

From Earth Observation Data to Flood Risk Management Services

Entrepreneurial Opportunities on Bonaire

Kim Bosch



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by

Kim Bosch

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Thesis committee: Dr. ing. V.E. Scholten, TU Delft, chair
E. van Andel MSc, TU Delft, first supervisor
Dr. N.Y. Aydin, TU Delft, second supervisor
Dr.ir. J. Timmermans, TU Delft, external advisor

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Executive Summary

Climate change is making extreme rainfall and flooding more frequent, and small islands such as Bonaire are especially exposed. Infrastructure and economic activity are concentrated in low-lying coastal areas, while the local capacity and data to manage flood risks are limited. The risks became visible during the extreme rainfall of November 2022, when roughly 80 mm fell in a single night, submerging streets and homes, closing the hospital and schools, and sending polluted run-off onto the coral reefs. The economic stakes are high: storms and floods are projected to cause around US\$317 million in damage on Bonaire by 2050, and degradation of the reefs that buffer the coast could contract the island's economy by up to a quarter of its GDP. In January 2026, a court ruled that the Netherlands had not adequately protected the island, placing flood risk higher on the political and legal agenda. Earth Observation (EO) data can help monitor and predict floods, and for the Dutch Caribbean it is already openly available. Raw satellite data, however, cannot be used directly: it must be processed into products that local stakeholders can understand and act on. This study asks how EO data can be translated into entrepreneurial flood risk management services on Bonaire.

The research is a qualitative, exploratory case study built on 21 semi-structured interviews with stakeholders across the local and national government, knowledge institutions, nature organisations, the private sector, and EO companies. The interviews followed a needs-first (Mom Test) logic, probing actual practices and past problems rather than hypothetical demand. Transcripts were analysed through a hybrid deductive-inductive thematic analysis in ATLAS.ti, using open, axial, and selective coding, which produced seven themes. Two theoretical lenses structure the analysis. The EO value chain, running from data providers through service providers to customers, organises the needs by the level at which they arise. Bryson's power-interest grid (Bryson, 2004) maps stakeholders by their power to act and their interest in flood risk, locating where demand sits and where the power to fund and adopt a service lies.

At the *data level*, satellite coverage is abundant but insufficient on its own: global datasets are too coarse for a small island, with grids on the order of 100 km, and outputs need in-situ ground validation, historical imagery of past events, and currently missing base registrations before they become reliable. Subsurface conditions, such as the porous coral dike that carries seawater hundreds of metres inland, are poorly captured by standard EO. At the *service provider level*, the dominant need is to turn raw data into products that non-technical users can operate, integrating optical imagery, aerial photos, and LiDAR-derived elevation models, and reporting the uncertainty of forecasts and models rather than obscuring it. Matched to these needs, the most suitable modalities are high-resolution optical and LiDAR elevation data for flood mapping and spatial planning, cloud-penetrating SAR for monitoring through the rainy season, and optical time series for mangrove monitoring, the last being the most successful pilot application observed. At the *customer level*, four needs recurred: restoring water storage through dams, rooien, and salifias; improving drainage; a faster and more reliable early warning system, which is currently absent and runs through informal channels; and greater awareness of what EO can do. Most applications fall under flood prevention, with response and recovery still largely unexplored.

The central finding is that the binding constraint is not the availability of satellite data but the translation of that data into accessible, usable products. This service provider role exists on Bonaire only in fragments, through individual projects and pilots, rather than as a continuous, locally embedded service. Three findings explain why the link is hard to fill. Awareness of EO is low across most user groups, though it varies, with nature organisations and some individuals inside government more aware than others. The main obstacle is financial and organisational rather than technical: services struggle to stay funded once a pilot ends, in a small market that leans heavily on project-based public money, and the party that would pay is rarely the party that benefits. Finally, adoption depends on governance and trust. The power-interest grid reveals a structural mismatch: the actors with the most interest in flood risk, such as residents, nature organisations, and infrastructure operators, have the least power, while

the powerful actors, mainly the Ministry of Infrastructure and Water Management (IenW) and the Ministry of the Interior and Kingdom Relations (BZK), have a distant interest, and real estate developers hold an interest that runs counter to flood management.

EO data can support flood risk management on Bonaire, but the data alone is not enough. It becomes useful only when a service turns it into usable products, funding keeps that service running, and local support ensures it is actually used. The recommendations are therefore directed at the two groups whose action matters most.

For an entrepreneur, the opportunity lies in the service provider role: turning raw data into an integrated tool that combines elevation, water flows, and infrastructure with local data and knowledge, bundled with education and engagement, and targeting prevention first. A commercial venture aimed at Bonaire alone is unlikely to be viable; a regional service spanning several islands, which spreads the fixed cost of acquisition and processing across more users, is the more realistic path. Because adoption depends on trust, such a service would need to work through a local champion, possibly one of the EO-aware individuals already within the OLB.

