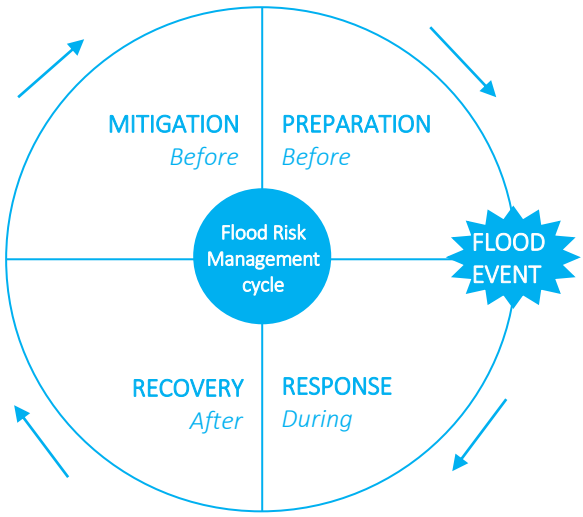


Fig 1.2: Flood Risk Management cycle, including the mitigation, preparation, response and recovery phase

This research will focus on the institutional dimension of FRM, while zooming in on the case of St Maarten, that is introduced in the next paragraph.

St Maarten as a case study

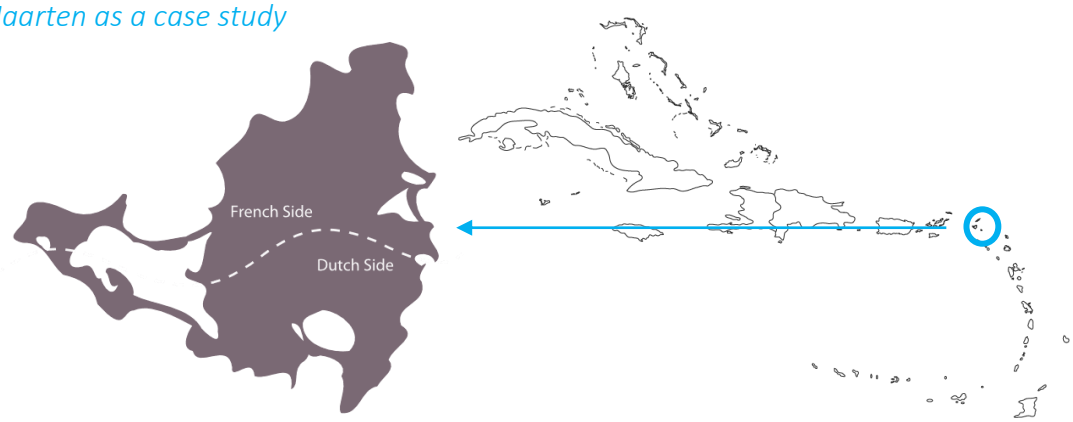


Fig 1.3: Map of Caribbean (right), with St Maarten in blue circle; map of St Maarten (left)

St Maarten is an 87 km^2 island, located in the north-western part of the Caribbean (see figure 1.3). About half of the island, 34 km^2, is the former Dutch colony St Maarten. The French side, Saint Martin, is still part of France. From now on, when referring to St Maarten, the Dutch part is meant. St Maarten has a population of about 38,000 inhabitants. However, an unknown number of illegal immigrants inhabits the island as well (Department of Statistics, 2015).

Since 2010, St Maarten has been an independent nation within the Kingdom of the Netherlands. St Maarten is a democracy. The head of state is a governor that is appointed by the crown. The per capita GDP is about €26,000. The main economic pillar of the island is tourism (Department of Statistics, 2015).

In the Caribbean, floods are the most frequent natural disasters. These floods are mostly caused by tropical storms and hurricanes. The 1995 hurricane Luis caused the destruction of 60% of all housing and infrastructure, and a drop of about 20% in visiting tourist. Tourism is the main source of income on the island, and the drop in visiting tourist caused the loss of 152 million USD (Mathew, 2013).

The problem addressed in this research breaks down into an increasing natural flood hazard, increasing vulnerability and exposure and a lack of knowledge on the institutional dimension of human-water system. For St Maarten, the problem is further specified in table 1.1.

Table 1.1: Problem definition for case study area St Maarten

The natural flood hazard is increasing, due to climate change	*Vulnerability and exposure to floods are increasing, due to rising populations and levels of welfare*	*We lack sufficient knowledge on the institutional dimension of flood risk management*
Anthoff et al. (2010) state that "relative to other areas, small islands are disproportionately affected by current hydro-meteorological extreme events, both in terms of the population affected and losses as a percentage of GDP." On Caribbean islands, floods are often a result of peaks in precipitation. Due to limited storm water infrastructure and high building density, the natural ecosystem's ability for storm water retention is impaired. Thus, the risk of pluvial (surface) floods is also increased by climate change (IPCC, 2012).	On St Maarten, the focus has been on economic development the last four decades, which has led to a booming tourist branch. Tourism is the main pillar of the island's economy. Many hotels, restaurants and apartment buildings are constructed close to the coastline, hereby increasing vulnerability of these proper-ties. Moreover, there has been little attention to natural gutters in property development, leaving large amounts of precipitation no other route than through public roads and private properties (Mathew, 2013).	Being a small island state, resources are a limiting factor for St Maarten. Budget, expertise and knowledge may be lacking for adequate flood risk response (IPCC, 2012). The overall governance structure of the island has recently changed from a special region, into an independent nation within the Kingdom of the Netherlands.

St Maarten is one of the case studies within the European research project Preparing for Extreme And Rare events in coastaL region (PEARL). PEARL aims to design and develop adaptive flood risk management approaches that minimise social and economic losses and environmental impacts and

increase resilience. More practical, the program aims at both improving forecasting and developing robust prevention, mitigation and preparedness strategies (PEARL project proposal, 2013).

Understanding flood risk requires a deeper understanding of hydrodynamic processes and social institutions that guide flood risk management (PEARL, 2016). In St Maarten two branches of PEARL research are currently in process: a Risk and Root Cause Analysis (RRCA), focusing primarily on the social dimension of the flood risk problem, and a the development of a coupled Agent-Based Model (ABM). This agent-based flood model focuses on the human-flood interaction. Both branches of research are further explained in appendix A.

The addition of this research to PEARL would lie in a further exploration of the institutional dimension of flood risk management, to better understand the role of institutions in adaptive risk management. The previous research on St Maarten within PEARL provides an interesting knowledge base to further zoom in on the institutional dimension of flood risk management. We see opportunities to integrate the rich data set that was collected through the RRCA in the agent-based flood model, focussing on the institutions that define decision making.

1.1 Research gap

The young, interdisciplinary field of socio-hydrology studies the dynamic interactions between water and people, starting from the assumption that neither the water system, nor the human system can be researched independently from the other (Sivapalan et al., 2012). This study wants to add to this field by zooming in on institutional complexity in flood risk, as this has not been studied within socio-hydrology yet ((Baldassarre et al., 2014; Brown and Damery, 2002; Gober & Weather, 2014; Manuta and Label, 2005; Naess et al., 2005). We want to understand how institutional complexity relates to the resilience of a flood risk management system.

Institutional dynamics can be defined in many ways, but in this study the focus will be on the interdependencies and connectivity between institutions. We seek to understand the complexity of interactions between institutional decision makers and the following, monitoring and sanctioning of institutions. It is important to understand the coherence and relations between institutions, in order to understand how well a system performs on FRM.

Goal of this research is thus to address interdependencies and connectivity between institutions in human-water systems. More specifically, the research aim will be to develop a methodology that guides research in this undiscovered aspect of institutional complexity. This methodology will be applied to a case study: flood risk management on St Maarten.

However, this methodology will not focus on the dynamics of institutional change. Institutions are defined, shaped and redefined by individual decision makers on multiple levels. Strategies may become norms, and new rules may be implied, due to undesired system level outcomes of individual behaviour. To address this latter type of institutional complexity, Agent-Based Modelling (ABM) might provide the right methodology, as these models study Complex-Adaptive Systems bottom up, by modelling individual actors that perform certain actions. ABMs offer a tool that embraces complexity, whilst giving insight in effectiveness of policy measures (Nikolic & van Dam, 2013). The institutional dimension has been added to ABM through the Modelling Agents based on Institutional Analysis (MAIA) tool, which may provide a successful start for implementing institutional interdependencies and connectivity into ABM. In other words, institutional complexity in both the smaller definition that guides this research and in the broader definition of institutional change may be studied through developing an ABM.

The research gap that is addressed in this thesis is the lack of knowledge of interdependencies and connectivity between institutions within FRM. The research objective is to develop a methodology to

study this aspect of institutional dynamics in coupled human-water flood systems. Moreover, this methodology may provide a solution for a methodological gap: the interdependencies and connectivity between institutions may add to further incorporating institutional complexity in ABM.
From now on, when referring to institutional complexity the interdependencies and connectivity between institutions is meant, unless explicitly stated otherwise.

1.2 Research questions

As explained above, understanding institutional dynamics in flood risk response is key to better prepare for flood events, that are expected to increase in both frequency and magnitude due to climate change (IPCC, 2014). In an effort to untangle this complexity, this research will seek an approach to understand interdependencies and connectivity between institutions.

The main research question will be:

> What is the effect of interdependencies and connectivity between institutions on flood risk management, for the case of St Maarten, the Netherlands?

In order to address this main research question properly, three sub research questions will be studied:

I. How can interdependencies and connectivity between institutions be studied?

To answer this first research question, both a theoretical framework and an applicable methodology to study interdependencies and connectivity between institutions are developed.

II. What interdependencies and connectivity between institutions can be identified in flood risk management on St Maarten?

Once a theoretical framework and methodology have been defined, these are applied to the case study of flood risk management on St Maarten. The goal of this application is twofold: on the one hand, we want to better understand the usability of the developed framework and methodology, and on the other hand, we want to better understand the institutional dimension of flood risk management in St Maarten to be able to improve FRM on the island in future.

III. How can insights in interdependencies and connectivity between institutions be translated to better flood risk management?

This last research question focuses on the further use of insights in interdependencies and connectivity between institutions. First of all, the link between insights stemming from this research for the case study St Maarten and improving flood risk management is discussed. Secondly, we will reflect on the advantages and drawbacks of the used methodology for research on institutional complexity beyond the case study.

In the next chapters, the theoretical background and methodology for this research are explained. I then explain one of the key products of this research: a methodological tool to research interdependencies and connectivity between institutions. Afterwards, this tool is applied to the case study of FRM on St Maarten. This research concludes with reflections on the link between institutional interdependencies and connectivity and better FRM on St Maarten specifically and a discussion of this research approach to understand institutional complexity more generally.

2

Theoretical background

“Socio-hydrology: the science of water and people.”

Sivapalan et al., 2012

Studying flood risk is by definition interdisciplinary: it requires an understanding of natural processes that cause floods, an understanding of potential flood risk reduction measures – both in terms of technological and social measures -, and an understanding of the social reality in which measures should be implemented. What is more, the researcher’s perspective should include the notion that the ecological, technological, and social realities are interlinked and should be studied from a system’s perspective.

This chapter gives a theoretical background of flood risk management. Furthermore, the link between this research and the fields of socio-hydrology and Industrial Ecology are discussed. To conclude with, a theoretical framework will be developed to address interdependencies and connectivity between institutions in regard to flood risk management.

2.1 Flood Risk Management

In this section, I will introduce some key concepts in risk management literature that will be used throughout this research. I will relate these concepts to flood risk specifically.

A disaster is defined as “a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources” (ISDR, 2004). Material development has both lead to a detachment from nature and an increased vulnerability to disaster events. Therefore, a disaster is described as “a result from the combination of hazard, vulnerability and insufficient capacity or measures to reduce the potential chances of risk” (Vasilescu et al., 2008).

Hazard can be defined as “a dangerous condition or event, that threats or has the potential for causing injury to life or damage to property or the environment” and can be sub divided in natural and manmade hazards. A hurricane is an example of a natural hazard, whereas waste leakage would be considered a manmade hazard. An overlap – socio-natural hazards – of the two categories is possible as well. An example of such a hazard would be floods, as a combination of natural and social processes may cause floods (Vasilescu et al., 2008). Vulnerability is “the extent to which a community, structure, services or geographic area is likely to be damaged or disrupted by the impact of [the] hazard”.

Flood Risk Management (FRM) strives to mitigate, not to eliminate flood hazard, as the latter is impossible. In urban areas impacts of flood events are usually higher, as exposure and vulnerability are higher. Causes include high density of population and property, the latter creating impervious urban areas. Non-structural measures, such as land use planning, are increasingly recognized as important tools to mitigate flood risk (Tinsanchali, 2011).

Flood Risk Management cycle

As described in the introduction, the disaster management cycle consists of four main four main activities or phases: mitigation, preparation, response and recovery (figure 1.2). Here, I further define these four concepts. Mitigation is the minimisation of effects of a disaster. Mitigation of flood risk will add to the resilience of a CAS to floods. Resilience is defined as “the degree to which a complex adaptive system is capable of self-organizing and the degree to which a system has the capacity to learn and adapt” (Folke et al., 2002; Folke, 2006). Preparedness is “planning how to respond”. Response includes all efforts to minimize the hazards created by a disaster. Recovery is the phase in which the community seeks its pre-disaster equilibrium (Vasilescu et al, 2008).

How active a community is in FRM depends on the institutional culture, shaped by organizations, stakeholders and society (Metz et al., 2010). Risk perception - "the subjective judgement that people make about the characteristics and severity of a risk" (IPCC 2014) – is a driver at this level.

2.2 Socio-hydrology

This research adds to the field of socio-hydrology, by focussing on institutional complexity, as part of the the dynamics and co-evolution of coupled human-water systems. Whereas water management used to focus on structural measures, driven by top-down governance, socio-hydrology has grown to understand the importance of non-structural measures and bottom-up governance as well.

Integrated Water Resource Management

Socio-hydrology can be seen as the next step towards a more integrated approach of water management. Before socio-hydrology, the most integrated approach towards water management in general was Integrated Water Resource Management (IWRM). IWRM research shows that effective water management should be organized in a polycentric manner. Ostrom (2008) showed that neither open, competitive markets, nor centralized governments form the right institutions. Polycentric governance systems are more effective, yet more complex. A polycentric governance system is characterized by both the existence of several power centres and an effective set of rules that is recognized by all these power centres (Andersson and Ostrom, 2008).

As Pahl-Wostl et al. (2012) have shown, FRM systems with the highest performance show high resilience and are characterized by polycentric governance, the distribution of power, and effective coordination. An adequate FRM system should allow for active stakeholder involvement and learning (Ashley et al., 2012). Participatory activities in FRM yield three main benefits: opportunities for individual and collective learning, building a sense of ownership and improving compliance (Özerol, 2012). This may often mean that a change in culture is required, which can only be brought about by professionals and major stakeholders (Ashley et al., 2012). Other scholars have argued that good governance starts with flood risk awareness and the willingness of communities to act on flood risk (Marrero, 2008, Marrero & Tschakert 2011). Schelfaut et al. (2011) state that resilience can be evaluated according natural, physical, economic, institutional and social criteria.

Integrated Water Resource Management (IWRM) treats floods as part of the water cycle and integrates land and water management. Based on risk management, IWRM argues that a mixture of FRM strategies, including structural and non-structural measures will increase flood risk mitigation (Grabs et al., 2007). This mixture of measures should address all four stages of the FRM cycle, that is explained in more detail below.

Socio-hydrology: dynamics and interaction between water and people

The main difference with IWRM is that socio-hydrology focuses more on the dynamics of the interaction between water and people. The goals of socio-hydrology are to understand patterns and dynamics of biophysical/human systems on different spatial-temporal scales; to forecast socio-hydrologic system responses; and to understand water in a cultural, social, economic and political sense (Blair & Buytaert, 2015).

The notion of complexity and its characteristics, such as non-linear dynamics, adaptation, resilience, and vulnerability, from Socio-Ecological Systems theory (SES) lies at the core of socio-hydrology. In that sense, Troy et al. (2015) argue that socio-hydrology can be seen as a sub discipline of SES theory.

Modelling in socio-hydrology can contribute to a better system understanding, forecasting or predicting system level change and policy decision making (Kelly et al., 2013). Baldassarre et al. (2013) conceptualized a simple, dynamic flood model to represent interactions between hydrological, economic, political, technological, and social processes. An important insight is that recently, efforts

have been made in for example the Dutch river areas to move away from trying to reduce the probability of flooding, while increasing the potential adverse consequences by focussing on structural measures like dams and dikes.

Modelling the dynamics between the human and hydrological system should thus provide insights for policy making. The approach taken in this research, zooming in on the institutional dimension of flood risk response can offer valuable insights for this new research field.

2.3 Industrial Ecology

Industrial Ecology (IE) can be defined as a "systems-based, multidisciplinary discourse that seeks to understand emergent behaviour of complex integrated human/natural systems" (Allenby, 2006). In this approach of sustainability integrates the social, environmental and technological dimensions of a system (Allenby & Graedel, 1993). The objective of industrial ecology is to understand how to better integrate environmental concerns into our economic activities to address environmental concerns (Lifset & Graedel, 2002).

In the "Handbook of Industrial Ecology", Ayres and Ayres (2002) identify core elements of the field. Two of these core elements – the use of a systems perspective and forward-looking research and practice seem highly applicable to this research. Only by understanding the complexity at a systems level, effective governance can be shaped in future.

To move systems towards sustainability, innovation is key. Not just technological innovation, but social innovation as well: more sustainable techniques should be accepted and adopted, often requiring a change of beliefs and behaviour. Transfer of innovative technologies requires the transfer of hardware (a new technology), software (skills and knowledge), and orgware (capacity building of institutional actors in adapting to a new technology) (Klerkx & Leeuwis, 2009). Systems with high institutional capacity are seen as more resilient, however, capacity building is not easy.

Social and cultural changes seem the most difficult to establish, which emphasizes the importance of social sciences in Industrial Ecology (Ayres & Ayres, 2002). Societal change towards a more sustainable approach of CAS requires coordinated action: adjusting actions and activities to one another. Governance is defined as the coordination of actions to deal with collective problems (Boons & Baas, 1997). Institutions are coordinating mechanisms that define governance: rules, norms and strategies are developed to guide individual action towards a preferred outcome.

In short, the field of Industrial Ecology takes a system's perspective at sustainability issues. By its focus on barriers for social or societal change, IE provides a valuable starting point for this research on the institutional dimension of the problem of flood risk.

I have now placed this research within the field of socio-hydrology and Industrial Ecology. In the next two sections, I will explore theories that help untangle institutional complexity.

2.4 Institutional analysis

In this section, I will give more background on institutions and introduce the Institutional Analysis and Dynamics (IAD) framework developed by Ostrom and the syntax for formalizing institutions Crawford and Ostrom have developed (1995).

2.4.1 Types of institutions

To overcome dilemmas of collective action where individual interests are not in line with collective interests, communities govern their actions. Governance can be defined as all processes of governing – trying to steer, direct, and influence – decisions and actions of actors to achieve a certain objective. Governance is not solely limited to state actors, but can be seen on all levels in society. Institutions are

developed to govern action and can take the shape of formal rules, norms and shared strategies (Allenby, 2002).

Scott (1995) distinguishes three types of institutions: regulative (rules, regulations), normative (norms) and cognitive (shared strategies) institutions. Regulative institutions use coercive powers to ensure compliance. This type of institutions is legally sanctioned and used to create stability. Normative institutions are followed because individuals want to act in such a way that they are recognized as part of the group. Individuals are morally governed to follow role expectations, values and norms. Cognitive institutions are for example shared strategies, priorities and beliefs. They are taken for granted and part of the culture. Cognitive institutions spread through individuals mimicking, learning and imitating each other. Table 2.1 gives an overview of these three types of institutions.

Table 2.1: Three types of institutions, based on Scott (1995)

	Three types of institutions		
	Regulative (Rule)	Normative (Norm)	Cognitive (Shared strategy)
Examples	Formal rules, laws, sanctions, incentive (cost/reward) structures, governance/power systems, protocols, standards, procedures	Values, norms, role expectations, authority systems, duty, codes of conduct	Priorities, beliefs, bodies of knowledge, models of reality, search heuristics
Compliance	Expedience	Social obligation	Taken for granted
Mechanisms	Coercive (Force, punishment)	Normative pressure (Social sanctions, such as shaming)	Mimetic, learning, imitation
Logic	Instrumentality, creating stability	Appropriateness, becoming part of the group	Orthodoxy, shared ideas concepts
Basis of legitimacy	Legally sanctioned	Morally governed	Culturally supported

2.4.2 Understanding the dynamics of institutions

To study the complex processes that drive institutions, the Institutional Analysis and Development (IAD) framework was developed by Ostrom and others (Kiser & Ostrom, 2000; figure 2.1). This framework builds its analysis on individual actors and actions, that affect the institutional response on a system level. Polski and Ostrom (1999) state that individual actions shape institutions on four levels: the operational, collective-choice, constitutional and meta-constitutional level. Individual actions are performed by actors in the so-called action arena. This action arena is affected by the biophysical world, the community it is embedded in and the rules that these actors comply to. From individual actions patterns of interactions are formed. These patterns have certain outcomes, on basis of which performance is evaluated. These outcomes affect the outside world and the action arena. In other words, feedback processes guide individual action (Ostrom & McGinnis, 2010).

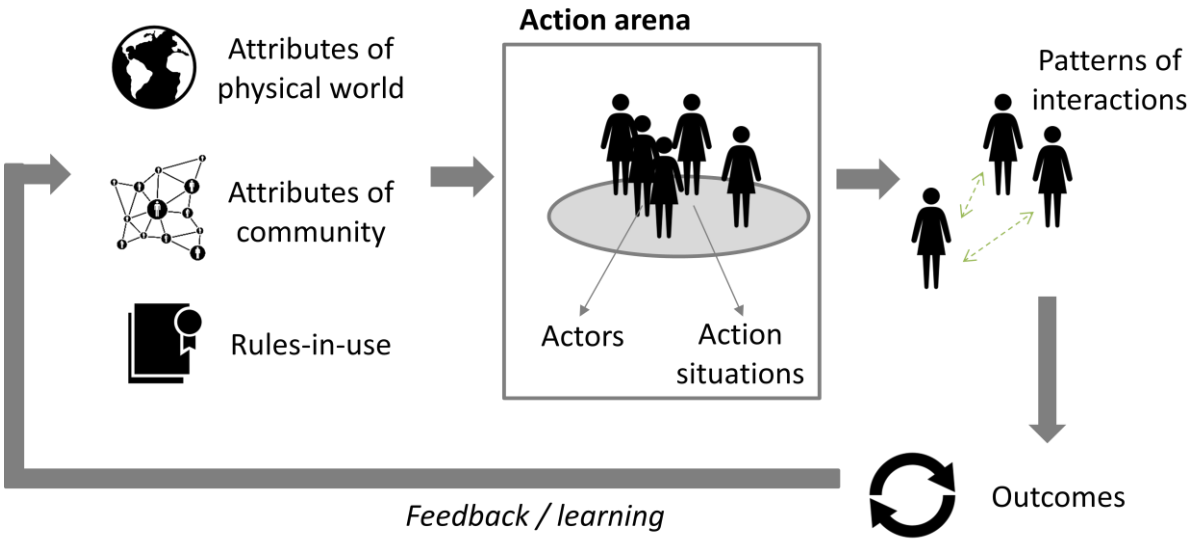


Fig 2.1: Institutional Analysis and Development (IAD) framework

A key strength of the IAD framework is that it captures the dynamics of institutions. Actions that take place within the action arena are guided by external factors, ranging from physical attributes, to attributes of the community and rules in use. Actions lead to patterns of interactions that have certain system level outcomes. These outcomes lead to learning as they influence attributes of the physical world, the community and the rules-in-use. In other words, institutions are not static, but constantly object to feedback mechanisms and change. Within this study, analysing the development of institutions falls out of scope. However, I will discuss this form of institutional dynamics in chapter 6 and 7.

2.4.3 Formalizing institutions

Institutions can be described in institutional statements. In line with Crawford & Ostrom (1995) institutional statements are defined as a "shared linguistic constraint or opportunity that prescribes, permits, or advises actions or outcomes for actors ... [they] are spoken, written, or tacitly understood in a form intelligible to actors in an empirical setting". Crawford and Ostrom developed the ADICO grammar of institutions to structure institutional statements (see Table 2.2). Institutional statements are not always articulated, they can be implicit (Crawford & Ostrom, 1995). Watkins & Westphal (2015) show that translating human language to formal syntax is a challenge as people do not talk in institutional statements.

Table 2.2: ADICO syntax

	Meaning	Explanation
A	Attribute	Who?
D	Deontic	May, must, must not
I	aIm	What/How?
C	Condition	When and where does it apply?
O	Or else	What is the sanction?
Types of institutional statements		
ADICO	Rule	
ADIC	Norm	
AIC	Strategy	

The Or else-part of an institutional statement – the sanction – is not as strictly reserved for rules as tables 2.1 and 2.2 suggest. Schlüter and Theesfeld (2010) state that sanctions for rules are tangible. Sanctions for norms are automatic and emotional of nature, whereas sanctions for strategies are automatic as well – a strategy either increases or decreases productivity. The difference lies in the fact that sanctions for rules are formalized and captured in written form.

Frantz (Frantz et al., 2013, 2015) added the concept of nested institutions to the ADICO grammar: nADICO. He explains how institutional statements are nested. An example would be as follows:

> Traders [A1] must [D1] trade fair [I1] under any circumstances [C1],
> Or else [O]:
> Observers [A2] must [D2] report deviation [I2] under any circumstances [C2].

The statement that observers have to report deviations is nested in the initial statement that traders must trade fairly. In other words, the statement can be written as ADIC[ADICO], where the sanction in the main institutional statement beholds a new institutional statement. For researchers that lack a computation background, this way of conceptualizing nested institutions may be difficult to work with.

2.5 Interdependencies and connectivity between institutions

As stated in the research gap, there is a lack of knowledge on how to study interdependencies and connectivity between institutions. Interdependencies and connectivity of institutions have largely been treated as a black box in institutional literature.

Surprisingly, in the paper by Sivapalan et al. (2012) that marked the establishment of socio-hydrology as a new field of research, institutions were not mentioned once. The focus is rather on water management. In fact, the work of Baldassarre et al. (2014) on conceptualizing human-flood interactions makes no mention of institutions either. Within socio-hydrology, institutions can be seen as a blind spot.

In flood risk research, Manuta and Label (2005) and Brown and Damery (2002) both talk about the mainly technocratic approach towards FRM in governmental institutions. Manut and Label (2005) discuss 'institutional traps', such as the emphasis on emergency response, the tendency to highly centralize FRM and the difficulties that an absence of civil society poses on effective FRM. However, their studies do not zoom in on institutions any further.