For the government, the priority is continuity, since the main obstacle is not building a service but keeping it running. This calls on BZK and IenW to move from project-based towards structural funding, comparable to how the Delta Programme secures water safety in the European Netherlands. It also requires closing a governance gap: with neither a province nor a water board, responsibility for flood measures falls between the national government and the OLB, so BZK, as the coordinating ministry for the special municipalities, should assign a clear owner for such a service rather than leaving it in that gap. At the island level, the OLB can strengthen the basis for permitting itself, where procedures are currently slow because the underlying rules are unclear or absent. Setting clear criteria against which applications are tested, using the zoning-plan revision to assess flood risk at new developments, and introducing drainage requirements for private developers would give both the zoning plan and EO-based risk information a concrete point of entry into permitting decisions.

The first step, however, is not technical but a matter of building awareness and capacity among the users closest to the problem, and the upcoming zoning-plan revision, the developing climate plan, and the January 2026 court ruling open an institutional window in which to do so.

Contents

Executive Summary	i
1 Introduction	1
1.1 Background and context	1
1.2 Problem ownership	2
1.3 Problem statement	2
1.4 Research objective	3
1.5 Research question and sub-questions	3
1.6 Relevance to Management of Technology	4
2 Theoretical background	5
2.1 Case: Bonaire	5
2.1.1 Flood risks on Bonaire	6
2.1.2 Socio-economic context	7
2.2 The EO value chain	8
2.3 The data level: sources for monitoring floods	10
2.4 The service provider level: turning data into usable products	11
2.4.1 Flood risk management measures	11
2.5 The customer level: users and funding	12
2.5.1 Public-private partnerships and insurance	12
2.6 Existing EO flood services	13
2.7 Research gap	13
3 Methodology	15
3.1 Research design	15
3.2 Data collection	15
3.3 Data analysis	17
3.4 Validity and reliability	18
4 Results	19
4.1 Stakeholder analysis	19
4.2 Needs and applications	22
4.2.1 Data level	23
4.2.2 Service provider level	24
4.2.3 Customer level	25
4.3 Barriers and market conditions	27
5 Discussion	30
5.1 Potential customers and applications	30
5.1.1 Potential customers	30
5.1.2 Applications	31
5.2 Awareness and capacity	33
5.3 Continuity and funding	33
5.4 Governance and trust	35
5.5 Recommendations	36
6 Conclusion	38
6.1 The needs of potential customers	38
6.2 Suitable EO data and service features	38
6.3 Opportunities and challenges for entrepreneurs	39
6.4 Answering the main research question	39

6.5	Limitations	40
6.6	Future research	40
References		42
A Summary of interviews		45
A.1	National meteorological institute 1	45
A.2	Consultant in water management	45
A.3	Developer of flood maps for the Caribbean	45
A.4	National meteorological institute 2	46
A.5	International nature conservation organisation	46
A.6	National representative of Dutch Government on Bonaire	47
A.7	Local nature organisation 1	47
A.8	Research institute focused on water management 1	48
A.9	Public Entity Bonaire 1	48
A.10	Local nature organisation 2	49
A.11	Public Entity Bonaire 2	49
A.12	Research institute focused on water management 2	50
A.13	Bank on Bonaire	50
A.14	Dive school	50
A.15	Ministry of Infrastructure and Water Management 1	51
A.16	Ministry of Infrastructure and Water Management 2	51
A.17	Local government 3	51
A.18	Environmental NGO	52
A.19	Earth observation startup	52
A.20	Earth observation service provider	53
A.21	Tourism organisation	53
B Use of AI		55
C Interview protocol		56
D Codebook		58

1

Introduction

As climate change makes extreme weather events such as floods more frequent and severe, the demand for up-to-date and detailed information to manage flood risks has grown. This is especially true for small islands such as Bonaire in the Dutch Caribbean, where infrastructure and economic activity are concentrated in low-lying coastal areas, and where the capacity and data to manage these risks are often limited. Earth Observation (EO) data, collected by satellites, can help to monitor and predict floods. This makes it an increasingly important tool for flood risk management and climate adaptation more broadly (McCabe & Rodell, 2017; Schumann & Brakenridge, 2018).

1.1. Background and context

Bonaire is one of three Dutch Caribbean islands that form the BES islands, together with St Eustatius and Saba. Since 2010 these islands have been special municipalities of the Netherlands, which makes them administratively part of the country itself, rather than constituent countries within the Kingdom of the Netherlands such as Curaçao, St Maarten, and Aruba. All six islands face flood risks due to their geographical characteristics (Deltares, n.d. International Panel on Deltas and Coastal Areas (IPDC), 2024; Royal Netherlands Meteorological Institute (KNMI), 2025).

This study focuses on Bonaire because of its high exposure to flood risks. Small islands are generally more vulnerable to climate-related flooding than continental regions (Petzold & Ratter, 2015). Much of their land lies near the coast, leaving little high or inland ground to retreat to, and their towns, infrastructure, and economic activity tend to be concentrated in low-lying coastal areas. Critical facilities such as the hospital, airport, and port often exist only once and have no backup elsewhere on the island, so a single flood event can disrupt essential services across the whole island. At the same time, the small population limits the local capacity and resources available to manage these risks.