Naess et al. (2005) state that "institutions affect the social distribution of vulnerability, as well as determine the management of climate sensitive aspects of society and, in turn, the capacity to adapt successfully." They regard the different interests of stakeholders as social learning as key processes in institutional development. Their analysis focuses more on the interactions between institutional levels (municipal/national) and less on the interactions between institutions.

Gober & Weather's work on the science-policy interface with regard to socio-hydrology (2014) state that new patterns of extremes pose stress on societies to adapt through, amongst others, new infrastructure, institutions, building requirements and early warning systems. However, their description of policy is not detailed to a level of single institutions.

We can conclude that thus far within socio-hydrology, institutions and their connectivity are not defined and studied on institutional statement level. This research can add an understanding of the interactions between institutions to the research field.

In order to address this research gap, we turn to the field of network theory. Within network theory, the assumption is that the structure of the network may be just as defining or even more defining than the properties of the entities that are connected within the network. A network perspective might provide the necessary focus on links between institutions, rather than merely on the institutions themselves.

According to Rowley (1997), network models begin where stakeholder analysis stops, as network analyses capture the influence of multiple and interdependent relationships. Or as Krause et al. (2007) put it: "network analysis bridges the gap between individual and population behaviour". The key principles of network analysis are that behaviour is interpreted in terms of structural constraints, and that relations between actors and their effect on individual behaviour should be the focus of the analysis (Rowley, 1997). By taking a network approach, crucial actors, information transfer and social learning can be studied (Krause et al., 2007).

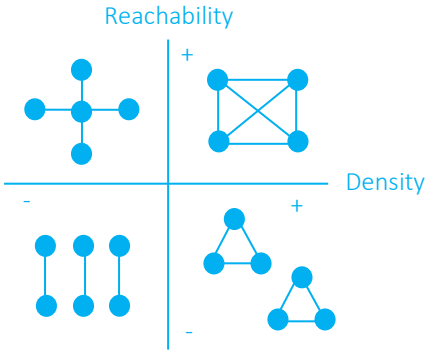
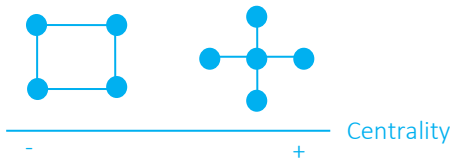
In Social Network Theory, the entities in focus are individuals or groups of individuals and power is obtained through the network's structure, rather than individual attributes. Those actors that hold a central position have more power within the network (Brass and Burkhardt, 1993). In dense networks, communication is more efficient and norms diffuse across the network more easily (Meyer & Rowan, 1977). Granovetter (1983) showed that weak ties with acquaintances are necessary to spread momentum beyond cliques. Weak ties allow for flexibility and mobility within a social structure and as such, weak ties form the basis of macro level, rather than micro level integration (Friedkin, 1980). Actors that share stronger ties, are usually more similar.

Network structure

In network representations, nodes represent the components (people, organizations etc.) and links represent their interrelations. By taking a network perspective, one focuses on the structure of interactions between components of a system. Hereby, the focus is shifted from properties of components to the dynamics between components.

There is a huge body of knowledge based on network theory, ranging from computation science and ecology to social network analysis. This research focuses on the implications of network structure and overall system resilience. This network perspective has been applied to study resilience in Social-Ecological Systems (SES) by Janssen et al. (2006). They propose SES networks, that consist of both social and ecological nodes. They focus on two key network concepts in order to analyse resilience of SES networks: level of connectivity and the level of centrality. In table 2.3, I explain these two concepts and conclude with the value of this theoretical work for my research.

Table 2.3: Network structure and resilience, based on Janssen et al. (2006)

Concept	
Level of connectivity The level of connectivity depends on the density of links within the network (number of links divided by the maximum possible number of links) and the reachability within a network (how easy can nodes reach each other).  	Level of centrality Besides the level of connectivity, the level of centrality is a key characteristic in network resilience. 

There is no straightforward link between connectivity, centrality and resilience (see table 2.4), but the level of connectivity and centrality can be used to understand the strengths and weaknesses of the network. For example, a high level of reachability may allow for rapid response to external changes. However, a high level of reachability may lead to the rapid spread of practices with negative outcomes as well.

Table 2.4: Overview of advantages and disadvantages of different network structures, based on Janssen et al. (2006)

Performance of a network, based on level of connectivity and centrality		
Level of connectivity: Density		
	Advantages	Disadvantages
High	Learning, rapid information exchange/ diffusion	Super connected, brittle
Low	Diversity in practices	Limited spread of information
Level of connectivity: Reachability		
	Advantages	Disadvantages
High	High access, quick response	Quick spread of negative practices
Low	Formation of efficient clusters, slow spread of negative practices	Inaccessibility of information
Level of centrality		
	Advantages	Disadvantages
High	Efficient coordination, high accountability	Reduced distribution of information, vulnerable to removal of node
Low	Fair, robust to removal of node	Inefficiency, lack of control and accountability

Apart from connectivity and centrality, embeddedness is seen as an important network characteristic. Embeddedness is also referred to as the "network effect": the position an actor has in a social network is related to social capital and comes with positional power. High embeddedness of an actor corresponds to high social capital and high positional power (Granovetter, 1985; Grewal et al., 2006). Zukin and DiMaggio (1990) differentiate between four types of embeddedness: cognitive embeddedness, cultural embeddedness (the role of shared collective understandings), structural embeddedness (relating to the patterns of interpersonal relations), and political embeddedness (the struggle for power).

In light of this research, I will focus on structural embeddedness, for which I use the definition by Galuti and Gargiulo (1999): structural embeddedness is the "structure of relationships around actors".

How these network metrics can be translated into empirical research will be discussed in chapter 4.

Network of institutions

The goal of this research is to understand institutional complexity by taking a network perspective. This may lead to insights in the structural strengths and weaknesses of institutional practices. Institutions are a mental construct: rules, norms and shared strategies influence actor behaviour, but they do not have a physical dimension.

To be able to understand institutions from a network perspective, institutions are linked through the actors that they influence. As in Social Network Theory, actors are seen as nodes within a network. These nodes are linked by institutional statements. Where links between actors in Social Network Theory are mainly based on interaction, institutional statements offer the opportunity to further specify the nature of these links. Based on the research by Janssen et al. (2006), I focus on the implications of network structure for the performance of the system.

2.6 Theoretical framework

In line with socio-hydrology, this research understands flood systems as coupled human-water systems. We focus on institutional complexity and dynamics. By dynamics the interdependencies and connectivity between institutions are meant. This research is both a methodological exploration of the field, as it is a case study application of this methodological exploration.

Within institutional theory, the Institutional Analysis and Dynamics (IAD) framework is one of the standards in the field. This framework is highly applicable to this research, as this framework seeks to understand institutions and their dynamics as a result of individual behaviour, so that the complexity of a system is researched bottom-up, rather than top-down. This research seeks to understand how individuals and individual decisions steer social interactions and institutional development within complex adaptive systems.

To understand interdependencies and connectivity between institution, institutions may be understood as networks. Network theory builds on the assumption that the structure of network components and interactions between these components are just as important or maybe even more important than component characteristics.

By focussing on a network of institutions, this research aims to untangle institutional complexity. The network perspective on institutions should yield insights in two main directions:

1. Insights that are based on the network of institutions itself (what implications does the structure have for governance within a system, and how can governance be improved based on this understanding of the network of institutions?).
2. Include insights from networks of institutions in ABM (how can results be integrated within an ABM to refine institutions that guide individual decision-making behaviour?).

This theoretical framework is summarized in figure 2.2. This figure shows how the backbone of this research is socio-hydrology with its notion of human-water coupled systems. This research zooms in on the institutional dimension of flood risk management, by learning from institutional theory. In the bottom right it is shown that this research zooms in one step further: by focusing on institutional complexity, explained as connectivity and interdependencies between institutions, hereby building on network theory.

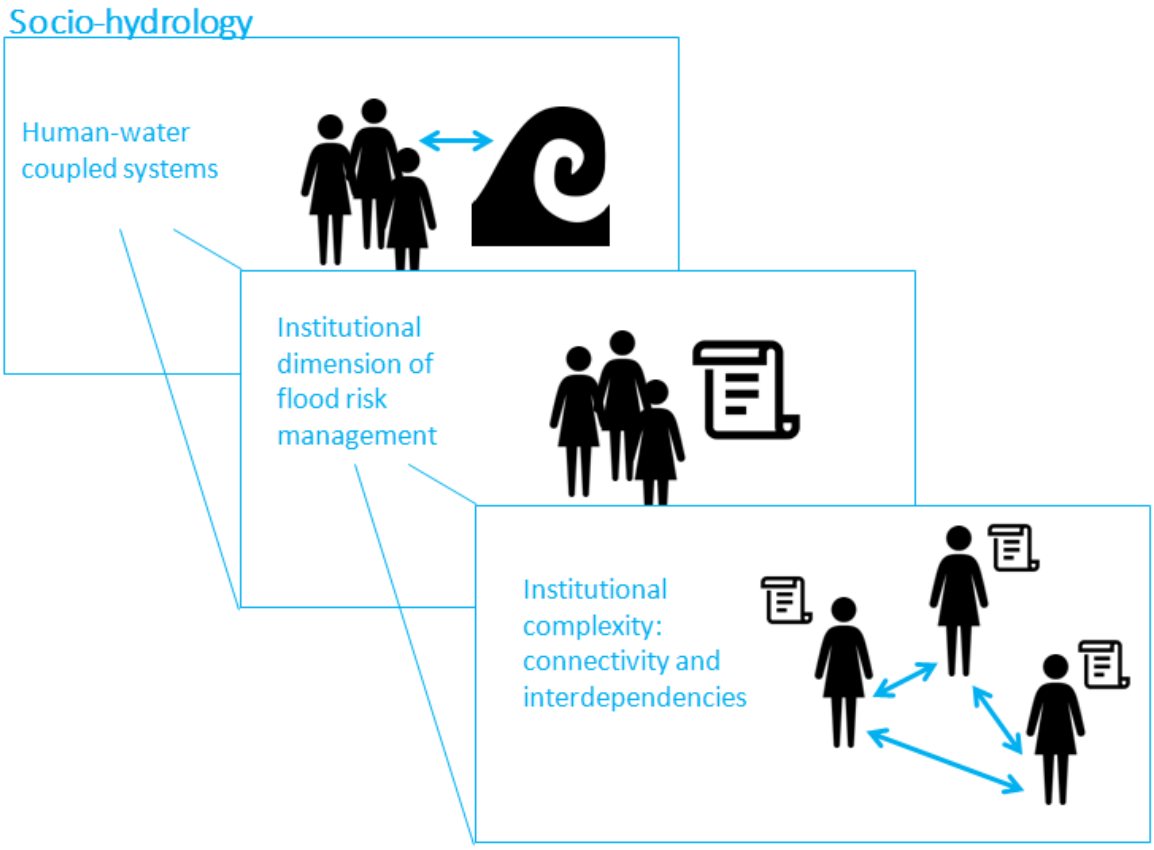


Fig 2.2: Graphical representation of theoretical framework

3

Methodology

"There is a trade-off between representing complexity and disclosing relevant information on institutional dynamics to stakeholders."

In this research, my goal is both to develop a methodology to study interdependencies and connectivity between institutions and to apply this tool to the case of FRM St Maarten. In this chapter I describe the methodology I used to build an understanding of the effects of interdependencies and connectivity between the institutions and FRM on St Maarten. This research lead to the development of a new methodological tool to study institutional complexity that will be introduced in chapter 4.

To understand the dynamics in a Complex-Adaptive System, it is important to take a bottom-up modelling perspective. Agent-Based Modelling is an often used methodology to build a CAS from single actor behaviour. In my methodology, I build on previous work in ABM to incorporate institutions in models. Therefore, I give a swift introduction of this previous work in section 3.1. In section 3.2, I introduce the methodology of this research.

3.1 Studying institutions using Agent-Based Modelling

In the previous chapter, a conceptual framework for the analysis of institutional dynamics was introduced: IAD. In this section, I will explain how this framework has been translated into modelling approaches. As stated in the introduction, Agent-Based Modelling (ABM) offers an interesting line of research to study institutions, as the underlying assumption of both this method and the IAD framework is that system dynamics should be studied bottom-up. The starting point is individual decision making, which shapes system level outcomes and feedback mechanisms. ABM offers a disaggregated approach to analysing Complex-Adaptive Systems and studies "evolution of a system from the perspective of the aggregate population of agents and with respect to individual behaviour" (Axtell et al., 2001).

Defining Agent-Based Models

An ABM represents a system as a "collection of agents and their states, the rules governing the interactions of the agents and the environment within which they live" (Shalizi, 2006). The method places agents, which comply with a simple set of rules and have assigned characteristics, in a physical environment. By formalizing interactions and outcomes of these interactions agents, an ABM can be used to study macro-level complexity from micro-level interactions (Macy & Willer, 2002). ABMs show complex processes in Complex-Adaptive Systems, such as path-dependencies, embeddedness and evolution (Nikolic & Van Dam, 2013).

The process of building and using an ABM can be divided in ten sub steps (Nikolic & Van Dam, 2013). In the first step, the problem is formulated and the actors are identified. After that, the system should be identified and decomposed. Step three is the formalization of the concept, step four consists of the formalization of the model itself. In the fifth step, the model should be implemented into a software. After that, the model is verified (step 6) – does the software implementation actually match the formalized model? Then, experiments can be performed (step 7), so that the model outcomes can be analysed (step 8). In step 9, the model is validated – is it a good representation of the real system? And the concluding step is to use the model, for example to examine the effectiveness of several policy options.

ABM and IAD

The MAIA-tool, which stands for Modelling Agents based on Institutional Analysis, was developed to facilitate the use of formal models for scientist with limited background in computational sciences (Ghorbani, 2013). The tool combines insights from both ABM and IAD. The links between IAD concepts and MAIA concepts are listed in table 3.1.

Table 3.1: MAIA as a framework that combines IAD and ABM, in light blue the focus areas of this study

IAD concepts in MAIA	
IAD	MAIA
Biophysical characteristics	Physical structure
Attributes of the community	Attributes of the agent; ADICO
Rules-in-use	ADICO institutions
Action arena	Action arena
Action situations	Action situations
Actors	Agents
Patterns of interaction	Observed in simulation
Outcomes	Observed from simulation
Evaluative criteria	Make changes in the situation

MAIA divides between five structures. The collective structure consists of agents; the constitutional structure consists of roles, institutions and dependencies. The physical structure is built up by physical components, connections and composition. The operational structure includes entity actions, plans, action situations, role enactments and the action arena. Lastly, the evaluative structure contains problem domain evaluation, a problem domain matrix, validation and a validation matrix (Ghorbani, 2013).

In this research, the main focus will be on the constitutional structure: on how the attributes of the community and the rules-in-use shape decision making in the action arena, that shape patterns of interaction. There will be little focus on institutional change through feedback mechanisms and attributes of the physical world, as this falls out of the scope of this research (see IAD framework, figure 2.1).

In the next section, the methodology of this research is introduced.

3.2 Methodology

Figure 3.1 shows the methodology that was used for this study. The research approach can be divided in two main processes, that are interlinked. I started off this research by focussing on FRM institutions on St Maarten. Research steps included data collection, data coding and clustering, and formalizing institutions. These subsequent steps will be explained in more detail in the next chapter. Outcome of these first three steps is a list of institutional statements in the ADICO syntax.

The goal of this research is to understand the interdependencies and connectivity between institutions, taking institutional statements as building blocks. However, no methodology was available to study this form of institutional complexity. Building on network theory (please see section 2.5) a network approach for studying institutions was developed (right side of figure 3.1). This methodology is one of the main outcomes of this research and is introduced in chapter 4.

Once this methodology was developed, it was applied to the case study of St Maarten, to find the effects of institutional interdependencies and connectivity on FRM. This research leads to conclusions in both main processes. Based on the institutional interdependencies and connectivity, conclusions will be drawn on FRM on St Maarten. This includes recommendations to local policy makers. Next to these insights on case study level, this research yields conclusions on studying institutional complexity on a higher level and will address the usability and potential lead for further development of the introduced methodology.

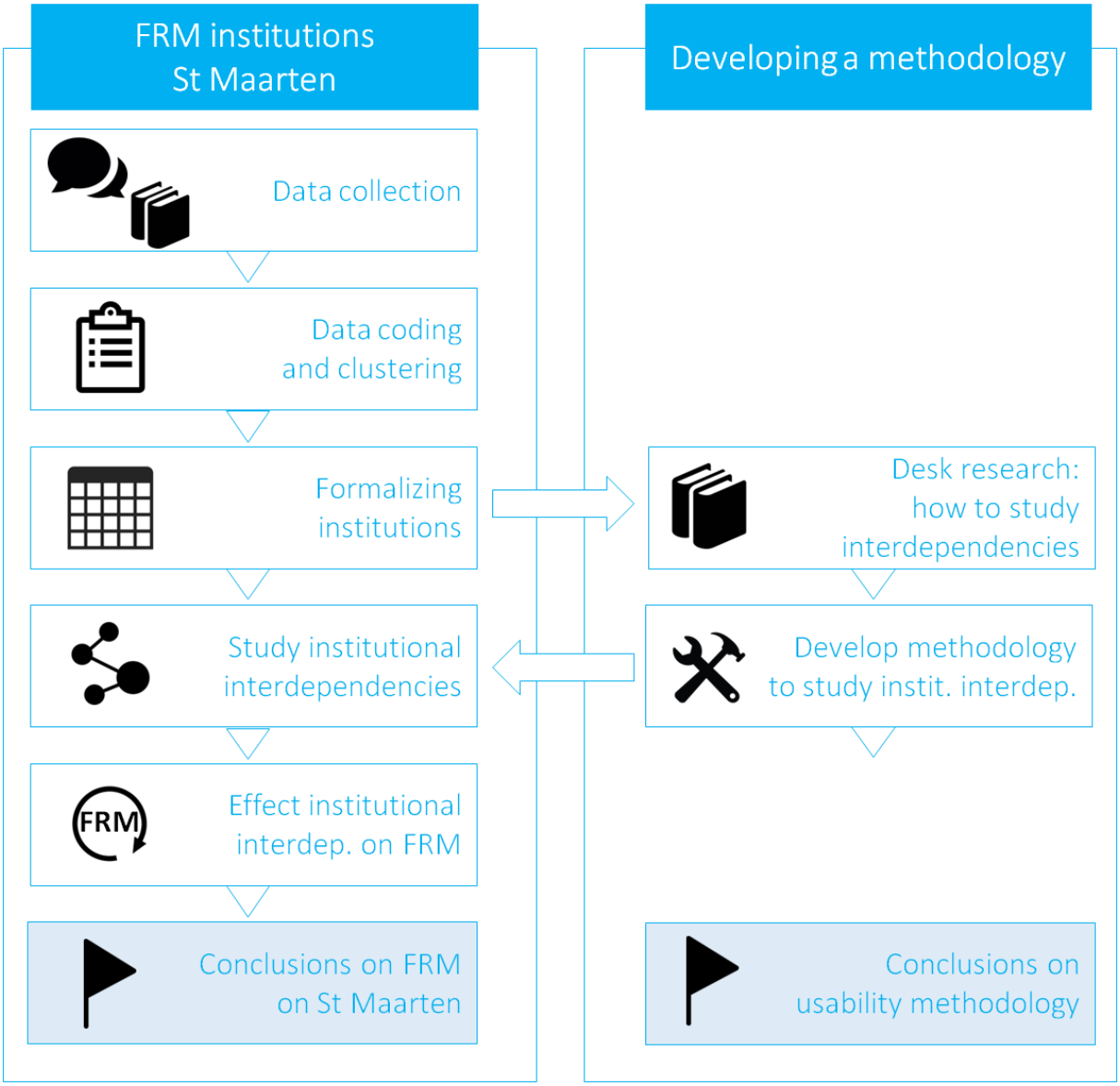


Fig 3.1: Overview of methodology for this research

This methodological chapter is build up quite unconventionally, to prevent redundancies with chapter 4, where the network approach of studying institutional complexity is presented. Here, I will focus on the right side of figure 3.1.

Criteria for a methodology to study institutional interdependencies and connectivity

To study institutional interdependencies and connectivity, the methodology that is developed in this research has to meet four main criteria:

1. In the theoretical background, Social Network Theory was introduced as a relevant perspective to study institutional interdependencies and connectivity. The methodology that is developed in this research should therefore translate links between institutions in a meaningful way.
2. As the goal is to understand the effect of institutions on FRM, it is important to capture the translation of institutions into actual action. Institutions are mental constructs, that only 'materialize' when they guide decision making behaviour of actors. This link to the physical world through actor behaviour was found to be of high importance and was taken as a starting point for drawing interdependencies between institutions. The methodology should allow the researcher to gain an understanding of the institutional dimension beyond a mere description of applicable rules, norms and shared strategies.

3. As we seek to capture institutional complexity, the methodology should allow the researcher to include all relevant decision makers within FRM. However, as the results should preferable be translatable to non-academics, there is a trade-off between representing complexity and disclosing relevant information on institutional dynamics to decision makers that the researcher needs to address.
4. The methodology should allow for a translation to Agent-Based Modelling, to include the dynamics of institutional change in a later stage.

The methodology was developed in a process of trial and error. Hereby, I tested my progressing ideas and understanding with Amineh Ghorbani (TU Delft). I will return to the four criteria that are defined above in the discussion in section 6.1.

4

Institutional Network Analysis

"An Institutional Network Diagram is a new graphical representation of a network of institutions that define an action arena."

In this chapter the methodology that is used to study interdependencies and connectivity between institutions is explained. This methodology – Institutional Network Analysis (INA) – consists of five research steps. After introducing these steps in section 4.1, I will explain how I applied INA to the case of FRM on St Maarten in section 4.2. In section 4.3, I explain how insights from INA may be translated into an ABM.

4.1 Institutional Network Analysis (INA)

Institutional Network Analysis consists of five subsequent steps (figure 4.1). After collecting data (step 1), all available data is coded and clustered (step 2), before institutions are derived from the data and formalized, using the ADICO syntax (step 3). The institutional statements form the basis of Institutional Network Diagrams (step 4), that are analysed in the last research step (step 5).

The process of translating qualitative data into institutional statements, INA step 1, 2 and 3, builds on work by Ghorbani, Dijkema and Schrauwen (2015) and Watkins and Westphal (2015). The fourth and fifth step are a contribution of this research.

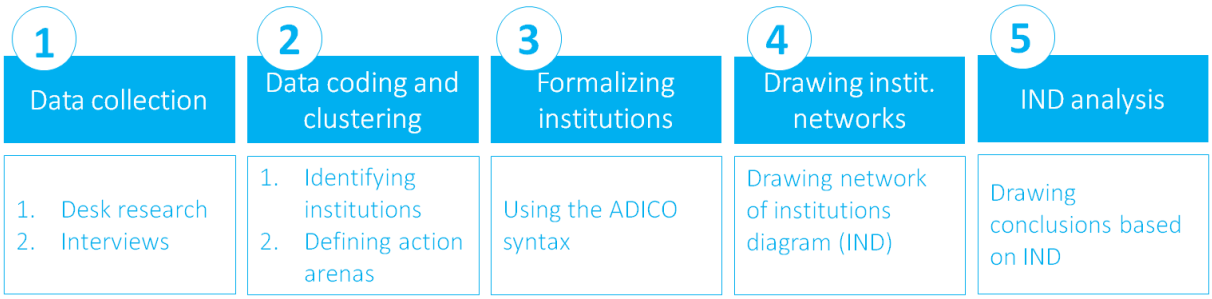


Fig 4.1: Translating quantitative data into institutional statements in three steps

STEP 1: Data collection

Data collection is done through semi-structured interviews with stakeholders, and through analysing publicly available case study information, such as laws, rules and regulations, statistical reports and newspaper articles.

The data collection process is an iterative, intertwined process of desk research and interviews. Desk research provides insights in the formal rules-in-use in FRM. When discussing these rules and policy documents with stakeholders in interviews, more implicit institutions, such as norms and shared strategies can be discovered. The researcher then returns to the collected documents to understand where stakeholder action and formal rules-in-use are aligned or not.

Desk research

To develop an understanding of the institutional dimension of flood risk management, publicly available written documents form a start of data collection. The four phases of the FRM cycle form a framework to guide the desk research. The FRM cycle helps the researcher to keep focus, but it does not narrow down the researchers perspective too much. Goal is to balance between extensive document review and keeping a clear relation to the original problem statement. Publicly available documents from governmental organizations with formal responsibilities in terms of FRM form an interesting starting point.

Stakeholder interviews

Interviews are necessary to gain an understanding of implicit institutions: institutions that are not written down in formal documents. Interviews serve as primary data on the design, installation, monitoring and sanctioning of FRM institutions and the cultural context in which decisions on FRM are made. Through semi-structured interviews, data is collected from stakeholders and experts. This semi-structured approach implies that the outcome of an interview is open, but that the conversation is guided by a prepared list of topics. Semi-structured interviews provide a balance between steering a conversation and allowing the interviewee to elaborate on topics important to him or her. Semi-structured interviews are often used when the researcher only has one chance to talk to the interviewee. By allowing interviewees to focus on those topics close at heart, their underlying sentiments and decision making processes can be uncovered, yet the list of topics keeps the conversation relevant and efficient (Harrell & Bradley, 2009, Schmidt, 2004).

STEP 2: Data coding and clustering

In the second research step, the collected data is coded and clustered. The goal of this step is twofold: both to converge the developed data set, and at the same time not to reduce the richness of the information too far.

Data coding

A first step is to code the gathered documents and interview notes. Data coding helps to structure data stemming from various sources and structures content. The coding criteria form a first step of data analysis, as this step narrows down the initial data set.

The criteria used for coding in this research are:

A. Information touches upon **views and perceptions** on FRM on St Maarten;
B. Information touches upon **FRM measures** on St Maarten;
C. Information touches upon **links or cooperation between actors** in FRM on St Maarten;
D. Information touches upon **flood risk related strategies** on St Maarten;
E. Information touches upon **decision making processes** in FRM on St Maarten.

Once information is labelled, the information was labelled with one of the four FRM phases:

1. Preparation
2. Response
3. Recovery
4. Mitigation

In this step, the researcher gains an initial understanding of important themes, topics and patterns. Although the research is guided by the FRM cycle, the researcher should be open to unexpected topics. These 'blind spots' make labelling an iterative process. Key themes can be recorded by adding memos to the source data. A drawback of this method is that defining important topics and sources is a process that is highly dependent on the researcher.

Data clustering

Goal of clustering is to divide the available information into meaningful clusters. Action arenas – in line with Ostrom's IAD framework – are defined as phases of the FRM cycle. However, if actions within a phase have little to do with each other, the decision to subdivide a phase in several action arenas can be made. At this stage, merely focussing on action arenas does not encompass the rich and complex information that interviews provide. Narratives are used to retain information that cannot be directly linked to action arenas within the FRM cycle.

Narratives

Narratives help understand why interviewees mentions certain processes and exclude others. Human beings understand events within a bigger picture: their overarching narrative. Human beings tend to

link everyday events (little stories) to institutional discourses (big stories) that are shared by many (Gubrium & Holstein, 1998). In social sciences, narratives are used to uncover the dense and contextual social forces that guide behaviour. When it is difficult to produce enough case material to perform a statistical analysis, detailed narratives may overcome this research barrier. It is important that researchers understand that the act of interviewing interferes with the outcome. A completely objective interview is impossible. The type of questions and themes that are touched upon, but also an understanding uttering like "uhm uhm", guide the interviewees answers (Holstein & Gubrium, 2004).

For all interviewees, narratives are documented. The researcher compares the narratives of various interviewees to find overlap or gaps in the way interviewees explain their perceptions and decisions. This process yields insights on a system level that can be further explored using ABM. I will return to this point in section 5.4.2.

STEP 3: Formalizing institutions

In this research, the terms institutional statement and institution are used interchangeably. Strictly speaking, an institutional statement has a linguistic component: it has been spoken or written, whereas institutions are more abstract (Basurto et al., 2009). In step 3, institutional statements are distilled from the coded and clustered data set, using the ADICO syntax. First of all, the difficulties in identifying institutions in qualitative data are explained. Secondly, the research process that will be used in this study is explained step by step.

Identifying institutions in qualitative data

An important methodological challenge is to formalize institutions based on quantitative data, consisting of written documents and interview notes. In this research, the ADICO syntax (Crawford & Ostrom, 1995) is used to categorize institutions. ADICO is mainly used to describe rules, there is only a limited body of knowledge on formalizing norms and shared strategies from qualitative data. This research builds on the methodological work of Ghorbani, Dijkema and Schrauwen (2015) and Watkins and Westphal (2015).

Ghorbani et al. (2015) used the MAIA framework to structure ethnographic data collection. In ethnography, rich and diverse information is collected through a combination of open ended, semi-structured interviews, participant observation and field work. Ghorbani et al. (2015) showed using MAIA as a tool to collect and structure ethnographic data for ABM had several benefits. The MAIA framework provides consistency, coherence and enhances structures and tractability in the ethnographic research process. Moreover, the framework was useful to guide the necessary abstraction process.

Watkins & Westphal (2015) use the ADICO syntax on in-depth, qualitative interviews and participant observation as well. They show the key importance of norms as motivational and guiding forces of human behaviour besides formal rules. In line with Schlüter and Theesfeld (2010), I regard sanctions as a continuum from which rules, norms and strategies can be defined (figure 4.2).

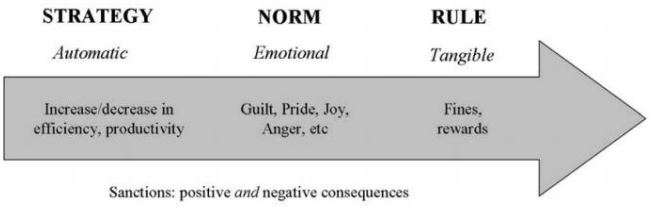


Fig 4.2: Strategies, norms and rules and their associated sanctions as a continuum (Watkins & Westphal, 2015)

Applying the ADICO syntax

In this research, the ADICO syntax will be used to formalize institutional statements on the case of flood response on St Maarten. This is a manual process, where information from official government documents, stakeholder interviews and other sources is interpreted and institutional statements are extracted from these sources of information.

The following steps are followed:

1. Institutional statement or not?

The minimum requirement to have an institutional statement is if an attribute [A], aim [I] and condition [C] are present. If one of these three conditions is missing, we talk about information, not an institutional statement (Watkins & Westphal, 2015). In case no further specific conditions are given, the default conditions of a statement are that they are effective "at all places, in all places", in line with Crawford and Ostrom (1995).

2. Type of statement?

If attribute, aim and condition have been identified, we seek a deontic [D]. If there is no deontic component, the statement is regarded as a shared strategy. In case there is a deontic, the statement is either a norm or a rule. For an institutional statement to qualify as a rule, a sanction/or else [O] component needs to be identified. For all statements, the type – shared strategy, norm, rule – is documented.

For a rule, sanctions may also be partly emotional and automatic, but a rule can be distinguished from norms and shared strategies by the presence of tangible sanctions, for example a fine. Rules can only come to place by previous collective action and require monitoring. Norms have emotional consequences, but no tangible sanctions. This however does not mean they are weaker guides of action than rules. Norms can change over time. A shared strategy is sanctioned by automatic consequences – if you do not bring your umbrella, you will get wet. However, there is no normative dimension to the obligation, there is no deontic. A strategy can be changes without collective action, since a strategy is not established by another actor.

3. Write statement down in ADICO syntax

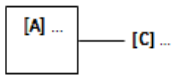
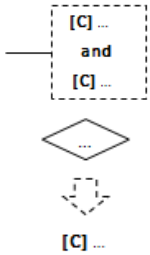
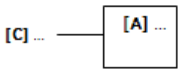
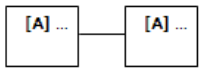
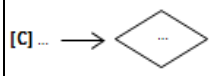
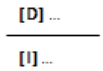
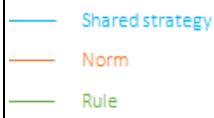
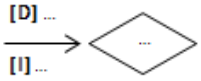
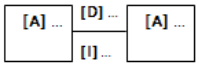
As a final step, the statement is documented in the ADICO syntax, that highlights the attribute [A], deontic [D], aim [I], condition [C], and sanction/or else [O]. For example: *All citizens [A] are at all times [C] forbidden [D] to build within 25 metres of the coastline to protect beaches [I], or else they will be fined [O].*

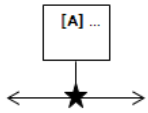
STEP 4: Institutional Network Diagram

An Institutional Network Diagram (IND) is a new graphical representation of a network of institutions that define an action arena. The institutional statements form the basis of the IND. Stakeholder narratives can help drawing these INDs, as they provide the necessary background knowledge of the institutional reality. In table 4.1, I explain how to draw an Institutional Network Diagram (IND) of an action arena in ten steps.

Table 4.1: Ten steps for drawing an Institutional Network Diagram

Drawing an Institutional Network Diagram				
Step		Concept in IAD	Concept in ADICO	Representation in IND
1	Define the action arena that forms the basis of the IND	Action arena	-	Title of IND
2	Determine what cluster of institutional statements defines the action arena	Rules-in-use, attributes of	-	NA

		community		
3	Define the primary attribute(s): the attributes [A] of the institutional statement that activate outcomes or other decision makers within the action arena	Actor	[A]ttribute	
4	Draw a link from the attribute to the condition, and write the condition(s) down following the institutional statement. The [C] interrupts a link or arrow. Note: • If condition is set to default (in all cases, at all times), it is not represented in the IND. Otherwise, this condition should be specified in the IND. • If several conditions hold for the statement, these conditions will be bundled within a square with a dotted line, using the 'and', 'or' or 'and/or' operator. • If another ADICO statement functions as the condition, the outcome diamond (see step 8) will be linked to the condition by a dotted line.	Patterns of interaction	[A]ttribute [C]ondition	 
5	If the ADICO statement links to another ADICO statement, draw a link from the condition to another actor. Note: if the conditions are set to default, the link will be drawn between two attributes (for example: statement 1 says that property owners should ask permit office for permission, than a link is drawn between [A1] property owner and [A2] permit office). Or: If the ADICO statement does not link to another statement, draw an arrow to an outcome (physical or non-physical) in a diamond (see step 8) or a sanction in a diamond with a dotted line.	Outcomes	[A]ttribute [C]ondition [O]r else	  
6	Write the deontic and the aim next to the link/arrow that was drawn in step 5. Write **[D] ...** and **[I] ...** to differentiate between deontic and aim.	Rules-in-use	[D]eontic [I]aim	
7	Use a colour code to distinguish between rules, norms and shared strategies. In this research, rules are green, norms are orange and shared strategies are blue lines. Not only the links/arrows are coloured, the corresponding written [D] and/or [I] are coloured as well. Note: these colours are only used for links/arrows with a [D]eontic and/or [I] aim; links between [A]ttributes and [C]onditions remain black.	Rules-in-use	[ADICO] [ADIC] [AIC]	
8	If deontic and aim are written next to an arrow, draw a diamond for an physical or non-physical outcome or a diamond with a dotted line for a sanction. Or: If deontic and aim are written next to a link, draw the attribute for the ADICO statement that follows the statement (see step 5).	Outcomes, feedback		 
9	Repeat these steps until all ADICO statements from step			

	2 have been incorporated. Check whether all ADICO statements either lead to other ADICO statements, or to an outcome/sanction.		
10	If two or more institutional statements yield different outcomes in the same action situation, a conflict has been identified. This is depicted with a black star. Here, institutional hierarchy should be addressed (see INA research step 5)		

As mentioned in chapter 3, one of the criteria in developing networks of institutions is to find meaningful links between institutional statements and the physical world. Actors – or attributes, these terms are used interchangeably in this research – are connected in social networks. Networks of institutions are different from standard social networks, as they specify the link between actors: these links are defined by the aim and deontic in an institutional network. Conditions may provide links to the physical world (institution applies if [C]: flood event, for example), but they can be mental properties as well (if aware of flood risk). Therefore, the choice was made to treat conditions differently from aim and deontic and to interrupt links or arrows with the conditions under which institutional statements hold.

Institutions guide behaviour towards a desired outcome or a sanction. These outcomes or sanctions are represented as nodes in the network as well. However, the choice was made to represent outcome nodes (diamonds) differently from attribute nodes (rectangles). To make the difference more explicit, outcome nodes are connected to other nodes through arrows. Attributes that are connected amongst each other are connected through links.

Example

To illustrate this method, an IND (figure 4.3) is discussed in detail here. For more information and the list of institutional statements within this action arena, please refer to section 5.2.1.

This IND shows the institutions that define the flood risk response action arena (step 1). This example includes 12 institutional statements (step 2), which easily follows from counting the number of aims [I] that are represented within the IND. There is only one primary attribute here: the prime minister (PM) (step 3). If the PM is advised by the MET office and the Chief Disaster Coordinator (step 4), the PM follows two institutions. There is a link from the condition to another attribute (rectangle) and an outcome (diamond) (step 5). The aim and deontic are written down: the PM [D] may [I] request help from the governor and [D] must [I] declare a national disaster (step 6). Both actions are rules, and therefore coloured green (step 7). The second action leads directly to an outcome: state of emergency, drawn in a diamond. The first action leads to a second attribute [A]: the governor, that follows an institutional statement in his turn (step 8). The dotted arrow from the diamond with *'state of emergency'* to the condition *'if state of emergency'* shows that the outcome of the statement where the PM declares a national disaster, forms the condition for a set of institutional statements concerning clean-up.

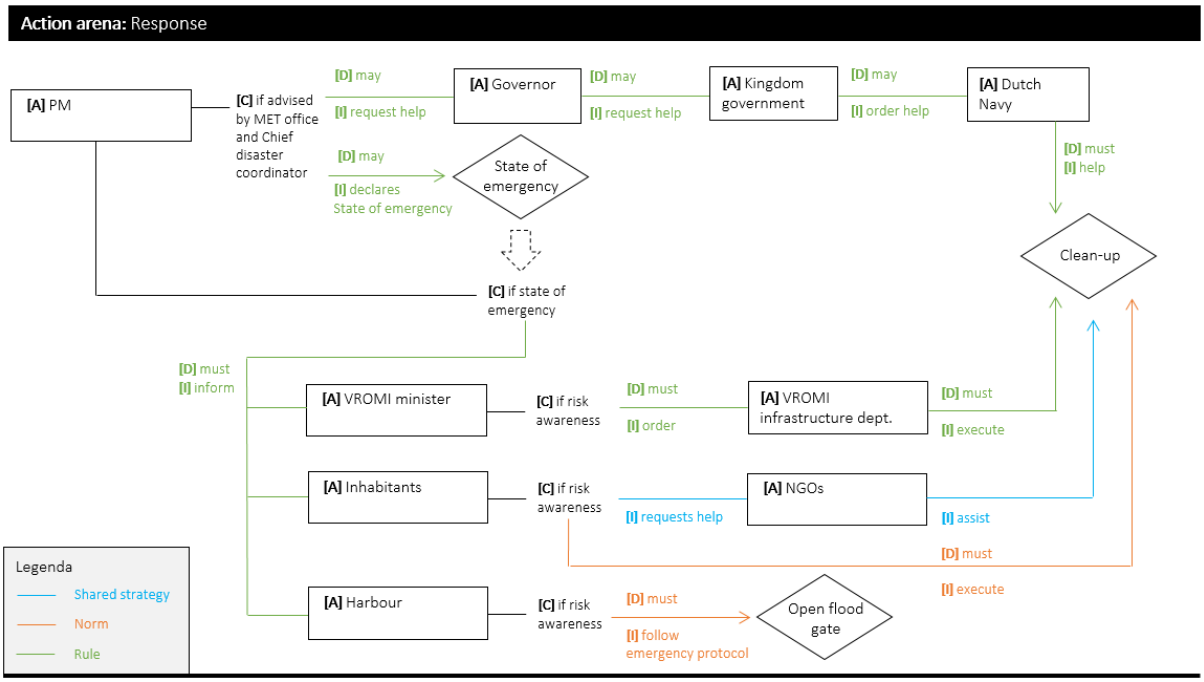


Fig 4.3: An example of an Institutional Network Diagram

STEP 5: Analysing Institutional Network Diagrams

INDs, drawn in step 4, can be analysed by focussing on institutional hierarchy, network metrics and the links between INDs.

Institutional hierarchy

INDs show what different institutional statements guide the actions of a decision maker within an action arena. This network will reveal conflicting statements (step 10 of the IND development process). For example a shared strategy and formal rule may suggest different actions. In such cases, the researcher needs to address hierarchy specifically.

This means that the researcher needs to return to the data set: what specific information is collected on the hierarchy of different institutions in the conflicting situation? If this brings no further understanding, the researcher should return to the data source, directly asking what happens in the situation of conflicting institutions. This understanding of institutional hierarchy may lead to recommendations for better flood risk management.

Institutional network structure

The metrics of network diagrams help understand the effect of network structure on FRM performance. In chapter 2, the concepts of density, centrality and embeddedness were introduced. Table 4.2 shows how the different concepts are calculated from the IND structure. In calculating density and centrality, I follow the calculations defined by Janssen et al. (2006). As indicator for embeddedness, I follow the Galuti and Gargiulo definition (1999) provided in section 2.5. I am interested in understanding whether decision makers activate other makers, or whether their actions lead to outcomes directly. Per attribute the number of links towards other attributes is divided by the total number of links that connect that attribute to other nodes.

Table 4.2: Network metrics and INDs

Network metrics and performance		
Concept		
Connectedness: density	Centrality	Embeddedness
Calculation		
Number of actual links divided by the maximum possible number of links (only including attributes as nodes) (Janssen et al., 2006)	Number of links per attribute, divided by the average number of links (Janssen et al., 2006)	Number of links per attribute (connecting two attributes), divided by the total number of links per attribute (connecting to attributes or outcome nodes)
Range: [0,1] A score of 1 is complete density, a score of 0 is no density at all	Range: [0, ∞] A score above 1 means that the node has a high rank on centrality, a score below 1 means that the node has a low rank on centrality	Range: [0,1] A score of 1 means complete embeddedness, a score of 0 means no embeddedness at all
Link to performance		
No straightforward link between density and performance or resilience of the network. Table 2.4 can be used to analyse the system in focus.	No straightforward link between centrality and performance of the network. Table 2.4 can be used to analyse the system in focus.	Insight in decision making space of attributes; high level of embeddedness implicates smaller decision space and may be more robust to corruption

In section 2.5, the concept of reachability (the number of steps necessary to link nodes) was introduced as well. Reachability may provide insights in hierarchy, if the assumption holds that the more steps a primary attribute has to take to get to a desired outcome, the more likely it would be for a shared strategy to develop that undermines official rules. For this assumption to hold, however, another assumption has to be made: that the primary attribute can oversee the next steps within the institutional network. This assumption cannot be checked based on the available data for the case of St Maarten and is thus not further explored. This would however provide an interesting topic of further research that I will elaborate on further in the conclusion (chapter 7).

Linking INDs

To understand the complexity of the institutional dimension, the links between INDs should be made insightful as well. This can be done in two ways:

- **Link INDs based FRM cycle**

INDs are based on action arenas within the FRM cycle. The FRM cycle can be seen as a sequential series of FRM actions: preparation may be followed by a flood event. Depending on the severity of the flood event, recovery, reconstruction and mitigation takes place. This sequence will help understand the links between INDs.

- **Link INDs based on outcomes**

The outcome of some INDs may serve as input for other INDs. For example, the outcome of one IND might be a budget for flood risk management, whereas this budget serves as an input for an IND that focuses on implementation of FRM measures.

4.2 Institutional Network Analysis (INA) of Flood Risk Management on St Maarten

INA is applied to the case of FRM on St Maarten. In this section, some case-specific additions to section 4.1 are made for INA research steps 1, 2 and 3.

STEP 1: Data collection on St Maarten

Data collection consists of desk research and stakeholder interviews. For both data sources, the method for St Maarten is further explained.

Desk research in St Maarten

For St Maarten, the governmental organization with key formal responsibilities is the Ministry of Public Housing, Spatial Planning, Environment and Infrastructure (VROMI). The documents made available by VROMI marked the starting point for desk research on FRM on St Maarten. The key sources per flood management phase are listed in table 4.3, a list of all reviewed documents can be found in appendix B.

Table 4.3: Overview of key documents in FRM desk research on St Maarten

Key documents desk research FRM on St Maarten	
FRM phase	Sources
Preparation	Reviewing policies VROMI
Response	Reviewing National Disaster Plan
Recovery	Reviewing policies VROMI, yearly reports and ministry plans
Mitigation	Reviewing policies VROMI, yearly reports and ministry plans

Stakeholder interviews in St Maarten

This research builds on interview notes of stakeholder interviews that were conducted by Dr. Fraser (King's College London) within the context of the PEARL RRCA. 27 stakeholders were interviewed to gain an insight in historic risk and root causes. The focus of this set of interviews was on governmental agents and local disaster response experts, but some key private sector actors were interviewed as well (see table 4.4).

Table 4.4: Overview of interviewees (2015)

List of topics guiding desk research	
Governmental agents	Ministry of VROMI (Ministry of Public Housing, Spatial Planning, Environment and Infrastructure), Ministry of Public Health, Ministry of Economic Affairs, Disaster Management team, both Dutch and French side of St Maarten
Experts	Disaster risk consultant, Meteorological Office
Private sector	Hospitality and Trade Association, Harbour holding, Insurers
NGOs	Nature Foundation, Red Cross

Additional interviews

Additionally, I conducted eleven interviews with locals to add the institutions that guide inhabitants' FRM actions. In table 4.5, an overview of the discussed topics is given.

Table 4.5: Overview of topics used in interviews with locals

Semi-structured interviews with locals	
Topic	Related questions
Life history	How long on St Maarten? Family situation? Occupation?
Risk perception	How would you describe flood risk? Increasing/stable/decreasing risk? Why?
Personal action	What measures do you take to prepare for floods? Any structural measures? Why (not)?
Community action	Any action in your neighbourhood? Cooperation on a local scale?
National action	What measures does the government take? What do you think of these measures? Drivers/barriers for action? Do you know about the zoning plans? What do you think of them?

STEP 2 and 3: Data coding and clustering and formalizing institutions

Both the coding and clustering process, and the formalization of institutions require the researcher to condense the available data. An inherent consequence is that the researcher has to make choices on what information to include and exclude and on how to formulate institutional statements using the ADICO syntax.

As this is a highly iterative process, preliminary results were discussed with three researchers, that have worked on the St Maarten case within the PEARL project: Yared Abebe (UNESCO-IHE), Arabella Fraser (King's College Londo), Amineh Ghorbani (TU Delft). If additional information was necessary to understand the data, or if a broader perspective was needed Paul Martens (Head of Disaster Management, St Maarten) was consulted.

4.3 Institutional Network Analysis (INA) and Agent-Based Modelling

INA is a static way of researching institutional complexity. The INDs form a snapshot in time. The IAD framework however, shows that institutions are dynamic and change over time. Agent-Based Modelling addresses system dynamics and can add to INA by providing adding a dynamic component to the research.

Institutions have been integrated in ABM through the MAIA framework developed by Ghorbani (2013). However, within this MAIA framework there is no flow chart included of action arenas. The INDs that are developed in step 4 may provide both the basis of the storyline of the ABM and the graphic representation of the storyline.

"The art of modelling is to incorporate the essential details, no more" (Levin et al., 2012). In other words, modelling always poses a trade-off between modelling complexity and keeping the model as simple as possible (Janssen & Ostrom, 2006). The connections between institutions are currently not included in MAIA. This can be added by making use of INA. INDs provide the necessary information on nested or linked institutions and encourages further research on situations of institutional conflict, to determine hierarchy.

Therefore, adding INA concepts to MAIA may contribute to developing representative ABMs of complex adaptive human-flood systems. Table 4.6 shows how INA and MAIA structures are linked. By following these links between INA and the MAIA structure, a conceptual model can be developed focussing on the institutional dimension. This means that some concepts – for example the biophysical world – may be simplified to the minimum representation that is necessary to model the institutional dimension, based on the INA research process.

Table 4.6: MAIA structures and building a conceptual model based on INA

MAIA structures and INA		
Structure	**Building a conceptual model based on INA**	**INA research step**
Collective	Define actors and their characteristics based on attributes in INDs	Step 4
Constitutional	Define roles based on stakeholder narratives Define institutions in ADICO-syntax Define interdependencies based on INDs	Step 2 Step 3 Step 4
Physical	Define physical structure, based on actor characteristics and (undesired) outcomes of INDs	Step 4
Operational	Define action arenas based on INDs Define sequence of INDs based on links between INDs	Step 4 Step 5
Evaluative	Narratives help formulate experiments that can be run with the ABM	Step 2

5

Institutional Network Analysis St Maarten

"The recent change in the institutional structure of the island, brings about new challenges for the national government and it has created a governance gap."

In this chapter, the Institutional Network Analysis (INA) methodology is applied to the case of St Maarten. As St Maarten merely functions as an example of how INA can be applied, this section does not include the entire research. I will present two INDs in detail. For those readers that are specifically interested in FRM on St Maarten, please refer to appendix C, where the full INA is given. I start this chapter with FRM practices on St Maarten (section 5.1), including FRM challenges and key insights from stakeholder narratives. In section 5.2 I then turn to the two INDs mentioned above and in section 5.3 I draw conclusions on the INDs, according to INA research step 5. This chapter concludes by exploring links between INA and ABM in section 5.4.

5.1 Flood Risk Management practices on St Maarten

In this section, FRM challenges on St Maarten are described from four dimensions: climate, technology, society and institutions. Moreover, four general conclusions, drawn from the stakeholder narratives are introduced.

5.1.1 Flood Risk Management challenges

St Maarten's challenges in terms of FRM are explained from an climatic, technological, socio-cultural and institutional perspective.

Climatic challenges

St Maarten is located in the hurricane belt, which poses significant flood threats (Department of Statistics, 2015). In the Caribbean, floods are the most frequent natural disasters. These floods are mostly caused by heavy rainfall during tropical storms and hurricanes. Hurricanes hit the island every four to five years on average. Cyclones strike St Maarten yearly. The 1995 hurricane Luis had a devastating effect on the island. 60% of the housing and infrastructure were destroyed. Although the warning system has improved since previous flood events, increasing flood risk remains a challenge for the island (Sommers, 2015).

Technological challenges

On the island of St Maarten, densely populated centres are located next to the coast line and the majority of the touristic activities take place on or around the beaches, which poses challenges to safe construction. One of the key issues in FRM on St Maarten is the lack of sufficient storm-water infrastructure: many roads lack a drainage system (Sommers, 2015). Moreover, according to the UNDP Millennium Development Goals (2011), measures to prepare for hurricanes are not sufficient.

In the past, structural FRM measures were seen as the primary solution. However, Dutch engineering practices were not always translated correctly to local conditions. Under Dutch rule, concrete drainage systems have been installed for example to mitigate flood risk. In practice however, these gutters have only increased risk: upstream, on hillsides, these gutters merely sent precipitation down faster. This means that downhill local precipitation and precipitation from other areas combine into a large quantity of storm water. This increases flash flood hazards (interviews VROMI officials). FRM is still mainly reactive: previous flood events guide action (A. Fraser, personal communication, June 30, 2016).

Socio-economic challenges

St Maarten has a mono-industrial economy, where tourism is the most important source of income. Being dependent on tourism, brings about two main challenges. First of all, decision-making may focus

more on the benefits of the touristic sector, than on the needs of permanent residents. Secondly, the economy is highly affected in case of a disaster, as the amount of visiting tourists will decrease. After hurricane Luis, the tourist sector took two years to recover (Mathew, 2013). Because of the tourist boom since the 1960s, the focus has been on economic development through construction activity. This has rooted a strong belief amongst St Maarten's population that free property development is a right that the government should not mess with through construction restrictions in for example land use planning (stakeholder interviews).

In 2012, INED studied the impacts of demographic and migration trends on cohesion. Two important risks for the island community were identified: the potential lack of social cohesion and the dependence on one industry. According to Transparency International (2015), one third of the population moves every 3 to 5 years.

Institutional challenges

Resources can be highly limited in a small island state like St Maarten. Budget, expertise and knowledge may be lacking for adequate flood risk response (IPCC, 2012). VROMI is responsible for implementing structural flood risk measures, however, past decisions have not always been based on a sufficient knowledge base. An example of this was given in the paragraph on technological challenges, where I described how engineering choices were not adjusted to local conditions.

The recent change in the institutional structure of the island, brings about new challenges for the national government and it has created a governance gap (A. Fraser, personal communication, June 30, 2016). While under Dutch rule, infrastructure projects were mainly funded by the Netherlands or the EU. Ever since 2010, the island government has been responsible for the finance of infrastructure projects. St Maarten has difficulties in acquiring budget and budget allocation. In addition to that, knowledge was also often brought in from the Netherlands before 2010 (interviews VROMI officials).

Moreover, the political culture is based on personal relations, rather than party ideologies. The high mobility, combined with the unstable political environment have caused an underdeveloped civil society (Transparency International, 2015). The lack of social cohesion on the island poses a serious threat to good governance in general. Local community councils are led by community officers, but these community councils are politicized, hereby undermining trust of local communities in these officers (interviews locals).