This vulnerability is not only a matter of exposure, but also of the capacity to act on it, which is what makes small islands a relevant setting for Earth Observation specifically. Satellite data now covers almost the entire planet, but the value it generates depends on the local capacity to process and apply it, which is often limited in regions with little technical infrastructure (Codyre & Murphy, 2025). Small islands sit clearly in this gap: the data is available, but the resources to turn it into usable products are scarce. These conditions make the demand side and the feasibility of EO-based services, rather than their technical potential, the open question on small islands. Bonaire is a useful case for examining this question, as it combines a high-income status with the limited local capacity more typical of lower-income regions. Studying it therefore offers insight not only for Bonaire, but for small islands and small user groups that face the same combination of high exposure and thin capacity.

The seriousness of flood risks became clear in November 2022, when around 80 mm of rain fell in a single night. This caused severe flooding, submerging streets and some homes (De Boer et al., 2023). The flooding led to power outages, debris on roads, and polluted run-off reaching the coral reefs. It highlighted the island's vulnerability to extreme weather and the shortcomings of its drainage systems.

This event was not an isolated incident, but part of broader water management challenges on Bonaire (Waterschap Rijn en IJssel, 2023). The island's drainage capacity is limited, and maintenance of its dams and waterways is overdue. Combined with a growing expanse of paved surfaces, these factors make heavy rainfall more likely to cause flooding. In addition, erosion and sediment run-off during heavy rain can damage the coral reefs, which are crucial for coastal protection, tourism, and the local economy. The economic stakes are high. Storms and floods are projected to cause around US\$317 million in damage on Bonaire by 2050, and degradation of the reefs that buffer the coast could contract the island's economy by up to a quarter of its GDP (Van Oosterhout et al., 2023).

These flood risks and their economic consequences have moved up the political and legal agenda in recent years. In 2024, the Public Entity Bonaire started a climate table with the aim of developing a climate plan for Bonaire, including agreements on adaptation and mitigation. Because the effects of climate change are already being felt, the local government requested support from the Dutch government. The climate table is meant to bring together different stakeholders to work jointly on climate action (Nijpels, 2023). The pressure increased further in January 2026, when the District Court of The Hague ruled that the Netherlands did not adequately protect the inhabitants of Bonaire against the effects of climate change, in violation of its positive obligations under the European Convention on Human Rights (Rechtbank Den Haag, 2026). The court found that the people of Bonaire received less protection than those in the European Netherlands, and that this difference was not justified, making it a case of unequal treatment. For adaptation, the most relevant part of the ruling for this thesis, the court ordered the State to develop a protection plan for Bonaire and have it implemented by 2030.

Dealing with these flood risks is not only a matter of political and legal pressure, but also of having good information about where and how flooding happens. EO data can provide much of this information, and for the Dutch Caribbean it is already openly available: the Netherlands Space Agency (NLSA), formerly the Netherlands Space Office (NSO), provides open access to EO data for the BES islands (Netherlands Space Agency, 2025). However, raw satellite data cannot be used directly. It first has to be processed and turned into products such as flood maps and early warnings before it becomes useful for decisions.

1.2. Problem ownership

Responsibility for flood risk management on Bonaire is shared between the national government and the Public Entity Bonaire (OLB). This shared arrangement is shaped by Bonaire's particular position: since becoming a special municipality in 2010, it falls under neither a province nor a water board, the layers that in the European Netherlands carry much of the responsibility for water and flood management. As a result, tasks are divided differently. The OLB is in charge of spatial planning, drainage, and crisis management. The national government carries the responsibilities that are especially relevant for funding and long-term protection, divided over two ministries: the Ministry of Infrastructure and Water Management (IenW), responsible for water and flood protection, and the Ministry of the Interior and Kingdom Relations (BZK), which coordinates the relationship with the special municipalities (Nijpels, 2023; Waterschap Rijn en IJssel, 2023).

Together these are the actors formally responsible for managing the problem. However, turning available EO data into usable information requires capacities these parties do not always have in-house. This points to a possible role for a different kind of actor: an entrepreneur or company that could take on the service provider role, turning raw satellite data into services that the responsible parties can use. Whether such a role is viable on Bonaire is the central question of this thesis.

1.3. Problem statement

Flood risk assessment and monitoring with EO data is a well-developed field within climate adaptation. EO data is already used to analyse precipitation patterns, surface water dynamics, land use, and coastal vulnerability, which provides useful information for flood risk management (Guo, 2010; Schumann & Brakenridge, 2018).