5.1.2 Conclusions on stakeholder narratives

As part of the richness of the obtained data is not easily translated into the ADICO grammar, stakeholder narratives were recorded. Four conclusions based on these narratives are highlighted in this section.

1. Dominance of national level solutions

Government level action is seen as the preferred level of action by most stakeholders. There is a trust paradox: on the one hand, the government is not trusted due to corruption and short-sightedness, but on the other hand the government is seen as the relevant actor. One would expect more community initiatives to protect private property, but on a household level individual strategies prevail over shared strategies.

It should of course be noted here that the island itself is small. A smaller governmental unit – whether it be provinces, regions or municipalities – is not in action on the island. Local community councils are not formally structured, nor structurally used by the government. At the same time these community councils are highly politicized, limiting trust from inhabitants even further.

2. Budget is a defining variable

All interviewees, both governmental agents, experts, business owners and locals perceive floods as a high risk. Many businesses and households are ensured against "Acts of God". Structural measures to tackle flood risk are expensive. There has been a budgeting issue on the national level ever since independence in 2010. Infrastructure projects are no longer funded by the Netherlands or the European Union and national budgets are limited. On a household level, budget may be the tilting factor as well. As property owners are fully responsible for the construction of structural measures, personal budgets limit the action space of these decision makers.

3. Structural measures vs. land use planning

In interviews with locals, the construction of gutters along roads was often mentioned as an example of the government taking action on flood risk. Although this infrastructure development is one of the most important areas of improvement in terms of flood risk on the island, the focus on land use planning was minor.

Strict land use planning in flood prone zones and on hillsides, that are critical for the retention of water is an important line of action in reducing vulnerability to floods. Based on UNESCO-IHE research and input, the zoning plans were developed. There is variable awareness amongst locals on these zoning plans. Most of the interviewed locals were unaware of these plan. Many stakeholders that did know about zoning plans mention the political difficulties in implementing them as formal policy or law.

4. Small island dynamics: informal over formal institutions

Multiple roles

Several actors have multiple roles in the public arena of St Maarten, due to its small size. Paul Martens for example, is both Chief Disaster Management and head of the local Red Cross branch. In this case, these two roles may add to a more integrated disaster response on the island.

However, the lack of sanctioning on land use policy violations might rise from the various roles that governmental decision makers may take. Politicians that decide over land use planning may be land owners at the same time. Restricted construction may personally affect them and this could lead to a mix of personal interests and interests of the population. St Maarten has a strong land ownership culture: there is a strong belief that a land owner has the right to develop its own land in his own interests.

Importance of personal relations

The political and social system on St Maarten are highly based on personal relations (Transparency International, 2015). The power structure are in the hands of a few families that have been living on the island for a long time. Groups of (illegal) immigrants mostly stay on St Maarten for the short term, as they view the island as a stepping stone towards the Bahamas or the USA. Combined with an excluding local community, these groups of immigrants tend to stick together, leading to a fractured social landscape. Political and social dynamics on St Maarten are for an important part shaped by who knows who. These tight networks lead to several forms of corruption.

Interviewees tell a different story than the formal rules and regulations, especially in terms of property development. Whereas the hillside policy should prohibit construction on hillsides, interviewees claim that there still is a lot of building activity and that it depends directly on who you know. VROMI interviewees state the same, when they explain that land owners start developing even without a permit. Some decision makers make a deliberate choice not to follow the formal framework of rules and regulations. This happens to an extent where it actually becomes a shared strategy not to comply with formal institutions.

5.2 Flood Risk Management institutions on St Maarten

For all four stages of the FRM cycle, institutions are described and formalized using ADICO syntax. A total of 36 rules, 9 norms and 30 shared strategies have been identified. All statements are numbered, and coded with a letter R (for rule), N (for norm) or S (for shared strategy). These institutional statements have been clustered into nine different action arenas, corresponding to the four stages of the FRM cycle (one IND for response; two INDs for recovery; five INDs for mitigation and one IND for preparation).

The default setting under Condition [C] is in all cases at all times, following Crawford & Ostrom (1995). The mentioning of actors is marked **bold** in the ADICO tables, to give a first insight in interdependencies. Many rules have no formal sanctions, but as they are formal responsibilities, representing them as norms would be misleading. For privacy reasons, I never directly refer to interviewees, but rather to the organization an individual represents or I refer to an interviewee as a local.

In this section, I will elaborate on two INDs: the IND for response and one of the INDs for mitigation, focusing on private property development and land use planning. For these two INDs, the institutions are explained based on the desk research and stakeholder interviews, formalized using the ADICO syntax and the INDs are drawn and discussed. The complete analysis of FRM on St Maarten can be found in appendix C.

5.2.1 Institutions in flood risk response

The first example concerns the institutions that guide immediate response to flood events on St Maarten.

National Disaster Management Plan

After hurricane Luis, St Maarten developed a National Disaster Plan (NDP) (Martens, 2015). This NDP allocates responsibilities to governmental and non-governmental agents. Within the NDP ten Emergency Support Functions (ESFs) and their responsibilities are defined, ranging from shelter and communication to clean-up activities. The supreme command lies with the prime minister (PM). Only he or she can call a disaster situation. Apart from the Ministries of Finance, Justice and Education, all seven St Maarten ministries have a role in the NDP. It should be noted that this plan is currently being renewed (interview VROMI).

The public-private cooperation that is formalized in the NDP creates institutional resilience on the island. A historic lack of public resources on the small island, has led to the involvement of the private sector in disaster management. An example is that the Red Cross opens up emergency shelter, before the Community Development Department takes over formal responsibility (Fraser, 2016).

Dutch Navy help

St Maarten became independent from the Netherlands in 2010, but the country still is part of the Kingdom of the Netherlands and thus falls under the Dutch crown. The four countries within the Kingdom cooperate on military activities. For St Maarten, this means that the governor can formally request Dutch military aid for national security reasons or humanitarian projects. During the hurricane season, a navy unit is stationed on the island. This unit provides humanitarian aid in disaster situations, when formally commanded by the lieutenant admiral, the highest rank within the Dutch navy. This Dutch navy help includes clean-up activities.

Infrastructure clean-*up*

I consider immediate clean-up, for example by making roads passable, to be part of the response phase. Hereby, I follow the more extensive disaster management cycle that is used by the European

research program FLOODsite, that states that service restoration can be a priority in the response phase (Lumbroso, 2007).

Immediate cleanup of public infrastructure may be the responsibility of VROMI, but inhabitants usually clean private roads. They may call in help through community councils or NGOs. This process is further explained under recovery. The institutions of the response action arena are formalized in table 5.1. Risk awareness in N1, N2 and S1 does not necessarily relate to flood risk awareness, but to inhabitants and/or the harbour organization being aware of the risks of not cleaning up. As most properties use septic tanks, the risk of debris in open air includes an increased risk for public health (Sommers, 2015).

Table 5.1 gives an overview of the 8 rules, 2 norms and 2 shared strategies that have been identified in flood risk response on St Maarten.

Table 5.1: Identified institutions in disaster response

No.	Name	A	D	I	C	O
			Rule			
R1	National clean-up	VROMI minister	must	order **infrastructure dept.** to clean-up	if necessary after storm event	
R2	VROMI clean-up	VROMI infrastructure dept.	must	execute clean-up activities	if requested by **VROMI minister**	
R3	State of emergency	PM only	may	declare state of emergency to raise risk awareness	if informed by **MET office** and **Chief disaster coordinator**	
R4	Emergency communication	PM	must	inform **inhabitants**	after declaring emergency	
R5	PM request Dutch Navy help	PM	may	request governor to request **Dutch Navy** help	if necessary after storm event	
R6	Governor request Dutch Navy help	Governor	may	request **Kingdom government** to order **Dutch Navy** help	if requested by **PM**	
R7	Government Kingdom orders Dutch Navy help	Kingdom government	may	order **Dutch Navy** to assist in clean-up	if requested by **Governor**	
R8	Dutch Navy help	Dutch Navy	must	help clean-up in a disaster situation	if ordered by **Kingdom government**	
			Norm			
N1	Private clean-up	Inhabitants	must	clean-up their own property	if risk aware and after disaster event	
N2	Harbour response	Harbour	must	follow emergency protocol to open flood gates	If risk awareness	
			Shared strategy			
S1	Request community help	Inhabitants		request help from **NGOs** with clean-up	if risk aware and after disaster event	
S2	Community clean-up	NGOs		assist in clean-up	if requested by **inhabitants**	

The institutions in table 5.1 form the basis of the Institutional Network Diagram depicted in figure 5.1 (note: this is the same IND that has been used as an example of drawing an IND in section 4.1 to explain the methodology). All institutions from table 5.1 are represented in the IND in figure 5.1.

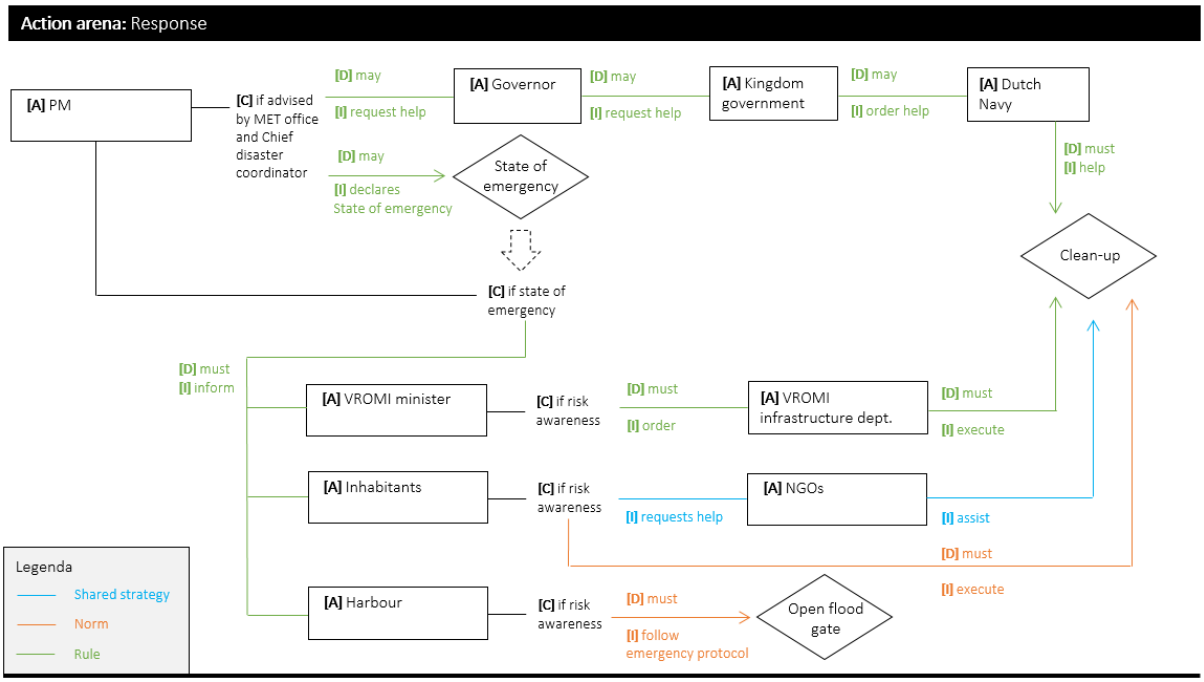


Fig. 5.1: IND for flood risk response

For the flood risk response IND, there is only one primary attribute: the prime minister (PM). All other eight attributes are activated through the institutional statement R3: only the PM can declare a disaster situation. Within this IND, there are no situations of institutional conflict, so institutional hierarchy does not have to be addressed here.

5.2.2 Institutions in flood risk mitigation: property development and land use planning

The second example of concerns land use planning and property development, as part of the mitigation phase of FRM on St Maarten.

Land use planning

On St Maarten, several policies guide land use planning. Table 5.2 gives an overview of these policies and their link to flood risk response. These policies range in status from laws (can only be issued by the King of the Netherlands) and island ordinances (highest regulation the St Maarten government can issue independently) to guidelines (not legally binding).

Due to the differences in formal status of these land use policies, not all policies lead to formal sanctions. However, not complying to the building ordinance and the building code (its pursuant) leads to three types of sanctions. First of all, the permit may not be issued. Secondly, the land owner can by fined by a maximum of 300 ANG if the guidelines are not properly followed. The third and most severe measure, is that a land owner can be issued by the minister of VROMI to demolish the constructed building on its own costs (VROMI, 2010a, 2010b)

Table 5.2: Land use policies and their links to flood risk response

Formal land use rules and regulations			
Policy	Formal status	Summary of the policy	Link to flood risk management
Building ordinance	Island ordinance	The building ordinance describes the rules that land owners should follow when they construct or rebuild properties. These rules include guidelines for building in relation to public roads, construction of floors, walls and roofs, and discharge of faeces.	From a flood risk perspective, important rules include that (1) all ground floor levels should be elevated 0.2m, and (2) that land owners are responsible for constructing and maintaining a sewage system.

Building code	Island ordinance	The building code further specifies the guidelines introduced in the building ordinance. In addition to the building ordinance, the building code describes the permit procedure in more detail. Permit applications should be processed within a month and permits may be withdrawn if there is no building activity one year after issuance, or if the land owner deviates from the original plans.	From a flood risk perspective, key takeaways are the procedure: how permits are treated and what rules guide inspection.
Beach policy (1994)	Island ordinance	The beach policy (VROMI, 1994) protects St Maarten's beaches against human influences. Beaches within 50 metres from the shore line should be usable for recreation by everyone. This means that within the 50 metre zone no development of buildings with a physical negative influence on recreation is allowed.	Properties on beaches are more prone to flood risk, so a building free zone increases resilience of the built environment.
Hillside policy	Island ordinance	The hillside policy (VROMI, n.d.) was installed to conserve, protect, and restore the green hillsides of St Maarten. Incentives to install this policy stem from an economic perspective as well: the green hillsides attract tourists to the island and are the main pillar of St Maarten's economy. All areas above 50 metres altitude are seen as hillsides. Above 200 metres altitude and in dedicated nature parks building is prohibited. On hillsides, only residential development is allowed, within restricting guidelines. These guidelines include maximum lot size, the maximum percentage of building allowed per lot, and measures to include the prevention of erosion.	Properties on hillsides increase flood risk as they (1) may cause erosion and landslides, because properties replace the natural Caribbean forest ecosystem, and (2) they may be located in natural gutters, hereby relocating water flows.
Zoning plan *	Guideline	The zoning plan is a result of the 1993 *'Eilandsverordening Ruimtelijke Ontwikkelingsplanning'* and was a response to a Dutch law that required land use plans for all municipalities within the Kingdom. The zoning plan function as a guideline in permit procedures. The zoning plan was developed through a process of participation: in all island regions, the draft plans were explained and all interested inhabitants could express their opinions. With a government change the participatory process seems intermitted. In appendix D, a map of the zoning plan is included.	From a flood risk perspective, the most important characteristics of the zoning plan are (1) the protection of nature and (2) the inclusion of additional building requirements for flood prone areas. For flood prone areas, building requirements in the zoning plan include an elevation of ground floor level with 0.5, 1.0 or 1.5m.

* The zoning plan is part of the National Development Plan (NDP) and has no formal status yet. The status of the NDP is unclear, since the first quarter of 2015 no quarterly NDP report has been published by the St Maarten government.

Construction permits and inspection

Properties should be constructed following the beach and hillside policy and the building ordinance and building code. However, in the stakeholder interviews it became apparent that many land owners start building without a permit, even in areas where property development is prohibited by the beach policy or the hillside policy. Interviewees says that the inspection department rarely orders sanctions, yet the specific conditions under which they do/do not order sanctions are unknown.

According to the VROMI 2015 year report, a total of 286 building inspections were conducted, of which 229 were completed within that year. Of all cases in 2015, about 62% of the inspections followed a permit request, 38% of the inspections were performed after the inspection department received a warning, and about 6% were routine inspections.

Table 5.3 lists the 5 rules and 6 shared strategies that have been identified in flood risk mitigation, linked to land use planning on St Maarten. It should be noted that this action arena only concerns property development, inspection is discussed in another IND (please refer to appendix C).

Table 5.3: Institutions in mitigation I: private property development and land use planning

No.	Name	A	D	I	C	O
				Rule		
R14	Request permit	Property owner	must	request construction permit through **permit dept.**	*Default*	Or else: permit is not issued; or fine of maximum 300 ANG
R15	Issue permit	VROMI permit dept.	must	issue permit	if building ordinance is followed	
R16	Propose sanction	VROMI permit dept.	must	propose sanction	if request for non-designated area (areas B, C, D, GD, K, M, R-JH, R-VB, R-DR, W)*; or if building ordinance is not followed	
R17	No permit	VROMI minister	must not	issue permit	if correct sanction proposed by **VROMI permit dept.**	
R18	Order fine	VROMI minister	must	order fine	if correct sanction proposed by **VROMI permit dept.**	
				Shared strategy		
S13	Illegal construction	Property owner		constructs property	without permit and/or in non-designated areas	
S14	No report permit dept.	VROMI permit dept.		does not report case	if unaware of construction activity; or if unaware of risk **	
S15	No sanction VROMI minister	VROMI minister		does not order sanction	if unaware of risk **	
S16	Political priority (minister)	VROMI minister		is not supportive of strict land use policy	if he/she is landowner at the same time	
S17	Political priority (governmental agents)	Government agents		is not supportive of strict land use policy	if he/she is landowner at the same time	
S18	Land ownership	Inhabitants		press for free construction	if he/she is landowner	

* These areas are based on the zoning plan within the NDP. In appendix D the zoning map is included.
** For statement S14 and S15 the condition reads "if unaware of risk". Here, the effect that construction activities pose on vulnerability (for example, building in natural gutters) is meant.

The shared strategies S16, S17 and S18 are coloured blue, as it was difficult to incorporate them into the IND (figure 5.2). These institutional statements concern cultural values, rather than tangible outcomes. This shortcoming of INDs to capture the cultural reality is partly tackled by using these statements as input for experiments within an ABM. I will return to this point in the discussion section (Chapter 6).

In the IND for private property development, the property owner is the only primary attribute. The VROMI permit department and the VROMI minister are the other attributes within this action arena. Three situations of institutional conflict can be identified (black stars in figure 5.2). To understand what happens in these situations of conflicting institutions, we have to go back to the data collected. In section 5.3.1 institutional hierarchy for all FRM INDs for the case study is discussed.

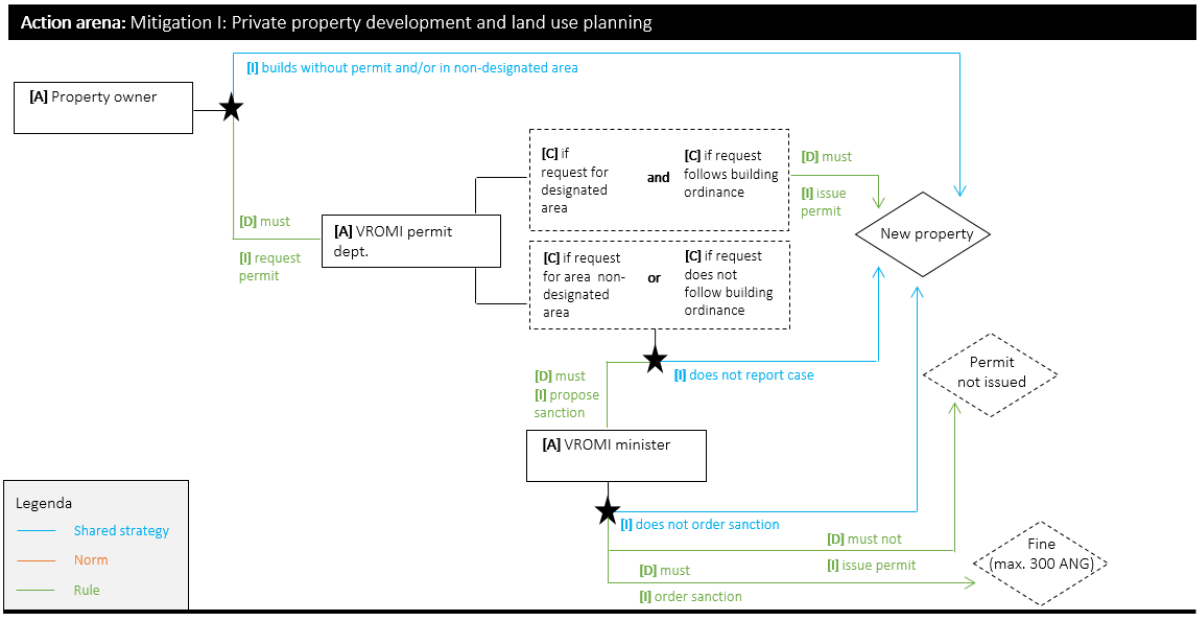


Fig. 5.2: IND for flood risk mitigation: private property development and land use planning

5.3 Analysing Institutional Network Diagrams for St Maarten

The previous section zoomed in on two of the nine action arenas that were identified and studied for the case of St Maarten. In this section, the fifth research step of INA is performed. I will first look into situations of institutional conflict to address hierarchy, then I will turn to the IND metrics to gain a better understanding of the strengths and weaknesses of the institutional networks guiding FRM in St Maarten and I will conclude this analysis by finding connections between the different INDs to get a better understanding of how the whole FRM cycle is linked.

5.3.1 Institutional conflict and hierarchy within FRM on St Maarten

Within the nine INDs that make up the FRM cycle on St Maarten, a total of seven situations of directly conflicting institutions can be identified. The INDs provide a clear graphical insight for the researcher when a further understanding of the hierarchy between institutions is necessary. In this section, these seven situations will be discussed by returning to the data set and, if necessary, the data sources. In table 5.4 a further analysis of these conflicting institutions is given.

Table 5.4: Conflicting institutions in FRM on St Maarten, in blue the institutional statement that rank higher in the institutional hierarchy

IND	Institutions	Further analysis
Recovery I: reconstruction	**Rule**: Minister VROMI must choose contractor based on tender, if damage to infra/public property **Shared strategy**: Minister VROMI chooses contractor based on personal relations, if damage to infra/public property	When returning to data, interviewees show different insights: • One interviewee (NGO) states that corruption is common practice and tenders are often more informal than formal. • One interviewee (Economic Affairs) states that not following tender procedures both saves time and money, since prices rise fast on a highly damaged island with limited number of constructors. When returned to the data sources, a VROMI employee was asked for more insight. He stated that the requirement of all projects above 5,000 ANG provides a buffer for corruption amongst government agents. The minister himself has to report finances back to the governor and the CFT (financial authority), which builds in a quite successful buffer against corruption. Therefore, it is assumed that tenders are held in most cases, and that personal relations may be followed in extreme disaster situations.

Mitigation I: Private property development and land use planning	**Rule**: Property owner must request a permit at VROMI permit dept. **Shared strategies**: Property owner builds without permit and/or in non-designated area	When returning to data, many locals and NGO workers claim that there is little to no inspection and that building without permits is almost a norm. Even in non-designated areas (hillside, beaches) locals state that new properties are being developed. Moreover, there are interviewees who mention that a permit may also be bought after construction. Therefore, it is assumed that building without a permit is a strategy that is followed by a larger share of the property developers than following the formal guideline of requesting a permit.
	Rule: VROMI permit dept. must propose sanction to VROMI minister **Shared strategy**: VROMI permit dept. does not report case.	In line with the previous situation of conflicting institutions, follow-up when the permit procedure is violated is not common. In fact, interviewees mention that VROMI has only pursued one court case against a private developer who built in a natural gutter. This private developer claims that he did so, as illegal development was already there. Locals mention this issue as well: "If you know people in the right places, you can build anywhere on the island." Therefore, it is assumed that sanctioning mechanisms stemming from the permit department are weak and maintain a situation where permits are retrieved after construction.
	Rule: VROMI minister must order sanction: permit not issued **or** fine of max. 300 ANG. **Shared strategy**: VROMI minister does not order sanction	Formally, the VROMI minister has to approve sanctions before they can be executed. This means that there is another 'step' where a permit report can be lost. Interviewees mention that this step is merely a formality. Therefore, it is assumed that the minister does follow the proposed sanctions by its permit office.
Mitigation II: Land use planning and inspection	**Rule**: VROMI inspection dept. must propose sanction to VROMI minister. **Shared strategy**: VROMI inspection dept. does not report case.	Random inspection is rare, in most cases either the permit department or a complaint by a local starts an inspection procedure. Interviewees claim that there is too little incentive for inspection to be proactive, there is only an internal incentive program and there are no other performance indicators. Depending on the circumstances, the inspection department suggests a sanction. These sanctions range from a fine or a revoked permit to the ordered demolishing of a new property. Of the latter, no interviewee could mention an example. As with the permit department, the effectiveness of the inspection department is low. Therefore, it is assumed that sanctioning mechanisms stemming from the inspection department are weak and maintain a situation where inspection has little influence on property development on the island.
	Rules: VROMI minister must order sanction: permit revoked **or** fine of max. 300 ANG or demolishing **Shared strategy**: VROMI minister does not order sanction	As with sanctions proposed by the permit department, the minister has to formally effectuate sanctions proposed by the inspection. Again, it is assumed that the minister does follow the proposed sanctions by the inspection department. *Here, two situations of conflict are combined, as the only difference between the situations is the type of sanction that is proposed.*

5.3.2 Institutional network metrics within FRM on St Maarten

In this section, three network metrics are calculated for FRM on St Maarten: density, centrality and embeddedness.

Density

Network density can be calculated from network structure, by dividing the number of actual links per node by the total number of links possible in a network. As there are two types of nodes within INDs – attributes and outcomes – density is calculated in two ways (1) using all actual links (i.e., attribute-attribute and attribute-outcome links), and (2) only using attribute-attribute links. As we try to

understand how institutions are linked, understanding density based on the attributes may provide more useful insights than including the outcomes as well, since these outcomes are not linked. In appendix E a calculation table can be found.

Based on 22 attributes and while only taking attributes into account (calculation method 2), the density is 0.129 (on a 0-1 scale), which is a very low density. The average density per IND, calculated by taking the average of all nine INDs is 0.293, based on attributes only.

Advantages of a low density are that this allows for a diversity in flood risk management practices, but a downside of low density is the limited spread of information. In a more dense network system, learning and information exchange are enhanced by the network structure. Although some INDs within mitigation (I, II and III) show medium to high density, the density of mitigation as a whole is low: only 0.131. This shows that the mitigation action arenas are quite specialized and have little overlap.

Centrality

Another interesting insight in network structure can be retrieved by focussing on centrality. As explained in the methodology section, I will follow the less mathematical approach of Janssen et al. (2006) and focus on high- versus low-ranked notes. Centrality was calculated by dividing the number of links per attribute by the average number of links. Outcome nodes are not included in this calculation. The centrality rank is calculated for all INDs combined, as I am interested to find out who the central decision makers are in the whole FRM cycle. In appendix E a calculation table can be found.

Six out of twenty-two attributes are high-ranked nodes, with a centrality that is higher than average. These six nodes include both property owners and inhabitants, two actor groups that may show overlap. Moreover, the VROMI minister, VROMI infrastructure department, the parliament and the governor are high-ranked attributes in terms of centrality.

With six out of twenty-two attributes ranking high on centrality, about 27% of the attributes has a high centrality. We could therefore argue that the system is characterized by low centrality rather than high centrality. From a centrality perspective, networks with low centrality are more robust to the removal of one node, but they can be more inefficient as clear accountability is lacking. The VROMI minister has an extremely high level of centrality: over five times that of the average attribute in the FRM system. The advantages of high centrality are efficient coordination and clarity on responsibilities. However, high centrality also means that the network is vulnerable to the control of one person: the decisions the VROMI minister makes, define FRM on St Maarten to a high extent.

Embeddedness

As some actors make decisions that activate institutions that guide further actor behaviour, and some attributes make decisions that lead directly to outcomes or sanctions, embeddedness is calculated. This indicator of institutional embeddedness is retrieved by dividing the number of links that connect an attribute with another attribute by the total number of links (see appendix E for a calculation table). Attributes with an embeddedness score of 0 are not nested between other institutional actors, their actions directly lead to outcomes. Attributes with the maximum score of 1 on embeddedness have no direct link to outcomes, thus their actions should always be followed up by other attributes to lead to outcomes.

There are five actors that rank low on centrality, and that are completely nested within the institutional network: the VROMI new projects and policy departments, the French side of St Maarten, the Minister of Finance and the financial authority CFT. The department of communication is the only attribute with an embeddedness of 0, meaning that all its links directly lead to an outcome. Insurers and the harbour rank low on embeddedness as well, indicating that their actions regarding flood risk

management can be seen more independently from the intertwined FRM approach of governmental agents and inhabitants and property owners.

Average embeddedness is 0.62, corresponding to a high level of embeddedness. This implicates that on average the decision making space of actors within the FRM system on St Maarten is small, which would indicate robustness to corruption. However, this does not seem to correspond with our insights on the socio-cultural reality on the island. High embeddedness can be an indicator for redundancy in institutions as well, which requires a critical review of involved decision makers. Should the VROMI minister for example have a final say in all FRM-related VROMI activities?

5.3.3 Linking Institutional Network Diagrams for FRM on St Maarten

The nine different INDs are based on nine different action arenas, divided over the four stages of flood risk management. It would be interesting, to understand how these INDs are connected. Two approaches were taken: linking INDs based on the flood risk management cycle and linking INDS based on outcomes.

Linking INDs based on the Flood Risk Management cycle

While identifying institutions, the flood risk management cycle was taken as starting point. This means that the INDs that were constructed for the different FRM phases are subsequent steps of this cycle. Therefore, the INDs can be linked chronically, which is depicted in figure 5.3 below, where the INDs are treated as black boxes.

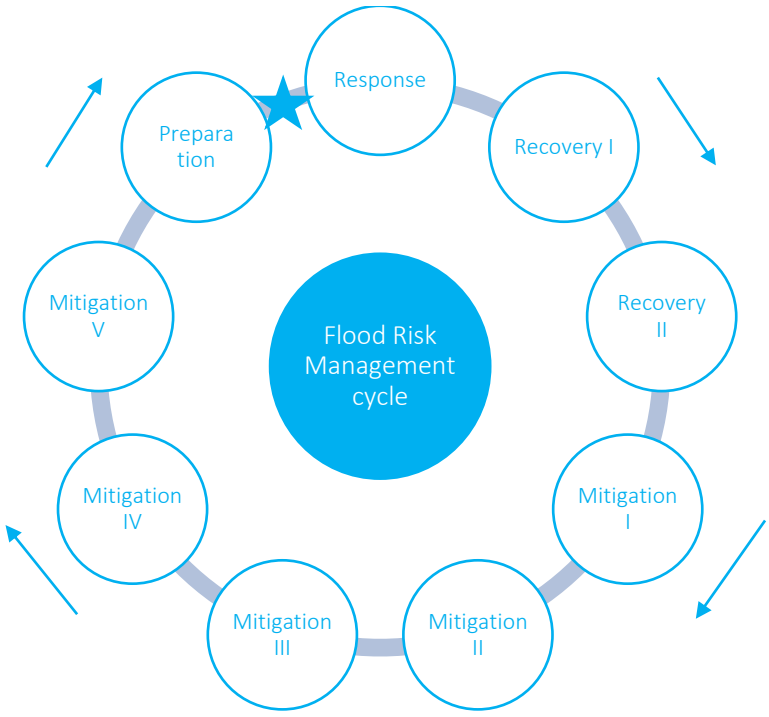


Fig 5.3: Link between INDs, based on FRM cycle, the blue star represents a flood event. The arrows indicate the chronological order

All INDs are activated in case there is a big flood event, that causes damage. However, in years without a flood event that leads to a disaster situation, that is acknowledged by the PM, the following institutions still guide behaviour (table 5.5):

Table 5.5: Institutions that hold if there is no flood in present year

FRM phase			
Preparation	Response	Recovery	Mitigation
R21, N8, S18-S20	-	S4, S5 (both based on previous flood event)	I: R8-R18, S9-S14 II: R19-R23, N5, S15, S16 III: R24-R26 IV: R27, S17 (less priority) V: R20, N7, S19-S23 (less priority)

These institutions include the preparation phase, the institutions regarding inhabitants vocalizing concerns and all institutions that guide the construction of new properties, formalizing VROMI policy, national FRM budget and FRM measure implementation. However, if there is no flood event in the present year or even for a couple of years, this will impact the willingness to act on flood risk management. This would introduce the dynamics of institutional change, which is not within scope for this research. It may be possible to include this in an ABM, please see section 5.3.4 and appendix F for an elaboration of this topic.

Linking INDs based on outcomes

For all INDs, the outcome(s) of the action arena are represented in diamonds or diamonds with a dotted line (sanctions). By focussing on these outcomes and treating the INDs as black boxes, several interesting links between INDs can be made. In figure 5.4 and 5.5, these links are visualized. Based on clean-up activities, the preparation and response INDs can be linked. Focussing on risk awareness, the preparation, response and recovery I INDs can be linked. These INDs follow each other chronologically as well.

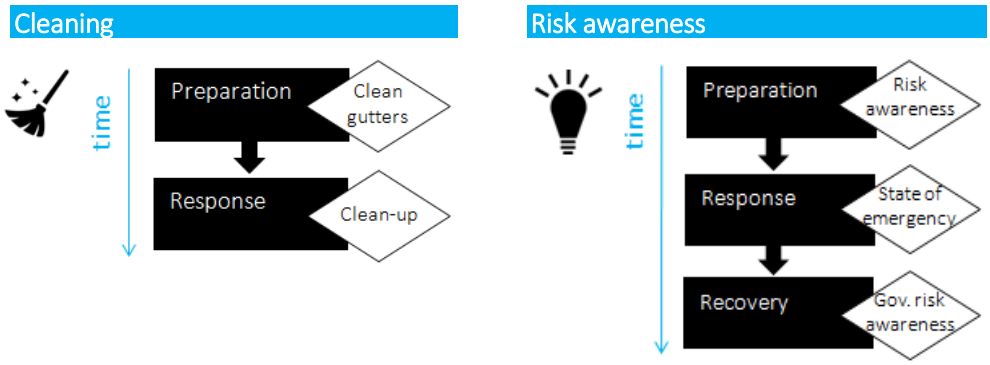


Fig 5.4: Links between INDs based on clean-up activities and risk awareness

In figure 5.5, links are drawn between INDs based on the outcomes 'construction activity' and 'budget'. For both of these outcomes, the links between INDs change if there is a flood event in the present year or not. For construction activity, mitigation I and II – focussing on new property development and potential sanctioning – are linked even if there is no flood event (top right). In case there is a flood event, the institutions that lead to reconstruction in the recovery I IND are added to the figure. This reconstruction might be linked to the installation of FRM measures by property owners in IND mitigation IV (top left). In case there is no flood, there will be no additional budget for FRM measures (bottom right). In case of a flood event, the budget for FRM measures will increase (bottom left).

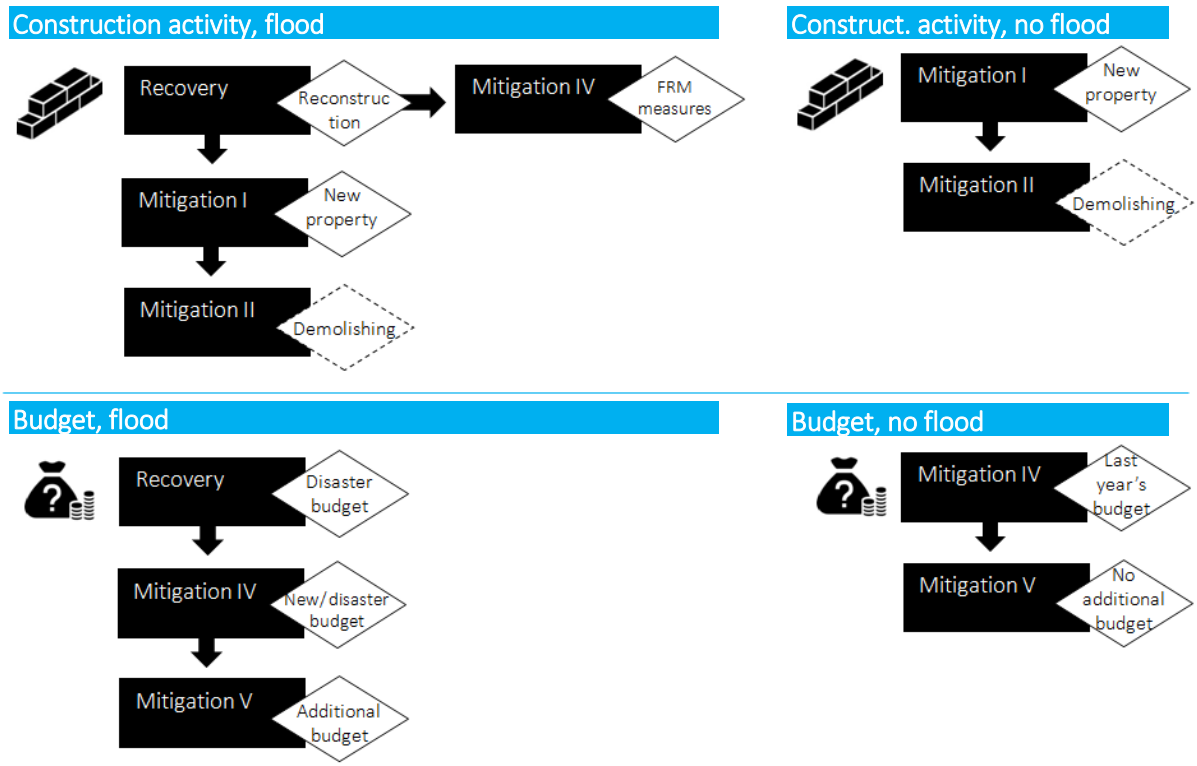


Fig 5.5: Links between INDs based on construction activity and budgeting

5.3.4 Institutional Network Diagrams and better FRM on St Maarten

In this section, I translate the insights from INA to recommendations for better Flood Risk Management on St Maarten. I will do that by addressing the three levels of IND analysis: institutional hierarchy, network metrics and links between INDs.

First, I want to note that the INDs themselves may provide an interesting point of discussion for policy makers on St Maarten. The nine INDs summarize and show overlap between a total of 36 rules, 9 norms and 30 shared strategies and may simplify the conversation, while still addressing the complexity and overlapping responsibilities of different stakeholders.

Addressing institutional conflict

The IND research has identified seven situations of institutional conflict. In three of these situations the shared strategy, that directly conflicts with the formally installed rule, is higher in the institutional hierarchy. These situations form a direct inducement to discuss the causes of the current situation and how St Maarten might be able to move away from these situations. The situations of institutional conflict could hopefully function as a conversation starter.

Addressing institutional network structure

The network structure, addressed through the network metrics of density, centrality and embeddedness provide an interesting insight in the workings of the institutions regarding FRM on St Maarten. For all three metrics, table 5.6 indicates how these metrics should be addressed to develop better FRM practices.

Table 5.6: Better FRM through transforming network metrics

Transforming network metrics for better FRM			
Network metric	INA findings	Implications	Policy implications
Density	Overall density is 0.129, which is very low. The average, calculated by taking the average density of all nine INDs is 0.290	A low density indicates a large diversity in practices on the positive side, but a limited spread of information on the downside	To address the low density from a policy perspective, action should focus on: - Creating structures to share knowledge on FRM - Emphasize links between stakeholders over all four FRM phases - Enable community action, by sharing best practices
Centrality	27% of the attributes have a higher-than-average centrality; system is characterized by low centrality; VROMI minister has a centrality of over 5 times the average	In a network that is characterized by low centrality, with one highly central actor, the network is not robust to the removal (or in this case: change of minister after elections) of the highly central actor. Moreover, low centrality results in inefficiency.	To address low centrality in general, and high centrality of the VROMI minister, policy implications would be: - Need for VROMI minister to share official responsibilities, to increase efficiency in FRM and to limit the implications of a change of minister - Enable self-organizing amongst inhabitants and commercial actors, to overcome inefficiency - Critical assessment on what actions require a strict line of command and what responsibilities may be shared
Embeddedness	The average embeddedness is 0.62, which is high. Five attributes are completely nested within the network structure, only one attribute is not nested at all.	A network that is characterized with high embeddedness, indicates that actors and their actions are linked to a high extent. This could indicate shared responsibilities on the one hand, and inefficiency on the other	To address the high embeddedness, policy implications would include: - Address lines of command: are all decision makers involved in an IND actually necessary? Or can redundant mechanisms be removed? - Embeddedness allows for control and limits the power of single decision makers, this is an important feature for fair FRM

Linking INDs

The links between INDs show how the action arenas follow each other chronically. Table 5.5 shows what institutions still hold in a year without a flood disaster event. They show the danger of shifting focus away from FRM. Moreover, links between INDs help understand the FRM system as a whole.

5.4 Institutional Network Analysis and Agent-Based Modelling

The insights from INA may be useful to develop an ABM that includes institutional complexity, as summarized in table 4.6. The MAIA-meta model can be linked to INA research steps and used to develop an ABM. For FRM on St Maarten, I have developed a conceptual model.

Conceptualizing an ABM requires significant reduction of the richness of the acquired data, but the interdependencies and links between institutions that were researched using INDs can be implemented. The goal is to contribute to ABM by adding interdependencies and connectivity

between institutions to the MAIA meta model. Moreover, the ABM could help include institutional change and hereby represent the institutional dimension better.

The Institutional Network Analysis may contribute to ABM development within the MAIA framework in several ways. First of all, the MAIA framework does not include any flow charts. The INDs can be read as flow charts for the action arena and by using the sequence of INDs that was defined in section 5.3.2, the storyline of the ABM can be defined. Secondly, the ABM can be run to get an understanding of the system level outcomes of individual action, based on the networks of institutions that guide actors. Third of all, conclusions on the stakeholder narratives (section 5.1.2) can serve as a basis to define valuable experiments in the evaluative structure.

The conceptual ABM can be found in appendix F. Here, I will include a table that summarizes the modelling decisions I made, based on the INA. Moreover, I suggest experiments based on the stakeholder narratives and elaborate on how ABM can enrich INA in return.

5.4.1 Linking Institutional Network Analysis to MAIA structures

In table 5.7 the key findings in translating the insights from the INA research process into the five MAIA layers are summarized.

Table 5.7: Translating INA insights into MAIA structures for FRM on St Maarten

MAIA structures and INA		
Structure	Building a conceptual model based on INA	INA research step
Collective	Define actors and their characteristics based on attributes in INDs	Step 4
	22 attributes were identified in FRM on St Maarten, which is a lot to model within an ABM. However, based on network metrics, the most crucial attributes in terms of centrality and density can be identified and included as actor types within an ABM. For FRM, the three defined actor types include inhabitants, commercial actors (harbour, insurers), and the VROMI minister.	
Constitutional	Define roles based on stakeholder narratives	Step 2
	Key properties that define the different roles of actors within FRM on St Maarten can be derived from the stakeholder narratives. However, this is a fuzzy process, that is partly coloured by the researcher. For this case, budget, risk awareness (translated into focus on flood risk or other focus), and flood experience (low, medium, high) were found as the defining characteristics of actors.	
	Define institutions in ADICO-syntax	Step 3
	The institutional statements (see appendix C) are part of the constitutional layer in MAIA.	
	Define interdependencies based on INDs	Step 4
	Interdependencies between institutions and attributes follow from the nine INDs for FRM on St Maarten (see appendix C).	
Physical	Define physical structure, based on actor characteristics and (undesired) outcomes of INDs	Step 4
	The physical properties do not follow directly from the INA. However, when the actor characteristics and IND outcomes are reviewed, an insight in the physical elements that should at least be included into the ABM can be gained. For FRM on St Maarten, the geographical location of infrastructure and properties is key, to assess whether these elements are actually flooded. This means that a flood model should be linked to the ABM as well.	

Operational	Define action arenas based on INDs The INDs can be read as a flow chart that guides action within an action arena. These INDs help develop the storyline within the ABM. The INDs could be simplified to develop the operational structure, by addressing primary attributes and nested attributes from the INDs differently. Primary attributes follow choice rules. Nested attributes may be left out of the ABM, if they have no choice (for example: VROMI infrastructure department has to follow orders by the VROMI minister). If nested actors do have a choice, a modelling option would be to include a chance that the nested attribute agrees with or prolongs an action.	Step 4
	Define sequence of INDs based on links between INDs Based on section 5.3.2 the chronological order of INDs can be used to develop the storyline within the ABM.	Step 5
Evaluative	*Will be discussed in section 5.4.2*	

5.4.2 Enriching Institutional Network Analysis with Agent-Based Modelling

In the previous section, I focused on how INA may be used as a basis to develop an Agent-Based Model, following the five MAIA structures. In this section I focus on how ABM in return may enrich INA. To do so, I turn to the evaluative structure, where system level phenomena can be observed. Within MAIA, the evaluative structure includes model validation (does my model actually do what I intended it to do) and the system level outcomes of experiments. An ABM can add institutional complexity, stemming from institutional change to INA, and the conclusions on stakeholder narratives (section 5.1.2) can be translated into experiments.

Institutional change

The concept of institutional change in FRM can be added to an ABM in several ways. I will briefly discuss three of them.

- **Role change, based on flood events**

A simple way of implementing institutional change is by changing the focus property of actors, based on the occurrence of flood events. So for example, a fraction of 10% of the actors that are not focused on flood risk may change roles the next year and focus on flood risk. Of course, in years without a flood event, 10% of the actors may change from a focus on flood risk to no focus on flood risk.

- **Changing institutions that have already been implemented, based on flood events**

Institutions that are already part of the proposed ABM may be activated or deactivated, based on the occurrence of a flood event. For example, S22 (political priority) may be activated in years with a flood event, whereas S23 (no political priority) is activated in years without a flood event.

- **Adding institutional change as a new institution**

A more sophisticated way of implementing institutional change is by introducing ADICO statements that describe this change. Smajgl et al. (2008) propose an addition of ADICO to allow for rule dynamics. They state that rule change can be caused by individual-level innovation mechanisms, where agents develop new actions, and by system-level rule mechanisms, where agents actively formulate new rules. Adoption of a new action or compliance to a new rule by individual actors is based on the evaluative capabilities of these actors. If an institution that is currently followed no longer leads to the desired result (for example: property is flooded every year), individuals change their strategies above a certain threshold (in the same example: property owners install FRM measures).

The adoption of a new institution is partly based on the properties of the network. An actor with a central position is more likely to be followed by other actors. From an INA perspective, this is highly relevant, but unfortunately out of scope for this research.

Addressing stakeholder narratives in experiments

For the four conclusions on FRM on St Maarten on a system level, that were based on collected stakeholder narratives, I make suggestions for ABM experiments. These experiments will lead to a better understanding of the dynamics within FRM on the island.

- Dominance national level solutions

Most interviewees – both governmental agents and inhabitants – see FRM action primarily as a government responsibility. However, polycentric systems with multiple power centres and effective sets of rules perform better (Andersson and Ostrom, 2008).

An interesting line of experimentation would be to add polycentricity to the system, to understand its implications on a system level. This might be done by creating sub regions within St Maarten that are governed by different decision makers. An easy way of implementing this would be to add multiple governmental actors (through the actor type 'VROMI minister'), with multiple roles and seek to understand the differences between this clustered governance and the centralized governance that is currently in place. These insights may help to formulate a way to combine the best of both worlds: a polycentric governance system from a FRM perspective.

- Budget limitations

Limited budget is almost without an exception mentioned as the dominant barrier to more adequate FRM in stakeholder interviews. This fact means that budget allocation is of high importance. ABM experiments could provide insights in budget allocation: what areas are under immediate risk? And where could initial action be limited to increasing awareness and enabling community action?

- Structural measures vs. land use planning

The focus of interviewees is mainly on structural FRM measures: installing pumps and flood retention walls, and constructing gutter systems on road sides. However, the link between land use planning and flood risk is less clear to most interviewed locals. Experimenting with different levels of sanctioning and by changing the hierarchy for property owners from mainly following the shared strategy of construction without a permit to construction with a permit, the coupled flood model could show the outcomes on a system level. The assumption here is that more focus on land use planning will lead to a decreased vulnerability to floods.

- Small island dynamics

St Maarten is characterized by small island dynamics. Its size limits its resources, both non-human and human. This results in the high relevance of personal networks and the overlapping roles for some actors. These strong personal ties result in corruption (Transparency International, 2015), which is mentioned by many interviewees. By experimentally changing situations of institutional conflict in such a way that official rules are followed, rather than shared strategies of non-compliance, the beneficial results from a FRM perspective can be addressed on a systems level.

6

Discussion

"The effect of interdependencies and connectivity between institutions on FRM can be addressed by taking a network perspective at institutions."

In this chapter, a summary of the most important findings is given. The research questions defined in chapter 1 will be answered. Moreover, this chapter will explain how this research has contributed to previous research in this area.

6.1 Understanding interdependencies and connectivity between institutions

The primary goal of this research is to understand interdependencies and connectivity between institutions within flood risk management, with the underlying assumption that understanding institutional complexity may add to better Flood Risk Management (FRM) in future.

Due to climate change, floods are projected to become both more frequent and more severe. Population growth and economic development mostly takes place around coastlines, hereby increasing vulnerability to flood risk (IPCC 2012, 2014). This requires a better understanding of the entanglement of human and flood systems in general, and institutional complexity in FRM more specifically.

Socio-hydrology, the science of people and water, proposed a new field of science dedicated to human-water interactions. An interdisciplinary systems approach should be taken, as opposed to the current gap in research between social systems and hydrological analyses of water systems (Sivaplan et al., 2012).

This research wishes to add to the young field of socio-hydrology by further exploring the institutional dimension of flood risk. The objectives were both to create a methodological approach for understanding the complex relations between institutions, and to provide a deeper understanding of the institutional dimension of Flood Risk Management for the case of St Maarten.

This island poses an interesting case in terms of FRM, as floods are the primary natural hazard. Nevertheless, the focus on economic development increases vulnerability and exposure to floods, requiring adequate institutions to manage flood risk. Moreover, within the European PEARL research project, St Maarten was chosen as one of the case studies, which has led to the development of a knowledge base on FRM on the island and data availability. More practically, the insights in the institutional dimension of FRM could be implemented in a human-flood coupled agent based model, currently under development within the PEARL project.

In this section I answer the research questions, starting with the main research question:

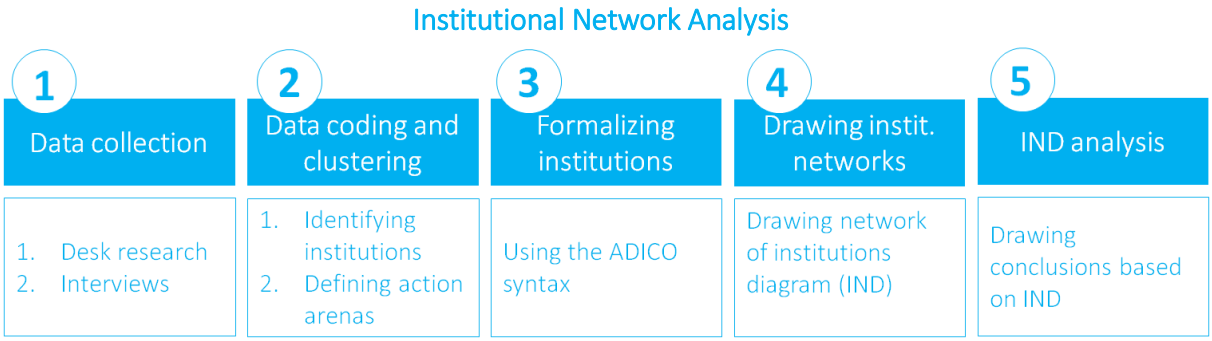
> What is the effect of interdependencies and connectivity between institutions on flood risk management, for the case of St Maarten, the Netherlands?

This question will be answered, after elaborating on the three sub research questions first.

I. How can interdependencies and connectivity between institutions be studied?

To understand interdependencies and connectivity between institutions, a suitable methodology had to be chosen. However, no methodology that dealt with the interdependencies and connectivity between institutions was found in existing literature (Baldassarre et al., 2014; Brown and Damery, 2002; Gober & Weather, 2014; Manuta and Label, 2005; Naess et al., 2005).

Therefore, the **Institutional Network Analysis** (INA) methodology was developed. INA builds on previous research on translating qualitative, raw data into institutional statements (Basurto et al., 2009; Ghorbani et al., 2015; Watkins & Westphal, 2015). To address interdependencies and connectivity between institutions, INA turns to Social Network Theory. An **Institutional Network Diagrams** (INDs) based on institutional statements, is a new, graphic way of representing the connections between institutions. This network approach turned out to be useful beyond this representation: network metrics help assess the performance of the institutional dimension of FRM. This will be discussed in more detail under the third research question. Below, a short summary of all five INA research steps is given.



1. Data collection

Data collection is structured by the FRM cycle, that consists of four subsequent phases: response, recovery, mitigation and preparation. Per phase, information is collected through desk research and semi-structured interviews. This is a highly iterative process, where the researcher's assessment of publicly available documents on FRM is discussed with stakeholders and stakeholder statements are checked with formally documented rules.