Despite this, turning raw EO data into usable flood risk management services remains difficult, particularly on small islands such as Bonaire. The data itself is increasingly available, but turning it into products that local users can understand and act on requires processing, interpretation, and local knowl-

edge, and this is often where small islands fall short: they tend to have limited technical resources and institutional capacity. Local governments and communities on Bonaire face clear flood risks, but they often lack the technical capacity and resources to work with raw EO data themselves (Bremmer, 2016; Schumann & Brakenridge, 2018). Existing EO tools compound this, as they are usually built for large markets and standard use cases rather than the specific conditions of a small island, and a market of one island is often too small to sustain such a service on its own.

This suggests that the problem is a missing link rather than a missing technology: the value of EO data depends on actors who can turn it into usable services. On Bonaire, however, it is not clear whether this role is being filled, which services would actually match the needs of stakeholders, or whether there is a viable position for entrepreneurs in this value chain. EO startups elsewhere show that there is demand for such services, but it is still unknown how well current services fit the Dutch Caribbean context and what opportunities and challenges entrepreneurs face when developing them. This shows the need for research that connects what is technically possible with the needs of potential users (Denis et al., 2017), addressed here through three sub-questions: what potential customers need, which EO data and service features suit those needs, and what opportunities and challenges entrepreneurs face in developing them.

1.4. Research objective

The objective of this research is to understand whether and how EO data can be developed into flood risk management services on Bonaire, and what this would require from an entrepreneur. Rather than testing or improving a specific tool, the study looks at the demand and entrepreneurial side of EO-based flood services: who the potential customers on the island are, what they need, and whether a viable service can be built around those needs.

This focus differs from most earlier research on EO and flooding, which concentrates on the technical side, such as flood monitoring, mapping, and risk assessment (Guo, 2010; Schumann & Brakenridge, 2018). Much less attention has been given to who would actually use the data, what they need, and whether providing such a service is feasible on a small island. In practical terms, the findings aim to help entrepreneurs identify realistic opportunities for EO-based flood services, and to give potential customers insight into how such services could strengthen flood risk management on the island.

1.5. Research question and sub-questions

This study examines how Earth Observation (EO) data can be translated into entrepreneurial flood risk management services on Bonaire. To explore this topic, the research is structured around a main research question and three sub-questions that address different aspects of the problem.

The thesis addresses the following main research question:

How can Earth Observation (EO) data be translated into entrepreneurial flood risk management services on Bonaire?

To answer this main research question, three sub-questions are developed:

1. **What are the needs of potential customers regarding flood risk management services on Bonaire?**
2. **Which types of Earth Observation data and service features are most suitable for addressing these needs?**
3. **What are the opportunities and challenges for entrepreneurs developing EO-based flood risk management services on Bonaire?**

The first sub-question explores the needs and expectations of potential customers regarding flood risk management services on Bonaire. Understanding these needs is essential to ensure that potential EO-based services are relevant and useful for local stakeholders. The second sub-question examines which types of EO data and service features are most suitable for addressing these needs. The third sub-question investigates the opportunities and challenges that entrepreneurs face when developing EO-based flood risk management services. Together, these sub-questions build towards an answer to the main research question.

1.6. Relevance to Management of Technology

This thesis fits well within the Management of Technology (MOT) programme, which prepares students to work as managers and entrepreneurs in technology-driven environments. The research investigates Earth Observation (EO), a technology with many possible applications, and explores how it could be turned into a commercial service for flood risk management on Bonaire. This combination of technology and entrepreneurship is one of the main themes of the MOT programme.

Several courses contributed to the way this thesis was set up. *Technology, Strategy and Entrepreneurship*, *Turning Technology into Business*, and *Idea to Startup* helped in thinking about how a technology like EO can be developed into a service. They also provided tools for looking at customer needs and value propositions. *Emerging and Breakthrough Technologies* provided a useful background for understanding how new technologies move from a technical capability towards real-world applications. *Inter- and Intra-organizational Decision Making* contributed to the stakeholder analysis and to thinking about how different actors are involved in flood risk management on Bonaire. *Technology Dynamics* helped to place the topic in a broader context by looking at how technological, social, and institutional factors influence the adoption of new services. Finally, *Research Methods* provided the foundation for the qualitative research design, the interview process, and the reflection on reliability and validity.

2

Theoretical background

This chapter builds towards the central question of whether there is a viable role for a service provider that turns EO data into flood risk management services on Bonaire. It does so in three steps. It first introduces the case of Bonaire, its flood risks, and its socio-economic context, which together define the setting in which such a service would have to operate. It then introduces the EO value chain, the framework that structures the rest of the chapter, and follows its three links in turn: the data level, where satellite and other observations are collected; the service provider level, where raw data is turned into usable products; and the customer level, where those products are used and paid for. Finally, it reviews the EO flood services that already exist and identifies the gap in the literature that this study addresses.

2.1. Case: Bonaire

Bonaire is the largest and southernmost island of the Caribbean Netherlands. It is located on the leeward side of the Caribbean Sea, approximately 90 kilometres off the coast of Venezuela. The island has a surface area of 288 km² and a population of around 27,000 inhabitants. Bonaire has an arid climate and is known for its coral reefs, which make it a popular destination for diving tourism (HKV Lijn in Water, 2024).

The island is relatively flat and mainly composed of coral limestone. The northern part is more elevated and includes a hilly landscape, with Mount Brandaris as the highest point at 241 metres. In contrast, the southern part of Bonaire is low-lying and includes salinas in the southwest and mangrove forests in Lac Bay in the southeast. The capital, Kralendijk, is located on the west coast and serves as the main urban centre and port of the island. Approximately two kilometres offshore lies Klein Bonaire, an uninhabited coral island that is part of the protected marine park (HKV Lijn in Water, 2024). Due to its low elevation and coastal development, Bonaire is particularly vulnerable to climate change impacts such as sea-level rise and flooding caused by heavy rainfall. Many important assets, including infrastructure, houses, and businesses, are located in low-lying coastal areas and are therefore at risk of inundation.

Until 10 October 2010, Bonaire was part of the Netherlands Antilles, a constituent country within the Kingdom of the Netherlands. Since then, Bonaire has become a special municipality of the Netherlands. Local governance is carried out by the Public Entity of Bonaire (OLB), which has an administrative structure similar to that of a Dutch municipality (HKV Lijn in Water, 2024). Despite this resemblance, Bonaire's position within the Dutch state differs from that of an ordinary municipality in two important respects. First, Bonaire does not form part of a province. In the European Netherlands, the province constitutes an intermediate administrative layer between the national government and municipalities, with responsibilities in areas such as spatial planning and regional water policy. The absence of this layer in the Caribbean Netherlands is widely regarded as a design flaw in the constitutional arrangement established in 2010, as it leaves a gap between the national government and the island administration (Nijpels, 2023).

Second, Bonaire does not fall under a water board (waterschap). In the European Netherlands, water boards are decentralised public authorities responsible for water management and flood safety, and

they form one of the four parties, together with the State, provinces, and municipalities, that jointly carry responsibility for water safety and climate adaptation. The legal basis for their work is the Water Act (Waterwet), which in principle does not apply to the Caribbean Netherlands. As a consequence, the institutional framework for water and flood management that exists in the European Netherlands is largely absent on Bonaire (Waterschap Rijn en IJssel, 2023).

This has direct implications for how responsibility for flood risk management is organised. Because neither a province nor a water board is present, tasks that these layers would normally perform fall to either the OLB or the national government. Responsibility is therefore shared between the two. The OLB is in charge of spatial planning, drainage, and crisis management at the island level (De Boer et al., 2023). The national government is responsible for water and flood protection through the Ministry of Infrastructure and Water Management (IenW), while the Ministry of the Interior and Kingdom Relations (BZK) coordinates the relationship with the special municipalities (Ministries of Agriculture, Nature and Food Quality, Infrastructure and Water Management and Interior and Kingdom Relations of The Netherlands, 2020; Waterschap Rijn en IJssel, 2023). National involvement is especially relevant for funding and long-term protection.

Taken together, these institutional characteristics mean that Bonaire lacks the dedicated water authorities and the layered administrative capacity that, in the European Netherlands, are responsible for translating data and knowledge into water and flood management. Responsibility instead rests with parties that may not always have the technical expertise or resources to fulfil this role in-house.

2.1.1. Flood risks on Bonaire

Bonaire lies within the dry zone of the Southern Caribbean and therefore has a more arid climate than its neighbouring islands, with an average annual rainfall of approximately 464 millimetres. The dry season runs from February to June and the rainy season from September to January, with November as the wettest month. During the rainy season, showers typically occur in the early morning or evening, and temperatures range between 26 and 29 degrees Celsius throughout the year. Tropical cyclones can occur between June and November. Although most Caribbean hurricanes pass north of Bonaire, the risk of hurricanes affecting the island is increasing, and such events can cause heavy rainfall and damage (De Boer et al., 2023).

This combination of an arid average climate and a concentrated rainy season means that Bonaire experiences long dry periods interrupted by short, intense rainfall events. These events, together with sea-level rise, hurricanes, and tsunamis, are the main drivers of flooding on the island. The HKV report distinguishes two main flood types: coastal flooding and pluvial flooding. Coastal flooding is caused by sea-level rise, storm surges, and tsunamis, while pluvial flooding is caused by extreme rainfall (HKV Lijn in Water, 2024). Both types are amplified by the concentration of towns, infrastructure, and tourism assets in low-lying coastal areas (International Panel on Deltas and Coastal Areas (IPDC), 2024). They are also worsened by water management shortcomings, such as limited drainage capacity, poor maintenance of dams and rooien, and the expansion of paved surfaces that reduce infiltration (Waterschap Rijn en IJssel, 2023).