2. Data coding and clustering

The collected data is coded, if the data concerns views, perceptions, measures, cooperation, strategies and decision making processes with regard to flood risk management. Moreover, the data is clustered according to the four FRM phases. Each phase is regarded to represent an action arena: a combination of actors and actions, guided towards a desired outcome. If the actions within one of the phases show little overlap, the researcher may decide to split a FRM phase into multiple action arenas.

To address the richness of the available data, stakeholder narratives are recorder from the stakeholder interviews. These narratives are compared by the researcher, to find overlap or gaps in the way interviewees explain their perceptions and decisions. This results in several conclusions on FRM based on stakeholder narratives that can be studied if the INA is translated into an ABM.

3. Formalizing institutions

The third research step formalizes insights in the institutional dimension of FRM, using the ADICO syntax developed by Crawford and Ostrom (1995). This syntax includes rules, norms and shared strategies and splits institutional statements in five sub components:

A	Attributes:	those actors to whom the statement applies
D	Deontic:	distinction between permission, obligation and prohibition
I	Aim:	action or outcome of the institutional statement
C	Condition:	circumstances (when, where, how) under which the statement applies
O	Or else:	sanction for not following the statement

Rules have tangible sanctions and include all five sub components (ADICO), norms lack a tangible sanction (ADIC), and shared strategies lack a tangible sanction and a deontic (AIC).

4. Drawing institutional networks

The subsequent research step is to draw Institutional Network Diagrams (INDs), based on the ADICO statements, that are clustered in the action arenas that were identified in step 2. These INDs link actors, based on the deontic and aim of an institutional statement. We chose to represent attributes/actors and outcomes as nodes, as they are the only physical dimension to institutions. Institutions are mental constructs, that guide decision making towards a certain outcome, only when applied by an actor. For a step-by-step explanation of how to draw an IND, please see table 4.1.

An IND is thus a graphic representation of all institutional statements that make up an action arena within FRM. Output of this research step is a set of INDs, linked to all relevant action arenas within FRM.

5. Institutional Network Diagram analysis

The last INA research step is the analysis of the INDs. INDs can be evaluated on three aspects: institutional conflict and hierarchy; institutional network metrics; and links between institutional networks.

The graphic representation of action arenas forces the researcher to address situations of institutional conflict: situations where two or more institutions with different outcomes guide actor behaviour. The researcher than needs to return to the raw data or even the data source to understand institutional hierarchy: what institution is followed over the other(s), under what circumstances?

Network metrics, such as density, centrality and embeddedness can be calculated based on (a combination of) IND(s). Network structure impacts the FRM performance of a network and helps the researcher understand the strengths and weaknesses of the current institutional reality. Translating insights from metric to learn how the networks may perform better is not straightforward. Low centrality, for example, results in networks that are robust to the removal of a node (advantage), but these networks are also inefficient and may lack control and accountability (disadvantage). By including the advantages and disadvantages of network structure, the researcher may suggest policy options to improve FRM by enhancing network performance.

By linking INDs, either based on chronological order, while treating them as black boxes, or based on overlap in outcomes, the FRM system as a whole can be better understood. In this step, the researcher gains an understanding of the interdependencies and connectivity between INDs, instead of between institutional statements.

INA and Agent-Based Modelling

INA provides a deeper understanding of the complexity of the institutional dimension of FRM. These insights however, are static: they describe the status at a certain point in time. To understand how the institutional reality may change over time, Agent-Based Modelling may provide interesting insights. This modelling methodology seeks to understand complex system dynamics, stemming from individual decision making behaviour.

Institutional statements in ADICO syntax have already been implemented into ABM through the Modelling Agents based on Institutional Analysis (MAIA) meta model, developed by Ghorbani (2013). MAIA divides between five structures, that can be linked to INA research steps. Insights from INA can serve as input for developing an ABM. On the other hand, ABM can enrich INA by including institutional change and allowing for experimenting. The conclusions based on stakeholder narratives can be a starting point for defining experiments. The links between INA and MAIA structures can be found in table 4.6.

Returning to the four methodological criteria

In section 3.1, four main criteria for this methodology were defined. I will discuss whether INA meets these criteria below.

1. Meaningful translation of institutions into networks

The translation of institutions into networks is done by using the ADICO grammar as a backbone. Assuming that actors are always sanctioned by other actors, links between actors are incorporated in the [O]/or else component of an institutional statement. Links can be observed between institutional statements on an actor level as well. Therefore, we chose that nodes represent decision makers or outcomes, links describe the 'content' of a relation between actors and/or outcomes (the deontic and aim of an institutional statement). The advantage of this method is that ADICO is a well-developed syntax that is a standard within institutional theory.

2. Show materialization of institutions

The advantage of using ADICO and linking actors is that the results of institutions – actor decision making behaviour – can be shown. However, in case there are conflicting institutions, the chance that a decision maker follows a certain institution is hard to quantify, which is a limitation of the presented methodology.

3. Trade-off between complexity and insightfulness

Goal of this research method is to gain insights on FRM that can be explained to relevant decision-makers. The INDs provide a graphic representation of complex interdependencies of institutions within an action arena. However, the interpretation of these diagrams requires an understanding of institutional theory and Social Network Theory. To understand the communicative value of INA, the work on the case of St Maarten should be discussed with local decision makers.

4. Translatable for Agent-Based Modelling

The translation of the INA research on FRM on St Maarten showed that the large number of decision-makers poses a challenge in defining agents in the ABM. However, the INDs provided to be useful in developing the model narrative. The implementation of institutional change over time was not done within this research and should be further researched.

II. What interdependencies and connectivity between institutions can be identified in Flood Risk Management on St Maarten?

The INA research method was applied to the case study of FRM on St Maarten. For this case, nine action arenas where defined within the FRM cycle, consisting of 36 rules, 9 norms and 30 shared strategies. These nine action arenas were translated into INDs (please see appendix C). Here, I summarize the key findings based on these INDs that may interest policy makers on St Maarten. Moreover, I have developed a conceptual ABM, based on insights from the INA (please refer to appendix F). Based on INA, several conclusions can be drawn. This can be found under the third research question on how these insights translate to better FRM.

III. How can insights in interdependencies and connectivity between institutions be translated to better Flood Risk Management?

To answer this research question, I first discuss how INA insights can be translated to better FRM for the case of St Maarten. Secondly, I describe how these results may be generalized beyond this specific case study.

What the INDs teach us about improving FRM on St Maarten

- Institutional hierarchy

Seven situations of institutional conflict have been identified. By returning to the collected data and data sources, in three of these seven situations, a shared strategy that specifically directed a decision maker to ignore official rules was found to be higher in the institutional hierarchy. An example of this is the permit process: property owners are required to request a permit. However, interviewees state that building without a permit is common practice. This result should lead to conversations on how these rule-breaking shared strategies may be discouraged.

- Network metrics

Density was found to be low in FRM management on St Maarten, indicating a large diversity in practices, but a limited spread of information as well. Policy should aim to install structures to share knowledge between stakeholders, emphasizing the importance of community action. Interviewees could not name examples of community action with regard to FRM. Sharing best practices may help inhabitants cooperate more.

Centrality was found to be low as well, with one remarkable outlier: the VROMI minister has a centrality that is five times higher than average. To move towards better FRM on the island, it is crucial that responsibilities are shared better amongst decision makers to increase efficiency. This highly central position of the VROMI minister endangers FRM practices on St Maarten. Interviewees stated that the formal processes to execute FRM measures or to improve permits for new properties are lengthy and hierarchical.

Embeddedness is high, indicating that decision making processes are linked to several decision makers. Although high embeddedness indicates that there are checks and balances in place, it is important to address redundancy in lines of command: are all decision makers actually necessary? All VROMI projects that exceed 5,000 ANG (about €2,600) have to be consented by the VROMI minister, which makes formal processes lengthy.

- Linking INDs

Linking INDs by treating them as black boxes helps the researcher to understand the FRM system as a whole. The nine INDs for FRM on St Maarten can be placed in chronological order, following the FRM cycle. Links between INDs can be identified by focussing on outcomes as well. Within this research, overlap in outcomes was found in clean-up (preparation, response), risk awareness (preparation, response, recovery), construction activity (recovery, mitigation), and budget (recovery, mitigation).

How ABM can add to understanding institutional dynamics on St Maarten

By following the MAIA structure, proposed by Ghorbani (2013), insights from INA can help develop a (conceptual) ABM. For FRM on St Maarten, a conceptual model was developed (please refer to appendix F). In this conceptual model, the focus is on the institutional dimension of FRM (constitutional structure). However, the institutional analysis provides insights in key decision makers and their properties (collective structure), physical attributes and outcomes (physical structure) and the INDs are graphic representations of the action arenas, that help develop the storyline of the ABM (operational structure).

The evaluative structure yields insight in system level dynamics that result from individual action. Institutional change can be implemented to address the static nature of INA. Institutional change can be implemented in several ways, for example by implementing role change, (de)activate institutions based on flood events, or even by adding institutional statements that guide institutional change, following the work of Smajgl et al. (2008).

Moreover, the four conclusions based on stakeholder narratives provide a valuable basis for designing experiments, as summarized in the table 6.1.

Table 6.1: Stakeholder narratives as a basis for ABM experiments

Possible ABM experiments, based on stakeholder narratives	
Conclusion	Possible experimentation
Dominance of national level solutions	Experiment with polycentricity: create multiple governmental actors to gain an understanding of difference between polycentric and top-down governance.
Budget limitations	Gain an understanding of what FRM measures should be prioritized
Structural measures vs. land use planning	Current focus is on structural measures, an ABM could show the impact of well-executed land use planning over time and may increase the perceived urgency of land use planning amongst stakeholders.
Small island dynamics	The small island dynamics result in the high importance of personal networks, sometimes resulting in corruption. By experimentally changing institutional hierarchy, awareness of the negative consequences of not following rules can be raised.

How INA insights can lead to better FRM

After discussing insights for the case of FRM on St Maarten, I now summarize how INA may add to better FRM beyond this case study. I will discuss this topic on three different levels: on the level of data, on the level of single INDs and on the level of the whole FRM cycle, combining INDs. I conclude with discussing the mutual benefit of combing INA with ABM.

- Data level

The first two steps of INA, data collection, and data coding and clustering, are structured by the four FRM phases: response, recovery, mitigation and preparation. This FRM framework, in combination with the concept of action arenas, have provided to be useful in structuring the initial, large, rich data set. It helps the researcher guide its search, whereas it is not so strict, that it causes blind spots. By noting down narratives from stakeholder interviews, the researcher is well-equipped to capture the richness of the data and to understand system level shortcomings of current FRM practices.

- Institutional Network Diagram

The development of INDs addresses the institutions that guide individual decision making behaviour. Clustered data is translated into institutional statements per action arena. The ADICO syntax helps to further structure and narrow down the collected, coded and clustered information. Translating institutional statements into the ADICO syntax is useful, as it enables the researcher to address the differences between types of institutions: rules, norms and shared strategies.

However, large ADICO tables may not be insightful for non-scholars, or scholars who are not familiar with institutional analysis. That is why the graphical representation in Institutional Network Diagrams (INDs) is so helpful. Even before further analysis, these INDs help understand the interdependencies and connectivity between institutions.

Moreover, in developing INDs, the researcher may find gaps in his or her research that need to be addressed. If interviewees mention the development of laws for example, drawing an IND will show the researcher that he or she has not included the institutions that guide the installation of a law yet. This will make the researcher return to the collected data or data sources. INDs will also immediately reveal situations of institutional conflict within an action arena. This will direct the researcher to further explore these situations.

- Flood Risk Management

Combined, the developed INDs should provide a chronological overview of FRM related institutions and actions. Moreover, the network metrics provide points of discussion for policy makers to install better FRM policies. The network metrics, including density, centrality and embeddedness provide insights in the effects of the network structure on FRM. As INA shows the interdependencies and connectivity between institutions, this methodology will help policy makers and other decision makers to address a whole action arena, not a single institution.

- From static to dynamic

INA yields static results. The INDs can be seen as a snap shot in time of the institutional dimension of a certain problem domain, in this case flood risk management. By using INA insights to develop an ABM, institutional change can be incorporated into the research. Moreover, the system level shortcomings that have been identified on a data level can be addressed in experiments. This can assist policy makers and decision makers in developing better FRM practices. Moreover, by combining the institutional dimension of FRM with a flood model, the relative impact of different policies can be addressed. For example, the effects of land use planning can be compared to the effects of structural FRM measures.

Now that we have discussed the sub questions, we return to the main research question:

> What is the effect of interdependencies and connectivity between institutions on flood risk management, for the case of St Maarten, the Netherlands?

The effect of interdependencies and connectivity between institutions on FRM can be addressed by taking a network perspective at institutions. Institutional statements define the links and relations between decision makers. In this light, institutional networks are an enrichment of social networks. In both approaches nodes correspond to human actors. However, in social networks these relations are often not further specified than the direction (A to B, B to A, or both). The aim and deontic of institutional statements clarify the link between decision makers.

Networks of institutions show the interdependencies and connectivity and help identify institutional flaws. These flaws can be determined by calculating network metrics and linking these network characteristics to performance.

6.2 Reflecting on the theoretical framework

To guide the search for understanding how interdependencies and connectivity between institutions can be studied to improve FRM, specifically for St Maarten, a layered theoretical framework was developed and used (figure 2.2). The research is encapsulated in socio-hydrology, focussing on integrated human-water systems. Within human-water systems, the focus is on the institutional dimension of flood risk, using the Institutional Analysis and Dynamics (IAD) framework. Within IAD, institutional complexity was defined in this research as the interdependencies and connectivity between institutions, turning to social network theory to understand the links between institutions.

Socio-hydrology seeks to understand human-water coupled systems as fully integrated, while focussing on dynamics. Institutional analysis within flood risk management has so far been a blind spot within socio-hydrology literature, and therefore the Institutional Analysis and Dynamics (IAD) framework by Ostrom was used as a framework for understanding the institutional dimension of complex-adaptive systems. Within institutional analysis, little attention has been paid to connectivity and interdependencies between institutions. To add to the understanding of these interdependencies and connectivity is the main goal and contribution of this research.

The theoretical framework has proved to be a useful guidance for this research. The understanding of complex water management systems stemming from socio-hydrology helped to keep a broad perspective on the matter. The IAD framework is a helpful framework to address institutions within socio-hydrology, as it grasps the complexity of institutional dynamics. The FRM cycle helped narrow down the collected information. To study connectivity and interdependencies, I turned to social network theory. Linking this body of knowledge with institutional theory helped understand the interdependencies and connectivity between institutions.

6.3 Scientific contribution

The research gap that was addressed in this research is the lack of focus on the interdependencies and connectivity of institutions, both in socio-hydrology and in flood risk management in general. The goal was to both find a methodology to address interdependencies and connectivity between institutions in human-water systems, and to gain a deeper understanding of the institutional complexity within FRM for the case of St Maarten.

The Institutional Network Analysis methodology that was developed, has proven to be applicable to FRM on St Maarten. Especially the graphic representation of networks of institutions helped understand how institutions are linked within different action arenas. Moreover, the network metrics help researchers and policy makers understand how the institutional interdependencies shape FRM. INA may provide a useful tool for further FRM research, especially in a world where flood risk is ever increasing, both due to climate change and factors such as population and GDP growth, that affect vulnerability and exposure to flood risk. INA can be used as a starting point for re-evaluation of FRM policies and INA shows the importance of stakeholder involvement, as it shows how all stakeholders together shape FRM.

Agent-Based Models are often used to understand the complex dynamics between human action and ecosystems. Thus, ABM provides a valuable approach to study human-water systems within socio-hydrology. However, within ABM the interdependencies and connectivity between institutions have not been introduced yet. The institutional dimension has been added to ABM through the Modelling Agents based on Institutional Analysis (MAIA) tool, but the institutional complexity is reduced to ADICO statements within MAIA. INA can help researchers to include institutional complexity, as interdependencies are made explicit in INDs. These INDs provide a storyline for an ABM. Moreover, ABM can enrich INA by including a dynamic approach of the institutional reality and by allowing for experimentation with key variables and institutions.

7

Conclusion

“Moving from a static snapshot of the institutional dimension of FRM, towards exploring institutional dynamics over time.”

In this concluding chapter, I summarize the contributions of this research, before exploring limitations and options for further research.

7.1 Research contributions

The goal of this research was to untangle institutional complexity in human-water coupled systems, by better understanding the interdependencies and connectivity of institutions. More specifically, this research looked into Flood Risk Management, as flood risk poses an increasing threat to societies on a global scale. Climate change invokes more frequent and more severe extreme weather events, which increases flood risk. What is more, over 60% of the world’s growing population lives in coastal areas, exposing both the population and the built environment to increasing flood risk. We seek to understand how institutions and their connectivity may contribute to better Flood Risk Management.

Socio-hydrology, a young research field that explores the dynamics in complex human-water systems was taken as a theoretical framework. As the institutional dimension is currently not well explored within socio-hydrology, the Institutional Analysis and Dynamics (IAD) framework is introduced to understand how institutions are shaped and reshaped by actors through feedback loops, that relate institutions to both physical and non-physical attributes. To understand links between institutions, a network perspective is taken, building on social network theory.

To research the interdependencies and connectivity between institutions, a new methodology is proposed: Institutional Network Analysis (INA), that was tested on a first case study: FRM on St Maarten. In this methodology, data on the institutional dimension of FRM is collected through desk research and stakeholder interviews, following the four FRM cycle stages. The collected data is coded and structured, to identify action arenas that correspond to the four FRM stages. Stakeholder narratives are analysed to identify system level problems from an FRM perspective. Insights in institutions is translated into institutional statements, following the ADICO syntax.

The interdependencies and connectivity between institutional statements are graphically represented in an Institutional Network Diagram (IND), that does not only provide an overview of all institutions within an action arena, but that points the researcher to situations of institutional conflict as well. The INDs can be analysed based on network metrics, which can yield insights in how FRM can be improved. Moreover, linking INDs helps the researcher understand the FRM cycle as one system, rather than a combination of action arenas.

The four criteria that guided the development of the INA methodology were (1) to include a meaningful translation of institutions to networks; (2) to focus on the actual impact of institutions on decision-making behaviour; (3) to balance between complexity and insightfulness for non-academics; and (4) to be translatable to ABM.

These first two criteria were met by using the ADICO grammar as a backbone and drawing links based on the deontic and aim of an institution between nodes that represent decision makers within FRM. The trade-off between complexity and insightfulness should be addressed by communicating the results on the case of St Maarten with local decision makers. Their feedback can add to the improvement of INA.

As socio-hydrology focuses on the dynamics in human-water systems, the static nature of INDs provide an interesting starting point of analysis, but it would be more interesting to study the dynamics of institutional change as a result of flood events into INA. INA can be used as a starting

point of developing an Agent-Based Model, following the five structural layers Ghorbani (2013) introduces in the MAIA framework. The INDs can be seen as flow charts that can be translated into a model narrative and hereby incorporate institutional complexity to a higher extent. Moreover, the analysis of narratives provides insights on system level outcomes, that can be further analysed through ABM experiments. In short, INA can add institutional complexity to ABM, whereas ABM provides a tool to further explore the institutional dynamics of FRM.

7.1.2 Insights for decision makers on St Maarten

For decision makers on St Maarten, several key conclusions can be drawn based on the performed Institutional Network Analysis. INDs show how decision makers within FRM are connected. Therefore, my hope is that these key conclusions lead to a strategic conversation involving all stakeholders on how FRM may be improved on St Maarten.

An ABM may add to this strategic conversation, as it makes system level and long term results of policies and institutions insightful. Experiments could address some core issues that were identified during data coding and clustering: the dominance of solutions on a national level; budget limitations; the emphasis on structural measures over land use planning; and the results of small island dynamics.

Based on the IND analysis, I present four key recommendations for decision makers on St Maarten in the bullet points below.

- Institutional hierarchy

  In FRM on St Maarten, seven cases of institutional conflict have been identified. All cases shared one characteristic: they revolved around a rule installed by the government and a shared strategy that directly undermined this rule. These situations should be discussed by policy makers and inspection parties.

- Network metrics: density

  Density is low, which indicates a limited spread of knowledge and information. Policy makers and decision makers should aim for better share of knowledge. When we turn back to the data, especially locals have limited knowledge on the effect non-structural FRM measures and action on a household level tends to be individual. Informing and helping communities cooperate in terms of FRM may be a policy option.

- Network metrics: centrality

  Centrality is low, which indicates that responsibilities are spread across actors. However, the VROMI minister has a centrality that is more than five times larger than the average centrality within the INDs. A recommendation for policy makers on St Maarten would be to critically review the involvement of the VROMI minister in the institutions that guide FRM to increase efficiency.

- Network metrics: embeddedness

  Embeddedness is high, which means that the INDs are characterized by chains of decision makers and this could indicate that there are checks and balances in places. However, a recommendation would be to critically review these chains of decision makers to increase efficiency in FRM.

Cultural reality of St Maarten

The main conclusion of the report by Transparency International (2015) was that close personal relations define the political arena of St Maarten. Corruption is a reality on St Maarten and is mainly observed in the form of favouring personal relations. The key recommendations listed above indicate that these processes negatively affect FRM performance on St Maarten. The provided opportunities

for improvement all indicate that a more critical dialogue that includes stakeholders beyond the VROMI ministry is key.

My hope is that this research provides an objective substantiation of the problems that arise because of the political culture on St Maarten. The power culture might not be easily overthrown. However, a hopeful sign is the growing local protest culture. In September 2016 for example, protestors called out local politicians who approved the development of a large hotel complex, funded by Chinese investors. This complex is to be build close to the capital Philipsburg on the natural overflow between the Great Salt Pond and the ocean, which would increase vulnerability to floods of the Philipsburg community (see figure 7.1; SNM news, 2016).

Objective research can provide the right arguments for inhabitants that are concerned for their own safety from flood risk.

Fig 7.1: St Maarten local protesting the development of a large hotel complex, source: SNM Facebook, published on September 17, 2016

7.1.3 How Institutional Network Analysis may lead to better Flood Risk Management

After discussing insights for the case of FRM on St Maarten, I now summarize how INA may add to better FRM beyond this case study. I will discuss this topic on three different levels: on the level of data, on the level of single INDs and on the level of the whole FRM cycle, combining INDs. I conclude with discussing the mutual benefit of combing INA with ABM.

- Data level

The first two steps of INA, data collection, and data coding and clustering, are structured by the four FRM phases: response, recovery, mitigation and preparation. This FRM framework, in combination with the concept of action arenas, have provided to be useful in structuring the initial, large, rich data set as well. It helps the researcher guide its search, whereas it is not so strict, that it causes blind spots. By noting down narratives from stakeholder interviews, the researcher is well-equipped to capture the richness of the data and to understand system level shortcomings of current FRM

practices. However, the behaviour and institutional reality that underlie these system level problem still need to be discovered.

- Institutional Network Diagram

The development of INDs addresses the institutions that guide individual decision making behaviour. First, the clustered data is translated into institutional statements per action arena. The ADICO syntax helps to further structure and narrow down the collected, coded and clustered information. Translating institutional statements into the ADICO syntax is useful, as it enables the researcher to address the differences between types of institutions: rules, norms and shared strategies.

However, large ADICO tables may not be insightful for non-scholars, or scholars who are not familiar with institutional analysis. That is why the graphical representation in Institutional Network Diagrams (INDs) is so helpful. Even before further analysis, these INDs help understand the interdependencies and connectivity between institutions.

Moreover, in developing INDs, the researcher may find gaps in his or her research that need to be addressed. If interviewees mention the development of laws for example, drawing an IND will show the researcher that he or she has not included the institutions that guide the installation of a law yet. This will make the researcher return to the collected data or data sources. INDs will also immediately reveal situations of institutional conflict within an action arena. This will direct the researcher to further explore these situations.

- Flood Risk Management

Combined, the developed INDs should provide a chronological overview of FRM related institutions and actions. Moreover, the network metrics provide points of discussion for policy makers to install better FRM policies. The network metrics, including density, centrality and embeddedness provide insights in the effects of the network structure on FRM. As INA shows the interdependencies and connectivity between institutions, this methodology will help policy makers and other decision makers to address a whole action arena, not a single institution.

- From static to dynamic

INA yields static results. The INDs can be seen as a snap shot in time of the institutional dimension of a certain problem domain, in this case flood risk management. By using INA insights to develop an ABM, institutional change can be incorporated into the research. Moreover, the system level shortcomings that have been identified on a data level can be addressed in experiments. This can assist policy makers and decision makers in developing better FRM practices. Moreover, by combining the institutional dimension of FRM with a flood model, the relative impact of different policies can be addressed. For example, the effects of land use planning can be compared to the effects of structural FRM measures.

7.2 Limitations and further research

In this section, I focus on limitations of this research, that I link to possibilities for further research. I follow the five research steps of INA to structure this section first. I conclude with some remarks on the link between INA and ABM, and more general limitations and suggestions for further research.

Improving Institutional Network Analysis

1. Data collection

In semi-structured interviews, questions or themes discussed and the selection of interviewees always leads to a certain degree of subjectivity (Holstein & Gubrium, 2004). Moreover, the interviews that are used as input for this research, were conducted at two points in time, which may lead to more static information set, whereas the dynamics of the system are under focus (Janssen & Ostrom, 2006).

Another limitation from a data collection perspective is that the 27 stakeholder interviews that were performed by Arabella Fraser were conducted with a different purpose: understanding the root causes of flood risk on the island, rather than understanding the institutions that guide behaviour in terms of FRM. If these interviews were conducted using the latter purpose, more valuable data might have been obtained.

2. Data coding and clustering

Data coding and clustering is a highly iterative process, where the researcher learns about the institutional reality in his or her case study area. However, the scientific value of this research step may increase significantly if a team of researchers works through the data set to code and cluster the data. Now, the coding and clustering depends merely on one individual, which colours the research outcomes to some extent. To overcome this bias, results were discussed with PEARL researchers and some key stakeholders. This holds for the analysis of stakeholder narratives as well.

3. Formalizing institutions

In formalizing institutions into ADICO syntax, I failed to capture some of cultural values of stakeholders. For example, interviewees spoke about governmental legitimacy and expressed a lack of trust in government functionality. Such sentiments are difficult to capture in ADICO statements. However, ADICO does force the researcher to structure institutional statements and makes the data more manageable.

The process of translating raw, clustered data into institutional statements is highly iterative as well. In this study, my insights with discussed with Yared Abebe several times (UNESCO-IHE). His additions or questions were crucial for me to improve my work. This indicates that, again, a team of researchers focussing on one case would improve the quality of the work.

4. Institutional Network Diagram (IND)

INDs provide many advantages, that have been discussed before. A key drawback is their fundamental nature: they provide static images of the institutional reality. Although they focus on dynamics, in a sense that they show how actions and actors are interdependent, they do not include the dynamics of institutional change. This may be tackled by developing an ABM, but an interesting line of further research may focus on how institutional change could be implemented in the INDs.