The extreme rainfall of November 2022 illustrates how these factors come together. Roughly 80 millimetres of rain fell in a single night, causing severe flooding across the island. In total, around 300 millimetres of rain fell during November 2022 (De Boer et al., 2023). Low-lying areas such as Kralendijk were heavily affected, with homes and streets flooded, the hospital closed for two days, schools closed for one day, power outages in several neighbourhoods, salt pans overflowing, and a dam flooded in Amboina. The vacuum sewer system in Kralendijk failed because it was not fully watertight, which led to backflow in toilets and the uncontrolled discharge of untreated wastewater. The heavy rainfall also caused significant sediment runoff, with mud and debris washed into the sea, damaging mangroves and coral reefs (Witteveen+Bos, 2024). The event made clear that flood impacts on Bonaire are not limited to inundation. They also affect drinking water and electricity, transport, healthcare, sanitation, and the coastal ecosystems that the local economy depends on.

Understanding how this kind of event may change in the future is constrained by the available climate information. The KNMI publishes climate scenarios every few years, but these have historically focused on the European Netherlands. The BES islands were only included from 2023 onwards, and even then

less climate data is available and no detailed regional climate models exist for the islands. As a result, the rate at which the frequency or intensity of extreme rainfall will change is harder to project for the BES islands than for many other regions, although it is clear that events such as November 2022 are a major threat to Bonaire. Taken together, flood risk on Bonaire is as much a spatial planning and infrastructure problem as a climate problem. The limited climate data available for the island also makes both monitoring and future projection more dependent on EO and other data sources than would be the case in better-instrumented regions.

2.1.2. Socio-economic context

Bonaire's socio-economic context shapes both the flood risks it faces and the kinds of EO-based services that can support flood risk management. Formally, Bonaire is a special municipality of the Netherlands and therefore not classified as a low- and middle-income country (LMIC) by the World Bank, which means it does not qualify for international development aid. It also lies outside the European Union, so access to EU funds is not guaranteed (Witteveen+Bos, 2024). For the same reason, Bonaire cannot draw on the international climate finance available to Small Island Developing States, even though it shares many of their characteristics, which leaves support from the Dutch state as the main route to funding climate adaptation (Grant Thornton Impact House & Greenpeace, 2026).

However, in practice Bonaire shares several characteristics with LMICs. Incomes are low relative to the cost of living, and economic opportunities are limited (Van Oosterhout et al., 2023). The island lacks the technical capacity and resources to fully utilize EO satellite data on its own. This combination of a high-income classification with LMIC-like constraints means Bonaire occupies an unusual position: eligible for Dutch government support, yet without the local capacity that high-income status would normally imply.

This mismatch is directly relevant for EO-based flood services. Codyre and Murphy (2025) states that although satellites cover 99% of the world's population, the value that EO satellite data can actually generate is limited by regional technological readiness, with LMICs facing barriers such as limited technical infrastructure and expertise. Bonaire faces similar barriers, even though it is formally part of a high-income country. Satellite data is available over the island, but the local capacity to process and apply it is limited. Tourism also shapes the context in which flood risk management takes place. The sector dominates the economy, accounting for around 40% of Bonaire's GDP, and has tripled over the past two decades, partly due to growth in cruise ship arrivals (International Panel on Deltas and Coastal Areas (IPDC), 2024; Verweij et al., 2020). This puts pressure on the infrastructure and natural environment that flood risk measures must protect, and it ties the economy closely to the same assets that flooding threatens.

The rainfall in 2022 showed how real this vulnerability is. The flooding caused direct damage to roads, homes, and utilities, with power outages in several neighbourhoods and a sewage system that backed up in Kralendijk. It also disrupted daily life and economic activity: residents were advised to stay home, the hospital closed for two days except for emergencies, and schools across the island shut their doors. Tourism was hit as well, with several attractions closing for days or weeks and a planned event postponed (De Boer et al., 2023). However, the most lasting damage was ecological. Sediment and polluted water washed onto the coral reefs, which matters economically because the island depends heavily on dive tourism (Witteveen+Bos, 2024).

The projected long-term impacts are substantial. Storms and floods are estimated to cause around US\$317 million in damage by 2050, and in the most pessimistic climate scenario the degradation of coral reefs could reduce dive tourist arrivals by some 118,000, contracting Bonaire's economy by up to 25% of GDP (Van Oosterhout et al., 2023). Reef degradation also amplifies physical flood risk: under a mid-range scenario with a degraded reef, the inundated surface area increases by 41%, from 8.0 to 11.3 km² (Van Oosterhout et al., 2023). The 2022 event showed how exposed this system already is to extreme rainfall.

Beyond these economic and institutional constraints, trust is another relevant factor. Where formal administrative structures are limited, social relationships can become a more important resource for collective action. While small islands are generally more vulnerable to climate change than continental regions, they often display higher resilience through denser social networks and relations of trust, a

form of social capital (Petzold & Ratter, 2015). This trust is a potential asset for climate adaptation, but it does not automatically translate into effective action. Linkages between micro-level networks such as family, friends, and neighbours and macro-level actors such as governments, NGOs, and companies determine whether it can be mobilised at the scale needed for flood risk management.