For the development of INDs I made the decision to use attributes or actors as nodes, as I argued that actors form a 'materialization' of institutions, that I regard as mental constructs. However, it would be interesting to explore the representation of institutions in networks in a different way. Institutional statements may for example be treated as nodes, independent of actors. This could provide researchers with a network of institutions that focuses less on decision makers. Another possibility is to draw INDs based on decision makers, rather than action arenas. Those INDs would give an overview of all institutions guiding one (group of) decision maker(s) and may be helpful in detecting institutional redundancy and conflict.

5. IND analysis

The goal of the IND analysis is to learn more about the institutions that guide FRM. Moreover, these network representations of institutional statements should help formulate recommendations for better FRM.

- Institutional hierarchy

Situations of institutional hierarchy become explicit through INDs. However, it is difficult to address institutional hierarchy on the appropriate level of detail. Decision makers can base their decision to follow institution A over institution B on an almost unlimited amount of variables, ranging from their occupation, their personal preferences, the fear of being sanctioned and their mood on a specific day.

This means that in institutional hierarchy it is not only important to assess what institutional statement is prioritized, but also to understand the circumstances under which this prioritization holds. This requires more in depth research than I have provided for the case of St Maarten. However, the advantage of an IND is that this research method visually indicates situations of institutional conflict and hereby 'forces' the researcher and stakeholders to address this issue.

- Network structure

The calculations on network structure provide an interesting basis for further research. Here, it may be difficult to base strong conclusions on these calculations, but when more FRM systems in different case study areas can be combined, the research of institutional performance may be facilitated. The differences between institutional networks in FRM with different levels of density and connectivity will help researchers understand the links between these metrics and effective FRM. Further research may focus on comparing institutional network structures in FRM.

Reachability, how many 'steps' decision makers need to take through the institutional network before reaching an outcome, may help to understand when strategies are developed that undermine official rules. Additional research into this topic, focussing on more cases may help unravel a link between this network characteristic and situations of institutional conflict.

- Linking INDs

Links between INDs were presented by defining the chronological order in which these action arenas take place and by linking outcomes. Linking INDs based on actors that define them may provide an additional way of understanding the links between action arenas in FRM. Linking INDs based on attributes shows what attributes are active throughout the whole FRM cycle and what attributes have a more specialized role, which may help to understand stakeholder positions within the FRM system.

Additional research could focus on more formal linkage of INDs as well. Some INDs may be nested in other INDs, as Frantz (Frantz et al., 2013, 2015) showed for nested ADICO statements.

Integrating Institutional Network Analysis and Agent-Based Modelling

The conceptual ABM for St Maarten may form a starting point for further research: to understand the mutual contributions of INA and ABM, an ABM should be developed by an experienced ABM-researcher. He or she could reflect on the value of using INA as a basis for developing an ABM and how INA may be improved to provide a better basis in future.

In developing the conceptual ABM, I already found the need for a simplification of INDs: not all actors can or should be introduced in an ABM as actor type, as this will unnecessarily complicate the ABM. In this research, those actors with the highest density and/or centrality were converted to actor types. It would be interesting to get a better understanding of how network metrics can help shape ABM actors and how these network metrics can be translated into actor properties as well.

To contribute to ABM, it would be interesting to further explore the concept of institutional hierarchy within the ABM context. How can conflicting institutions best be addressed in the storyline of the ABM? Institutional hierarchy has been treated as a static property of the institutional networks in this research, however, changing circumstances may change hierarchy as well. ABM may allow for a more dynamic approach of institutional hierarchy.

Further research

To conclude this section, I want to address two additional lines of further research that may provide to be useful: link the concepts of institutional change and network metrics; and how to apply INA beyond FRM.

In this research, network metrics have been calculated to understand potential flaws in the institutional system. These insights have been translated to recommendations for better FRM. However, it would be interesting to research whether these network metrics tell us something about the potential for institutional change within a network as well. One could for example argue that change within networks with a high density may be easier to establish than in networks with a lower density. It would be interesting to compare several FRM systems to find what network metrics correlate to institutional change.

Another direction of future research may move away from FRM. Institutional Network Diagrams were developed to gain an understanding of the institutional dimension of FRM. However, the method could be applied to other problem domains as well. Aggregated data on institutional networks from different problem areas may provide a basis for learning how to better manage a problem. Best practices from FRM may for example be shared with decision makers in the energy or food sector.

8

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Appendix

Appendix A – PEARL research on case of flood risk on St Maarten

In the introduction, the PEARL research project was briefly introduced. Here, I summarize the key lines of research within PEARL: the Risk and Root Cause analysis (RRCA) developed by King's College London and the ABM developed by UNESCO-IHE.

Risk and Root Cause Analysis

Starting point of an RRCA is to find an explanation why disasters are becoming more frequent and losses continuously increase, even though scientific knowledge on natural events progresses (IRDR, 2011). An RRCA uses historic insights to understand present risks. Root causes can be distinguished from drivers, as root causes relate to the structures and processes beyond individual events, whereas drivers are the more proximate processes and activities that translate root causes to vulnerability. This method emphasizes the importance of path dependencies and lock-ins. RRCA focuses on four domains: physical processes, governance processes, socio-economic processes, and perceptions and values (Fraser et al., 2014).

The RRCA on St Maarten gives a deeper understanding of how actors' behaviours influence the formation, propagation and accumulation of flood risk. The current discrepancy between observed and desired behaviour is hypothesized to be caused by conflicting interests and uncoordinated behaviour of actors. Another complicating factor for flood risk response on the island might be due to austerity measures (A. Fraser, personal communication, June 30, 2016). The main findings of this RRCA are presented in the table below. The focus is on governance processes, socio-economic processes and perceptions and values, rather than the physical processes.

Table A.1: Overview of results from RRCA on St Maarten

RRCA domain	Main findings
Governance processes	Reactive management: past events have led to action
	Ineffective management: there is a governance gap since St Maarten became independent in 2010
	Effective communication on emergencies
	Focus of governance is national/regional
	Land use directive is not formalized to law/regulation
Socio-economic processes	Rapid population growth
	High immigration and emigration, leading to rapid change in population
	Urbanisation
Perceptions / values	High awareness of hurricane/flood risk
	Limited development of civil society

Hydrological modelling

Based on their work in the Caribbean region, Vojinovic and Van Teeffelen (2007) advocate an integrated approach to storm water management. They describe how storm surges, flash floods and landslides form the most common and severe hazard events. The risk that is increasing due to climate change, poses a responsibility for scientific communities to evolve better storm water management. Damages should not only be minimized by structural measures, but simultaneously by prevention measures, improved preparedness, well-developed emergency and disaster response systems. Flood risk management has a strong local component, determined by the availability of resources and local culture. The lack of clear land use planning policies on many Caribbean islands allows for unplanned development, which increases pressure on disaster management systems.

Price and Vojinovic (2008) plead for the integration of storm water management in urban planning, using St Maarten as an exemplary case. A flood model for St Maarten was developed (Vojinovic et al., 2011; Vojinovic & Tutulic, 2009), combining the one dimensional representation of main channels and

a two dimensional representation of floodplains to analyze flood processes in urban areas. Currently, Vojinovic and Yared Abebe, PhD student at UNESCO-IHE, work on an Agent-Based Model, that incorporates both hydrological insights and actor behaviour. This actor behaviour is guided by decision making processes, shaped by institutions.

Appendix B – List of reviewed documents on FRM on St Maarten

The publicly available documents that were reviewed on FRM on St Maarten are alphabetically listed by author/organization below:

- EU
  - Caribbean regional indicative programme 11th European Development Fund (EDF) (2015)
  - Demographic and migration trends: impacts on territorial, social and cohesion (2012)
  - Saint-Martin/St Maarten EU cooperation 2014-2020 (2014)
  - St Maarten government: Biodiversity Protection and Sustainable Development of the Simpson Bay Lagoon, Waste Water Treatment Plant and Flood Mitigation for Belle Plaine to be Initiated Through European Union Funding Managed by French and Dutch St. Maarten (2014)
- Insurance: Catastrophe risk insurance conference (2014)
- Marine Community: clean-up hurricane Gonzalo debris (2015)
- Mathew: Possible macroeconomic impact natural disaster (hurricane) on St Maarten (2013)
- Meteorological Service: Hurricanes and tropical storms in Netherlands Antilles and Aruba (2010)
- News/media
  - Caribisch network: Ex-minister Buncamper-Molanus veroordeeld voor belasting ontduiking (2016)
  - St Maarten Daily Herald: Elections: NA 5, UP 5, USP 3, DP 2 (2016)
  - St Maarten Daily Herald: Hurricane preparedness (2013)
  - Today SXM: Maria Buncamper-Molanus: I still ask myself what have I done wrong (2016)
- STHA: hurricane seminar article 1 (2013)
- St Maarten government:
  - The Sint Maarten disaster management organization [PowerPoint presentation by Paul Martens] (2015)
  - Hurricane campaign (2016)
- SXM Statistics:
  - Statistics Magazine FACTors, 5th issue (2014)
  - Statistical Yearbook 2015 (2015)
- Transparency.org: National Integrity System (NIS) Assessment St Maarten (2015)
- UNDP: First Millennium Development Goals (MDG) report St Maarten (2011)
- UNESCO-IHE: Flood risk reduction St Maarten (2012)
- VROMI:
  - Policies:
    - Beach policy (1994)
    - Building code (2010), *('Landsbesluit, ter uitvoering van artikel 19 van de Bouw- en Woningverordening')*
    - Building ordinance (2010), *('Landsverordening, houdende voorschriften betreffende het bouwen en de volkshuisvesting')*
    - Hillside policy (n.d.)
    - Zoning policy (1993)
  - Other:
    - Storm-water management strategy (2015)
    - VROMI Ministry Plan 2012-2014
    - VROMI Ministry Plan 2015-2018

Appendix C – Institutional Network Analysis St Maarten

This appendix gives the full Institutional Network Analysis for St Maarten, following the FRM cycle.

Flood Risk Response on St Maarten

Please refer to section 5.2.1.

Flood Risk Recovery on St Maarten

VROMI prioritizing FRM measures

On St Maarten, the VROMI Departments New Projects and Infrastructure are responsible for installing FRM measures. Implementing structural FRM measures, such as gutters on roadsides, flood retention walls in vulnerable areas and pump installations around the ponds, is limited by budget. Therefore, institutions that guide prioritizing have been developed. These institutions include prioritizing those areas that were most recently flooded and basing decisions on the UNESCO-IHE flood model for St Maarten. This model makes use of relief maps to show flood prone areas. This research contributed to the zoning plans as well (see mitigation).

Private investment and community cooperation

For restoration and reconstruction of properties, inhabitants are largely dependent on their own budgets. Many have insurances (see under preparation), but for restoration and reconstruction community help is often involved.

Community councils have been formed throughout the years – some may be over twenty years old, others may be recently installed. These community councils should be a channel for community members to express their wishes and concerns towards the government. The other way around, community councils should provide a channel for the government to talk to councils that can speak on behalf of the community they represent as well. However, these community councils have become highly politicized (interview VROMI) and this has negatively impacted trust amongst inhabitants.

Church groups are good example of community organization that has not been politicized. In the past, church groups have mobilized help with clean-up and restoration actions through their strong networks. Moreover, church groups have pressed for more attention for social development, rather than just economic development, which has provided them with a significantly higher trust base (interview VROMI).

The institutions of recovery are formalized in two action arenas: reconstruction (table C.1) and budget (table C.2).

Table C.1: Institutions in disaster recovery I: reconstruction

No.	Name	A	D	I	C	O
			Rule			
R9	Public reconstruction I	VROMI minister	must	choose **contractor** based on tender procedure	if damage to infra/public property	
R10	Contractor	Contractor	must	follow contract	if agreed with **VROMI minister**	
R11	Public reconstruction II	VROMI minister	must	order **infrastructure dept**. to perform reconstruction	if damage to infra/public property	
R12	VROMI reconstruction	VROMI infrastructure dept.	must	execute reconstruction activities	if requested by **VROMI minister**	
			Norm			
N3	Private reconstruction	Property owners	must	reconstruct their own property	if in flooded area	

		Shared strategy		
S3	Request community help	Inhabitants	request help from **NGOs** with reconstruction	if in flooded area, and if damage
S4	Community reconstruction	NGOs	assist in reconstruction	if requested by **inhabitants**
S5	Public procurement	VROMI minister	chooses **contractor** without tender procedure	if wish for rapid action
S6	Vocalize concerns	Inhabitants	vocalize concerns through (social) media to raise governmental risk awareness	if damage to neighbourhood
S7	Prioritizing FRM	VROMI minister	prioritizes FRM projects	if vocalized concerns **inhabitants**

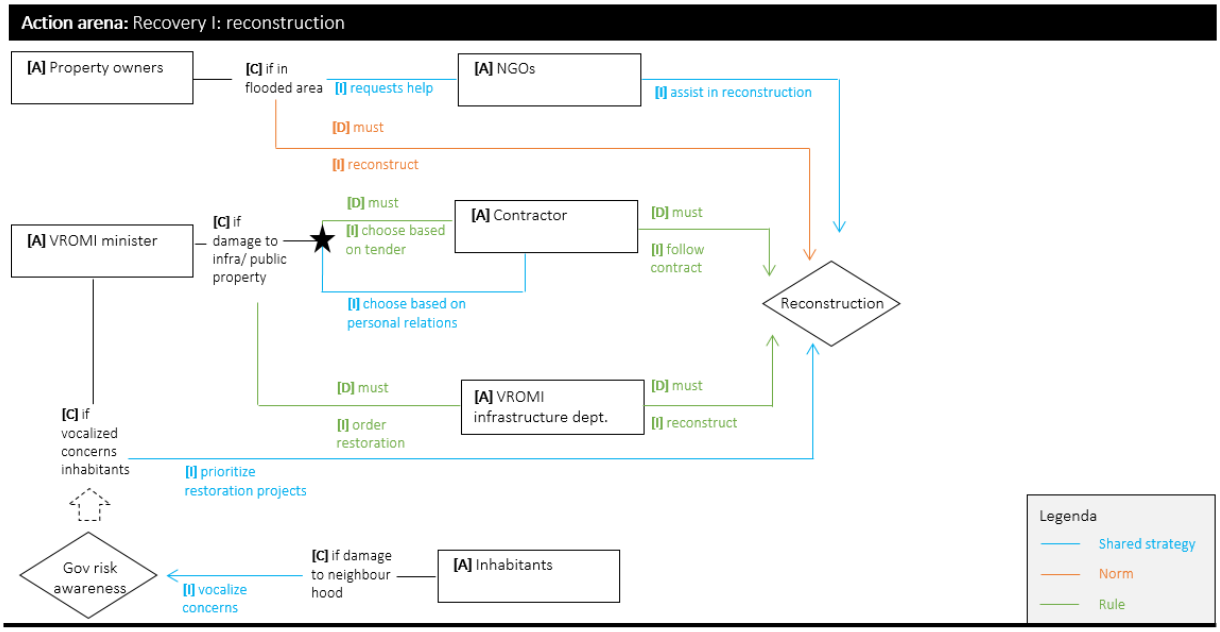

Fig C.1: IND for flood risk recovery: reconstruction

Table C.2: Institutions in disaster recovery II: budget

No.	Name	A	D	I	C	O
			Rule			
R13	Insurers pay out	Insurers	must	pay **property owners** out	if named storm and damage	N4
			Norm			
N4	Sue insurers	Property owners	May	sue **insurers**	if named storm, damage and not paid out	
			Shared strategy			
S8	Increase tariffs	Insurers		increase tariffs to build up buffer	if named storm and damage	
S9	Override budget	VROMI minster		overrides budget for reconstruction	if extreme damage	
S10	PM request Dutch financial aid	PM		request **governor** to request Dutch	if extreme damage	
S11	Governor request Dutch financial aid	Governor		request **government Kingdom** for financial aid	If requested by **PM**	
S12	Dutch financial aid	Government Kingdom		honors request for financial aid	if requested by **governor**	

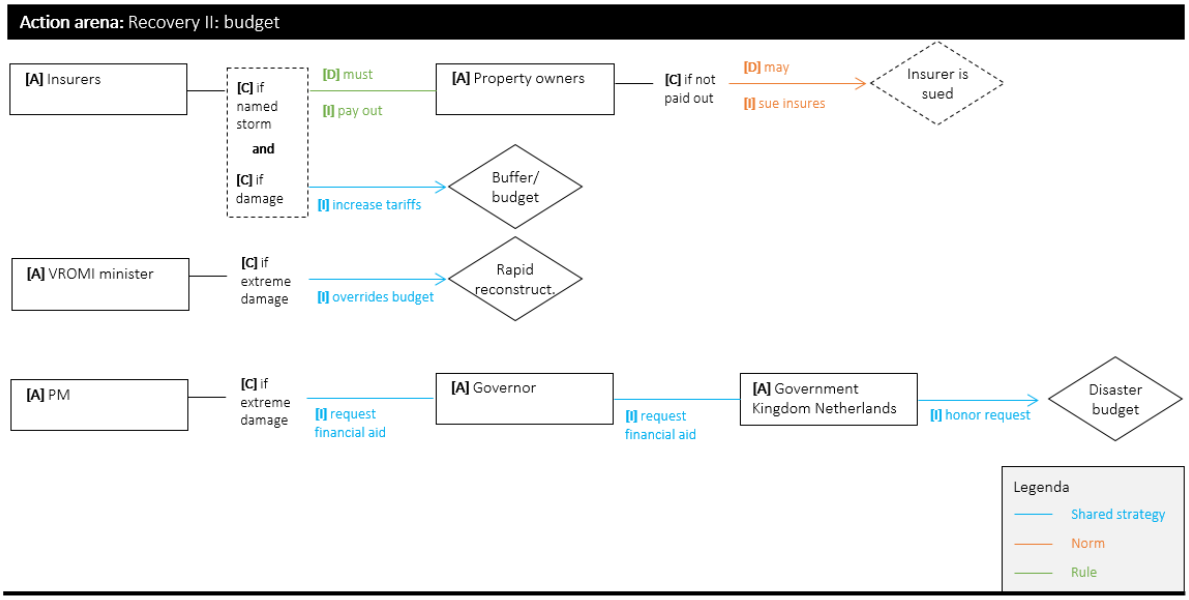

Fig C.2: IND for flood risk recovery: budget

Flood Risk Mitigation on St Maarten

Please refer to section 5.2.2 as well.

EU funding

St Maarten cannot directly apply for EDF CRIP budget. However, through partner projects with the French side of the island, St Maarten may still make use of this funding. The Belle Plaine project is an example of such a project (website St Maarten government, 2014). This joint program focused on storm-water management of a border area, by constructing storm water infrastructure.

Private investment

FRM measures to mitigate flood risk are installed both by businesses and private property owners. In this paragraph, some examples are given.

The harbour is of key economic importance to the island: this not only where products land on the island, but also where tourists go ashore. The harbour has installed flood gates to protect the harbour. This was a private investment, but protecting the harbour has an important public function at the same time. Another example is the installation of a board walk in Philipsburg. This was paid for by the Sint Maarten Hospitality and Trade Association (SHTA). They aimed to protect their businesses next to the shore, while at the same time adding (touristic) value to the area.

Private investment is closely related to individual risk perception. In interviews with locals, most respondents said that they perceive floods as a big risk. Only major events were seen as floods. More localized floods, where some roads are under water, are merely seen as a fact of life. Some households install private flood retention walls to protect their property. The main barrier for installing structural measures is lack of budget. Local interviewees mention that these measures are taken on a single household level.

Mitigation institutions were divided over five action arenas: private property development and land use policies (table 5.3); land use planning and inspection (table C.3); formalizing policy at VROMI (table C.4); national budget for Flood Risk Management (table C.5); and implementing FRM measures (table C.6).

Table C.3: Institutions in mitigation II: Land use planning and inspection

No.	Name	A	D	I	C	O
				Rule		
R19	Inspection requested by permit dept.	VROMI permit dept.	may	request **inspection dept.** to perform inspection	*Default*	
R20	No sanction	VROMI inspection dept.	must not	take action	if no violation building ordinance	
R21	Propose sanction	VROMI inspection dept.	must	propose sanction to **VROMI minister**	if no permit; building in non-designated area; deviation from building plans; or 1 year no building activity	
R22	Sanction: revoke permit	VROMI minister	must	revoke **property owner** permit	if 1 year no building activity; or if deviation from building plans	
R23	Sanction: fine or demolishing	VROMI minister	must	order fine or demolishing for **property owner**	if no permit; building in non-designated area; or if request does not follow building ordinance	
R24	Follow sanction	Property owner	must	follow sanction	if ordered by **VROMI minister**	
				Norm		
N5	Inspection requested by local	Inhabitants	may	request **inspection dept.** to perform inspection	if construction activity threatens own property, or if personal reasons	
				Shared strategy		
S18	No report inspection dept.	VROMI inspection dept.		does not report case, so no sanction	if no extra incentive; or if unaware of risk*	
S19	No sanction VROMI minister	VROMI minister		does not order sanction	if unaware of risk*	Twee keer?!

* For statement S18 and S19 the condition reads "if unaware of risk". Here, the effect that construction activities pose on vulnerability (for example, building in natural gutters) is meant.

Table C.3 shows nine institutional statements, whereas figure C.3 shows ten institutional statements. This mismatch in number of statements is caused by S19: the same statement applies in two cases, under different conditions (respectively if 1 year no building activity or if deviating from building plans, and if no permit or if in non-designated area or if request doesn't follow building ordinance).

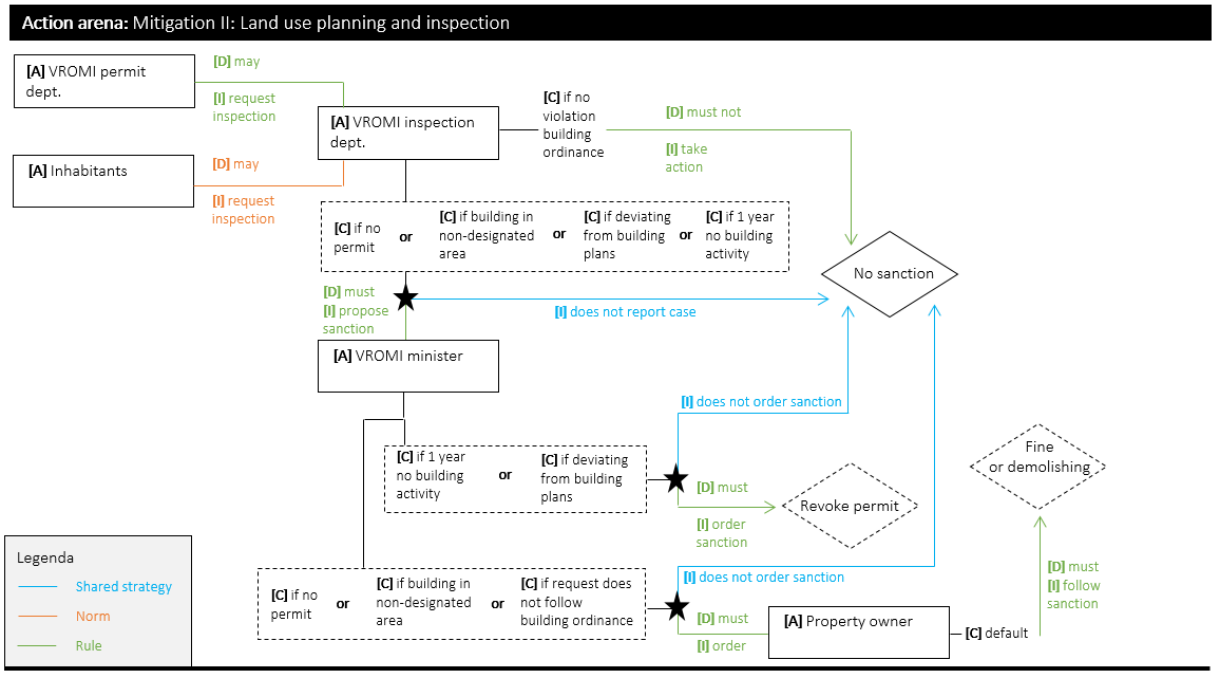

Fig C.3: IND for flood risk mitigation: land use planning and inspection

Table C.4: Institutions in mitigation III: Formalizing policy at VROMI

No.	Name	A	D	I	C	O
				Rules		
R25	Legislative process I	VROMI policy dept.	may	suggest policy to **VROMI minister**	*Default*	Or else not legally binding
R26	Legislative process II	VROMI minister	may	suggest policy to **parliament**	if suggested by **VROMI policy dept.**	Or else policy not legally binding
R27	Ordinance	Parliament	may	confirm ordinance	if requested by **VROMI minister**	Or else policy not legally binding
R28	Law I	Parliament	may	request permission to formalize policy to law	if requested by **VROMI minister**	Or else policy not legally binding
R29	Law II	Government of the Kingdom NL	may	confirm law	if requested by **parliament**	Or else policy not legally binding

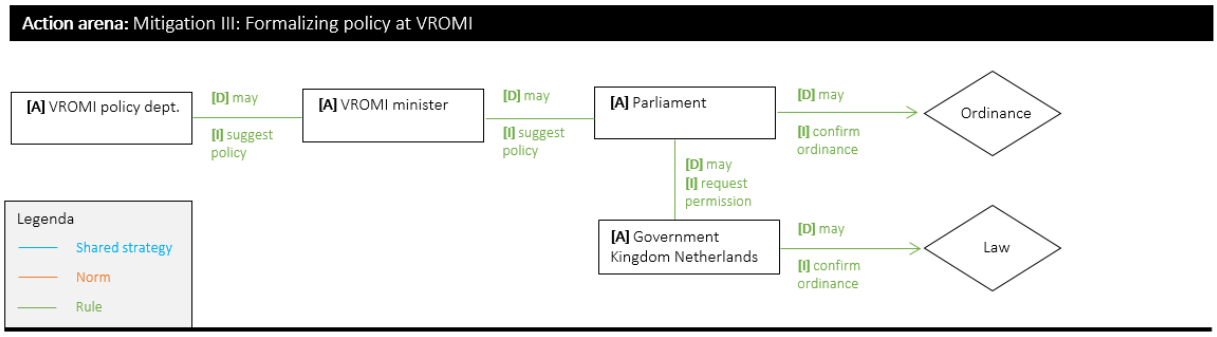

Fig C.4: IND for flood risk mitigation: formalizing policy at VROMI

Table C.5: Institutions in mitigation IV: National budget for FRM

No.	Name	A	D	I	C	O
				Rules		
R30	Budget of ministry I	VROMI minister	must	request **Finance minister** for budget approval	Every year	Or else last year's budget will be granted

R31	Budget of ministry II	Finance minister	must	request **CFT** (financial authority) for budget approval	if requested by **VROMI minister**	Or else last year's budget will be granted
R32	Budget of ministry III	CFT	must	request **Parliament** for budget approval	if requested by **Finance minister**	Or else last year's budget will be granted
R33	Budget of ministry IV	Parliament	may	confirm budget request	if requested by **CFT**	Or else last year's budget will be granted
				Norm		
N6	Joint projects II	French side	may	request **EU** funding for infrastructure projects	if requested by **VROMI new projects dept.**	
N7	Joint projects III	EU	may	honor project fund request	if requested by **French side**	
				Shared strategy		
S20	Disaster budget VROMI	VROMI		reserves 1/4 - 1/2 mln ANG for disaster budget	every year	
S21	Joint projects I	VROMI new projects dept.		suggests joint project with **French side**	*Default*	

Table C.5 includes eight institutional statements, whereas figure C.5 includes nine. This mismatch in number of statements emerged as the sanction [O] of R30 to R33 was included: if there is no budget approval by the finance minister, CFT or parliament, last year's budget is granted.