2.2. The EO value chain

To understand how raw satellite data becomes a useful flood risk management service, this study uses the idea of a value chain, which also structures the remainder of this chapter. A value chain describes the steps in which data gains value as it is turned into a service as it moves from one actor to the next. This structure is widely used in the Earth Observation field: the Sentinel Benefits Study, carried out for the European Space Agency and the European Union, uses a similar bottom-up value chain to show how data from the Copernicus Sentinel satellites creates value as it passes from data providers through service providers to end users and society (EARSC, 2024). Figure 2.1 applies this idea to EO-based flood services and shows three main links: data providers, service providers, and customers.

At the start of the chain, EO data such as Sentinel-1 imagery from Copernicus is collected and made available by data providers. On its own, this raw data has little value, because it still needs to be processed and interpreted. In the middle of the chain are the service providers, often entrepreneurs or specialised companies, who turn this data into usable products such as flood maps, alerts, and dashboards. At the end of the chain are the customers, such as governments, insurers, and NGOs, who use these products to make decisions and reduce flood risks.

This framework is useful for this study for two reasons. First, it shows that the value of EO data depends on every link in the chain: without a service provider to process and interpret it, the raw data never reaches the customer in a usable form. Second, it shows where entrepreneurs can add value, namely in the service provider role that connects the data to the end users. The Sentinel Benefits Study supports this point. It found that committed individuals, so-called champions, together with clear regulatory drivers, are the two strongest factors behind the actual uptake of EO services (EARSC, 2024). The value of EO data therefore depends not only on the data itself, but also on the actors who turn it into usable products and put it into practice.

The three sections that follow take each link of this chain in turn. Section 2.3 discusses the data level, where the observations that everything builds on are produced. Section 2.4 turns to the service provider level, where raw data is translated into usable products, and to the flood risk management measures those products support. Section 2.5 addresses the customer level, where the products are used and where the question of who pays for them arises.

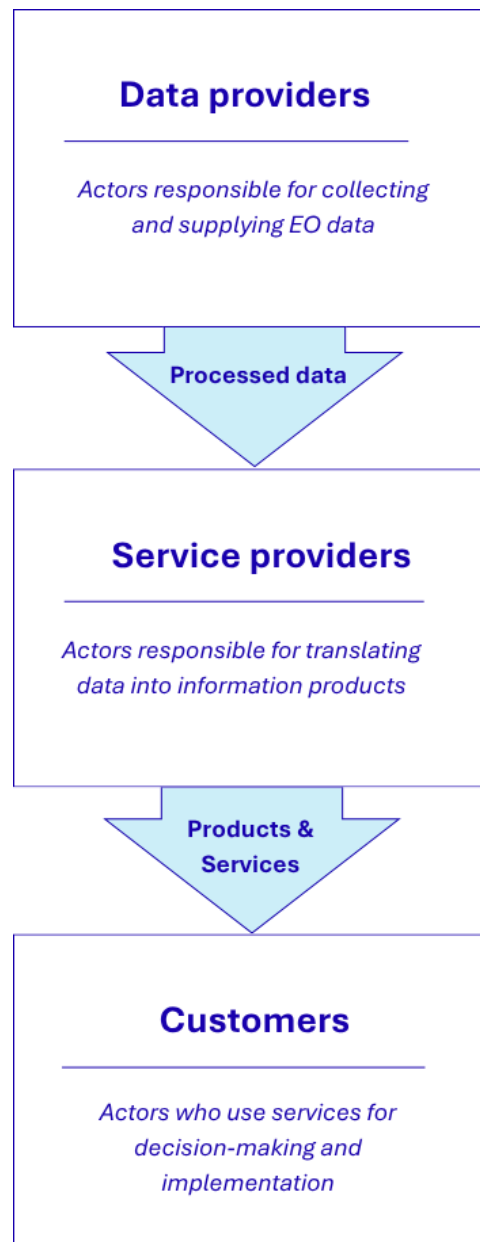


Figure 2.1: EO flood service value chain

2.3. The data level: sources for monitoring floods

At the start of the value chain sits the data level, where the observations that everything else builds on are produced. Flood monitoring relies on combining different types of data, each with its own strengths and limitations. This thesis considers three main sources: Earth Observation (EO) satellite data, airborne LiDAR data, and in-situ measurements. None of these data sources is sufficient on its own, but together they can provide the spatial coverage, temporal frequency, and local accuracy needed to monitor and prevent floods. This section introduces each source and then discusses how they can be combined.

Earth Observation is the collection of information about the Earth using satellites and ground stations, and is used to monitor environmental change, weather, and natural hazards. Satellites are particularly useful for monitoring floods because they observe large areas at once. Floods often cover areas larger than a single ground station can capture, and they can develop within hours. This makes a network of fixed sensors alone insufficient for tracking them (Guo, 2010). Two types of sensors dominate flood monitoring from space, and the choice between them has direct consequences for what can be observed. Passive sensors produce optical imagery by measuring sunlight reflected from the Earth's surface (Schumann et al., 2023). They can only be used during daylight and are blocked by clouds, which is a limitation during flood events, when cloud cover is usually heaviest. Active sensors such as Synthetic Aperture Radar (SAR) emit their own microwave signal and measure the reflection. Because SAR does not depend on sunlight and can penetrate clouds, it can collect data day and night and in poor weather (Schumann et al., 2023). For floods specifically, this difference matters. Optical imagery offers easily interpretable images and a long historical archive, but is often unavailable when it is most needed, while SAR is more reliable during events but harder to interpret without processing.