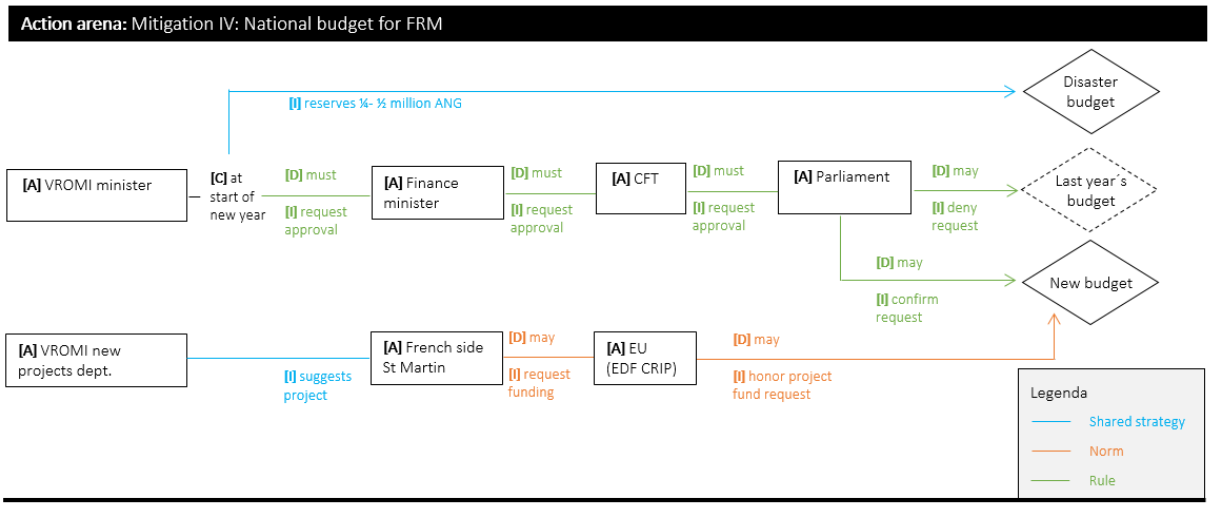

Fig C.5: IND for flood risk mitigation: national budget for FRM

Table C.6: Institutions in mitigation V: Implementing FRM measures

No.	Name	A	D	I	C	O
				Rules		
R34	Budget approval	VROMI minister	must	approve projects	if project costs exceed 5,000 ANG	
				Norm		
N8	Suggest FRM measures	VROMI infrastructure and new projects dept.	may	suggest **VROMI minister** prioritizing FRM measures	if following UNESCO-IHE research, and/or if area flooded in previous year, and/or if budget available	

Shared strategy				
S22	Political priority	VROMI minister	shifts focus towards FRM: adds budget	if election year, and/or flood in present year, and/or casualty due to flood
S23	No political priority	VROMI minister	shifts focus away from FRM: does not add budget	if election year and no flood in present year
S24	Reward FRM measures	Insurers	decrease tariffs to build up buffer	if **property owners** install FRM measures
S25	Self-protection	Property owners	install personal FRM measures	if risk awareness is high or if in cooperation with other **property owners**
S26	Community cooperation	Property owners	seek cooperation with other **property owners** to implement FRM measures	if risk awareness is high
S27	Harbour cooperation	Harbour	Seeks cooperation with **property owners** (businesses)	if risk awareness is high

Whereas table C.6 included eight statements, C. 6 includes eleven statements. These additional statements stem from S25 to S27, where cooperation between property owners (house or company owners) is sought. To include these aims and conditions, I had to add the potential co-operators as attributes within the IND.

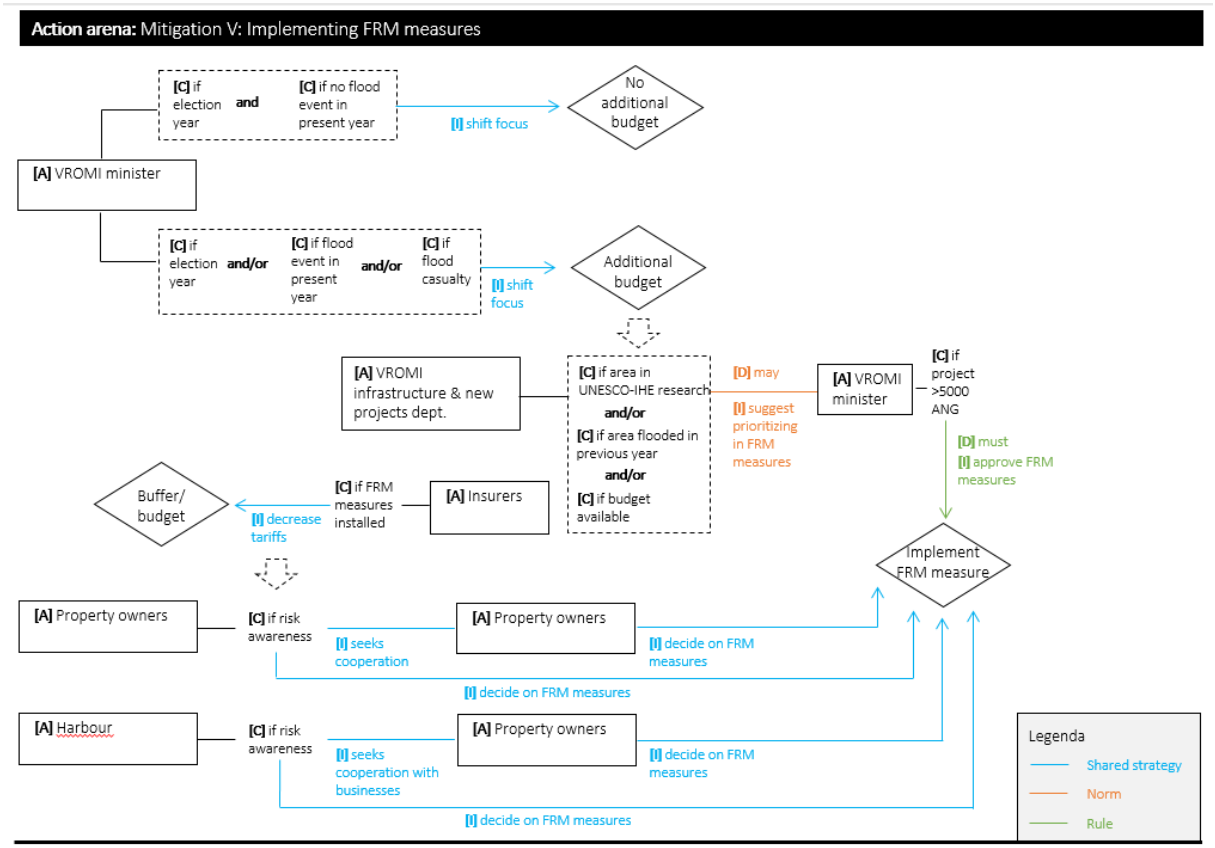

Fig C.6: IND for flood risk mitigation: implementing FRM measures

Flood Risk Preparation on St Maarten

Awareness campaigns

A yearly governmental awareness campaign focuses on protective measures families should take. Families are asked to draw a Family Disaster Plan, where they list the safest room or area in or around the house, determine escape routes, measures to help safe children and pets and check insurance coverage. Moreover, they should prepare a Disaster Supply Kit, with amongst others water, foods, first aid equipment, key documents and cell phones (website St Maarten government, 2016). All locals that were interviewed for this study state that they take preparations before the hurricane season arrives.

Insurances

Due to hurricane Luis, the majority of the properties on the island were damaged or completely destroyed. However, many islanders had insured their properties. That lead both to rapid development after 1995 and to the bankruptcy of many local insurers. For property owners with a mortgage it is mandatory to have an insurance. After flood events, premiums tend to go up, yet the interviewed house owners all mention insurance as an important strategy.

Regional cooperation in flood risk preparation

Formally, St Maarten is not a member of the EU or any of the country level regional organizations. Informally however, St Maarten has ties to regional organizations. Regional cooperation is not a priority for the St Maarten government (interview VROMI), barriers include the many languages spoken on Caribbean islands and the costs of meeting regularly. In preparing for flood events, cooperation with regional actors may help St Maarten.

The institutions that guide preparation are formalized in table C.7.

Table C.7: Institutions in relation to flood risk preparation

No.	Name	A	D	I	C	O
				Rule		
R35	Pre season clean-up	VROMI infrastructure dept.	must	clean gutters	before June (start hurricane season)	
R36	Mandatory insurance	Property owners	must	insure their properties	*Default*	or else property owner will not receive a mortgage
				Norm		
N9	Awareness campaign	Dept. of communication	may	run flood risk awareness campaign	before June (start hurricane season)	
				Shared strategy		
S28	Harbour protection	Harbour		updates and practices disaster management plan	before June (start hurricane season)	
S29	Inhabitants preparedness I	Inhabitants		develop household disaster plan	if risk aware and before June (start hurricane season)	
S30	Inhabitants preparedness II	Inhabitants		clean gutters	if risk aware and before June (start hurricane season)	

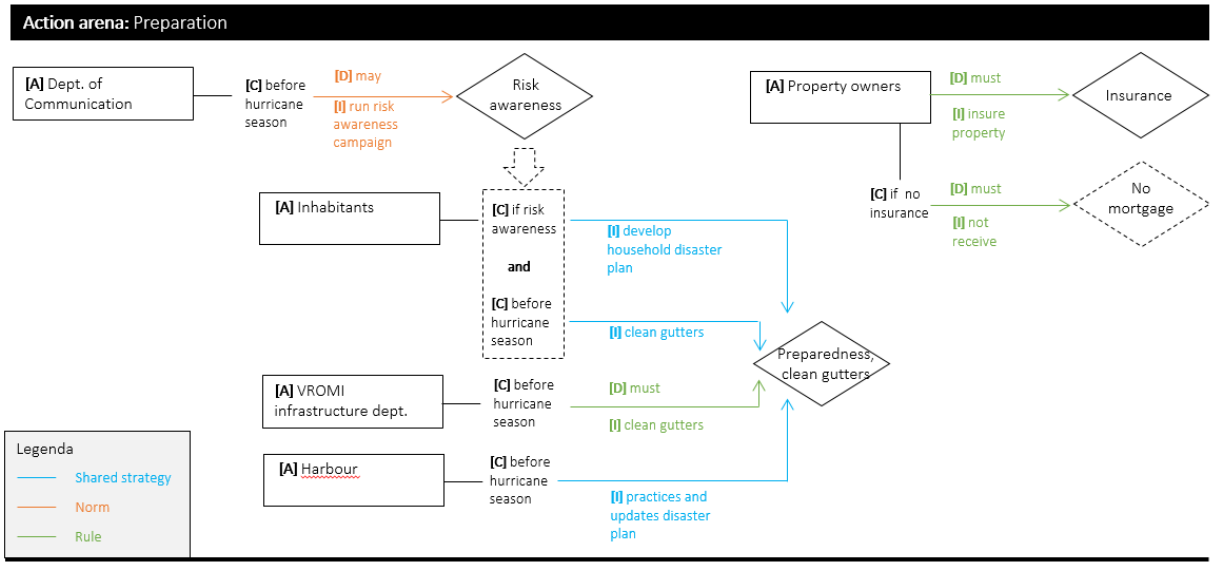

Fig C.7: IND for flood risk preparation

Appendix D – Zoning map St Maarten

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Appendix E – Calculations IND network metrics

The tables below show the calculations for the network metrics density, centrality and embeddedness that are discussed in section 5.3.2.

Table E.1: Density per IND

Density is given both only based on attributes and on all nodes (attributes and outcomes) and calculated by dividing the number of actual links by the number of possible links.

IND	# attributes	# nodes	# links between attributes	# links total	Possible # links between attributes	Possible # links	Density (based on attributes only)	Density (based on all nodes)
Response	9	12	6	12	36	66	0.167	0.182
Recovery I	6	8	4	10	15	28	0.267	0.357
Recovery II	6	10	3	7	15	45	0.200	0.156
Mitigation I	3	6	2	9	3	15	0.667	0.600
Mitigation II	5	8	4	10	10	28	0.400	0.357
Mitigation III	4	6	3	5	6	15	0.500	0.333
Mitigation IV	7	10	5	9	21	45	0.238	0.200
Mitigation V	6	10	3	11	15	45	0.200	0.244
Preparation	5	9	0	7	6	15	0.000	0.467
Subtotal recovery	10	16	7	17	45	130	0.156	0.131
Subtotal mitigation	16	31	17	44	130	465	0.131	0.095
Total	22	49	30	80	231	1176	0.129	0.068
Average density							**0.293**	**0.321**

Table E.2: Level of centrality and embeddedness per attribute

In blue: >1.00 centrality rank (2nd column) and an >0.5 rank on embeddedness (3rd column).

Attribute	Level of centrality (#links per attribute/ average # links per attribute)	Embeddedness (#links to other attributes/ total #links of attribute under focus)
VROMI minister	4.76	0.50
Property owner	2.97	0.47
Inhabitants	1.39	0.43
VROMI infra	1.19	0.50
Parliament	1.19	0.50
Governor	1.19	0.67
VROMI permit	0.99	0.60
VROMI inspection	0.99	0.60
Harbour	0.99	0.40
NGOs	0.79	0.50
Gov Kingdom NL	0.79	0.75
PM	0.79	0.75
Insurers	0.59	0.33
Contractors	0.59	0.67
Dutch Navy	0.40	0.50
VROMI new projects	0.40	1.00
French side	0.40	1.00
EU	0.40	0.50
Finance minister	0.40	1.00
CFT	0.40	1.00
VROMI policy dept	0.19	1.00
Dept communication	0.19	0.00
Average #links per attribute	5.05	NA
Average	1.00	**0.62**

Appendix F – Conceptual ABM for FRM on St Maarten

This conceptual ABM is structured around the MAIA layers, for all five layers the concepts are defined as far as possible based on this research on the institutional dimension of flood risk management on St Maarten. The collective structure is where actors, their properties and decision making criteria are defined. In the physical structure the physical properties and the physical impact of actions in the action arena are formalized. The constitutional structure entails institutions in ADICO syntax, actor roles and interdependencies. The operational structure is where the action arenas, the dynamics between decision makers and the frequency of actions are all defined. The evaluative structure allows for validation of the model, here variables that can be studied, the working of the model and expected findings come together.

Collective structure

One difficulty arises immediately when defining agents, based on the INA research. Here, a total of 22 decision makers were identified. Within INA, a difference is made between primary attributes – attributes that stand at the start of a sequence of institutions – and non-primary attributes. Here, non-primary attributes are not modelled as agents, but rather as a *chance* that an action is performed. This will be further explained in the operational structure.

When focussing on primary attributes, a distinction between private agents and public agents can be made. Based on centrality and density, the most crucial actors are defined: inhabitants, commercial actors and the minister of VROMI. For all three actor types the defining properties and potential values are listed below.

The actor type inhabitants includes property owners and business owners with a property as well, these are two of the key properties an inhabitant may possess. Commercial actors are here restricted to the harbour and insurers. As these are treated as organizations, rather than individuals they are modelled separate from the actor type inhabitants. The VROMI minister holds a crucial position in FRM on St Maarten and is therefore modelled as a separate actor type. Crucial characteristic for the minister is its focus: focus on flood risk management, on economic growth or neither. This defines his or her role (see constitutional structure).

Table F.1: Three actor types and their properties

Inhabitant	
Property	**Property values**
Property owner	[yes, no]
Business owner with property	[yes, no]
Budget	[small, large]
Focus	[flood risk, other]
Flood experience	[high, medium, low]
Commercial actor	
Property	**Property values**
Organization	[harbour, insurer]
Focus	[flood risk, other]
Flood experience	[high, medium, low]
VROMI minister	
Property	**Property values**
Budget	[small, large]
Focus	[flood risk, other]
Flood experience	[high, medium, low]

For simplicity reasons, other public actors are not modelled as actor types, but their actions are included in the storyline of the model and the interactions that take place in the action arenas in the operational structure.

Constitutional structure

The constitutional structure consists of roles, institutions and dependencies. First, I will define different roles actors can take. Secondly, I explain how the INA translates to the constitutional structure.

Roles

The willingness to act on flood risk is made dependent on the roles actors take within the model. Below, different roles for all three actor types are defined based on their key characteristics. I define five different roles for inhabitants, two for commercial actors and four for the VROMI minister. An interesting addition would be to make the factor of the population that follows a certain role dependent on the occasion of a flood event. In other words, in the year after a flood event, a portion x may change focus from economic growth or no focus to a focus on flood risk, hereby increasing the probability of for example installing FRM measures.

Table F.2: Three actor types and their potential roles

Inhabitant	No property owner	Risk aware, small budget	Risk aware, large budget	Unaware, small budget	Unaware, large budget
Property owner	No	Yes	Yes	Yes	Yes
Business owner with property	No	Yes or No	Yes or No	Yes or No	Yes or No
Budget	Small	Small	Large	Small	Large
Focus	Flood risk or other	Flood risk	Flood risk	Other	Other
Flood experience	Setup value: medium	Setup value: medium	Setup value: medium	Setup value: medium	Setup value: medium

Commercial actor	Active in FRM	Not active in FRM
Organization	Harbour or insurer	Harbour or insurer
Focus	Flood risk	Other
Flood experience	Setup value: medium	Setup value: medium

VROMI minister	Active in FRM, small budget	Active in FRM, large budget	Not active in FRM, small budget	Active in FRM, large budget
Budget	Small	Large	Small	Large
Focus	Flood risk	Flood risk	Other	Other
Flood experience	Setup value: medium	Setup value: medium	Setup value: medium	Setup value: medium

Institutions and dependencies

The dependencies between actors based on interlinked institutions have been defined in the INDs. The ADICO statements that guide action can be included in the MAIA framework directly. They can be found in appendix C.

Physical structure

The physical structure of MAIA includes all physical elements of the system. Institutional Network Analysis provides limited insight into the physical structure of an ABM. However, the institutions do affect the physical world through the outcomes. Two important physical features include properties and infrastructure.

For properties, it is important to include the geographical spot, so that it can be determined whether the property is located in a flood prone area or not. Moreover, for each property it should be specified whether structural flood risk management measures, such as constructing a retention wall or elevating ground floor level, were taken.

For infrastructure, the geographical area should be included as well, to understand when the road might be flooded. Moreover, the model should specify whether FRM measures are in place, such as a well-maintained gutter system.

The most important physical feature of the system are potential floods. For the case of St Maarten, UNESCO-IHE has developed a flood model that works with geographical information. By layering maps, including relief and precipitation, the flow of floods can be modelled. This flood model should be linked to the ABM in such a way that the model checks whether a property or piece of infrastructure is affected by a modelled flood or not. If a property lies in the flood prone area, but a specific flood does not reach the property, its owners will not take any response/recovery action for example.

In short, the physical features of the model should include a flood model, that is linked to the geographical location of properties and infrastructure, so that it can be assessed whether these structures will be affected by a flood.

Operational structure

The operational structure is where the dynamics of the system are defined: how and when do actors make decisions and how are they interlinked? Here, the information that the INDs contain comes in handy, as the INDs already provide insight in the sequence of actions. Below, the storyline of the model is given in bullet points. I explain what setup conditions are necessary to make the model work and I define one 'tick', one iteration of the model, assuming that one 'tick' corresponds with one year.

Setup

Here, the setup conditions for the model are defined: those variables that should be assigned before the model may be run.

- Introduce number of actors per category
- Assign roles
- Define physical attributes

An example of a simple setup of the model is given in table F.3. Here, 100 inhabitants are randomly located on the island and their roles are assigned randomly as well. Note that the focus of the actors might change over time as the model runs, due to the occurrence of flood events. Three commercial actors are included: one harbour and two insurers, with different focus. The minister is in this model set to be inactive in FRM with a small budget. Again, the political priority of the minister might shift during the run time of the model.

Table F.3: Setup conditions for the conceptual model

Actor type	Total	Roles	Physical attributes
Inhabitants	100	20 no property owner 20 risk aware, small budget 20 risk aware, large budget 20 unaware, small budget 20 unaware, large budget	- 20 properties, located anywhere 20 properties, located anywhere 20 properties, located anywhere 20 properties, located anywhere
Commercial actors	3	1 harbour, not active in FRM 1 insurer, not active in FRM 1 insurer, active in FRM	1 property, located where actual harbour is - -
VROMI minister	1	1 not active in FRM, small budget	Define %infrastructure with FRM measures

One tick

An ABM works on 'ticks'. During one tick, actors perform actions that affect their setup position for the next tick. Here, I choose to make one tick represent one year, as some of the institutions guiding the FRM cycle (yearly preparation before the hurricane season and national budget assignment for example). An assumption for simplicity reasons is that a major flood event can only occur once a year. Another key assumption is that structural FRM measures (for example flood retention walls for households and gutters for infrastructure) provide protection from flood events. This is of course not

completely realistic, but it does provide an easier basis for analysing the impact of smaller FRM measures. Below, in bullet point style, the storyline of the model, based on the institutions guiding action in the action arenas is given.

- Set up
    - Alter physical property based on previous year
        - Add new buildings
        - Subtract demolished buildings (both through sanctions and flood events)
    - Alter actor roles based on previous year
        - Set percentage of actors that change from 'other focus' to 'focus on flood risk' or the other way around, based on whether there was a flood event in the previous year
- Tick
    - Execute IND preparation
    - Include output flood model
        - Set chance for flood to occur and define randomly of this year holds a flood event
        - If flood:
            - Define flooded area, assuming that all properties in this area are affected in such a way that response (clean-up) is needed
            - Define what properties are located in the flooded area
            - Define actors that own properties in the flooded area

There will be different actions performed if the present year has a flood, compared to a year without a flood event. The sequence of action, guided by the INDs is summarized below for both options.

- In case flood model has 'no flood' as output:
    - Execute IND Mitigation I + II
        - Property owners may decide to build a property (chance based on the fact that in 2015, about 250 properties were developed, this should be corrected for the total number of agents that are included in the model)
        - Property owner checks budget first (building only possible if high budget)
        - Inspection may be less strict, if present (and previous) year no flood
    - Execute IND Mitigation IV
        - No request for extra budget
        - No cooperation with French side
        - Strategy of reserving disaster budget may be cancelled, if present (and previous) year no flood
    - Execute IND Mitigation V
        - No request for extra budget (S19 in action)
        - Little incentive for FRM measures for actors, if present (and previous) year no flood
- In case flood model has 'flood' as output:
    - If property in flooded area
        - Execute IND Response
        - Execute IND Recovery I + II
    - If property not in flooded area
        - Execute IND Mitigation I + II
            - Property owners may decide to build a property (chance based on the fact that in 2015, about 250 properties were developed, this should be corrected for the total number of agents that are included in the model)
            - Property owner checks budget first (building only possible if high budget)
            - Inspection may be more strict, if present (and previous) year flood
            - Property owners may be more willing to follow building procedures, if present (and previous) year flood
    - Execute IND Mitigation III

        - Institutions may be formalized, if present (and previous) year flood
    - Execute IND Mitigation IV
        - Request for extra budget
        - Seek cooperation with French side
        - Strategy of reserving disaster budget may be increased, if present (and previous) year flood
    - Execute IND Mitigation V
        - Request for extra budget (S18 in action)
        - Little incentive for FRM measures for actors, if present (and previous) year no flood
    - If property in flooded area
        - Execute IND Mitigation V
            - Property owners may decide to install FRM measures
            - Property owner checks budget first: only possible if high budget

Non-primary attributes are activated by actions performed by other attributes. There are two types of such situations, where institutions are nested and interdependent:

1. Nested attribute has no choice

For example, in the response IND, the VROMI minister orders the infrastructure department to participate in the clean-up. The infrastructure department is not a decision maker here, as this attribute simply follows instructions. I would suggest not to model such attributes, and link the decision making actors to the outcome straight away. Table F.4 shows in where in the FRM cycle these situations occur.

2. Nested attribute has a choice

The second category of nested attributes does have a choice. For example, the government of the Kingdom of the Netherlands may confirm a law proposed by the St Maarten parliament. A modelling option would be to implement a chance that the nested attributes agrees with or prolongs an action. A drawback of this way of representing these nested attributes is that it is difficult to base such a chance on the data that were obtained for this research. A standard factor of 0.8 (80% of all actions are prolonged) for example might overcome this.

Table F.4: List of secondary attributes, their possible actions and whether they have a choice or not

Attribute	Action	Choice
Governor	Passes on PM request for Navy help to Gov of the Netherlands	No choice
	Passes on PM request for financial aid to Gov of the Netherlands	No choice
Gov Kingdom NL	May order Dutch Navy to assist in clean-up	Choice
	May honour request financial aid in recovery	Choice
	May confirm law	Choice
Dutch Navy	Helps with clean-up if ordered	No choice
NGOs	May help with clean-up	Choice
	May help with reconstruction	Choice
VROMI infra dept	Executes clean-up	No choice
Contractor	Execute reconstruction activities	No choice
Property owners	May sue insurers if no pay-out	Choice
	Demolishes building if ordered:	No choice
VROMI permit dept	May issue permit	Choice
	May not report case	Choice
	May proposes sanction to VROMI minister	Choice
VROMI minister	May not order sanction	Choice
	May order sanction	Choice
	May suggest policy to parliament	Choice
VROMI inspection dept	May order no sanction	Choice
	May not report case	Choice
	May proposes sanction to VROMI minister	Choice

Parliament	May confirm policy to become ordinance	Choice
	May request permission of Kingdom of NL to issue law	Choice
	May approve budget request CFT	Choice
Finance minister	May approve budget request VROMI minister	Choice
CFT	May approve budget request Finance minister	Choice
French side	May request EU funding	Choice
EU	May honor project budget	Choice

Evaluative structure

Please refer to section 5.4.2