The usefulness of a satellite image also depends on its spatial and temporal resolution. Spatial resolution determines the level of detail a sensor can resolve. Resolutions can vary between 200 metres (coarse) and 30 cm (high-resolution) (Huang et al., 2018). For flood mapping, at least 20 metres is needed to identify flooded areas (Van Aken, 2025). Temporal resolution refers to how often a sensor revisits the same location, and is important for floods because flooding can develop within a single day (Huang et al., 2018). A trade-off exists between these two resolution types. Satellites with high spatial resolution generally have a narrower swath and therefore a longer revisit time, while satellites with high temporal resolution often have lower spatial detail (Donaldson & Storeygard, 2016). No single satellite optimises both, which means that flood monitoring relies on combining several satellites with different characteristics.

LiDAR (Light Detection and Ranging) sensors send out a laser pulse and measure how long it takes to return, which gives the distance to the Earth's surface. When mounted on an airplane, LiDAR can produce high-resolution Digital Elevation Models (DEMs) of the area of interest. DEMs are essential for flood analysis, because flooding patterns are largely determined by the shape of the land. Water flows downhill and collects in low-lying areas, so accurate elevation data is needed to predict where floodwater will go. For a low-lying island such as Bonaire, where small differences in elevation determine whether an area floods, accurate DEMs are a particularly valuable input. A new LiDAR-based DEM with a resolution of 0.5 metres and a vertical accuracy below 15 centimetres is now available for Bonaire, which is a major improvement over the previously available 30 metre global elevation model. Combined with optical and SAR imagery, these DEMs allow water surface elevation to be estimated and floodwater spread to be simulated, which is important for both flood mapping and flood modelling (Huang et al., 2018; Schumann et al., 2023).

In-situ measurements are observations made directly on the ground. They include weather stations measuring rainfall, wind, and temperature, tide gauges measuring sea level, and increasingly also citizen-operated sensors. While EO data and LiDAR provide spatial coverage, in-situ data provides high-frequency point measurements that are essential for calibrating models, verifying satellite observations, and tracking conditions in real time. The in-situ network on Bonaire is limited. The official KNMI weather station at Flamingo Airport is the only source for official measurements and severe weather warnings (KNMI, 2024), but a single station cannot capture the spatial variability of rainfall across the island. During the extreme rainfall of November 2022, the KNMI station recorded about 59 millimetres of precipitation, while personal weather stations in Kralendijk measured up to 84 millimetres (HKV Lijn in Water, 2024). In 2024, five additional all-in-one stations were installed and connected to the crowd-

sourced WOW platform, bringing the total to eight stations alongside the KNMI station and allowing for better monitoring of local weather patterns (KNMI, 2024). Bonaire has no tide gauge, so sea level changes have to be monitored using data from stations on other Caribbean islands (HKV Lijn in Water, 2024).

The three data sources are complementary rather than interchangeable. EO satellite data covers large areas and is updated regularly, but it cannot match the temporal frequency or local accuracy of a ground sensor. LiDAR provides the detailed elevation data needed to understand where water will flow, but it is only collected once in a while rather than all the time. In-situ measurements provide continuous point data but only at the few locations where sensors are installed. When combined, they support flood management across prevention, response, and recovery. EO satellites can map flooded areas during and after events, DEMs made with LiDAR allow flood spread to be simulated in advance, and in-situ data about rainfall, wind, and sea level feed into hydrological models that produce forecasts and early warnings (McCabe & Rodell, 2017; Schumann et al., 2023). EO-based flood services are most effective when they integrate all three sources rather than relying on satellite data alone (Schumann & Brakenridge, 2018).

However, data alone does not prevent floods. Its value depends on how it is processed, interpreted, and combined with local knowledge to support decisions. This is particularly true for Bonaire. As discussed in Section 2.1.2, satellite data is available over the island, but the local capacity to process and apply it is limited. In addition, the in-situ network is too small to fully complement what the satellites observe. The next section therefore turns to the second link of the chain, the service provider level, where observations are translated into practical flood risk management.

2.4. The service provider level: turning data into usable products

The second link of the value chain is the service provider level, where raw data is turned into products that users can act on. EO satellite data has great technical potential, but turning it into usable flood risk management services is not straightforward. Raw satellite data is complex on its own. It first has to be processed, interpreted, and combined with local knowledge before it is useful for a customer. Many potential users lack the technical skills or resources to do this themselves. This creates a gap between the data that is technically available and the data that is actually used. What users need is not the raw data, but information they can act on. Research on water and flood management shows that this means clear indicators, maps, or alerts that fit the decisions users face, rather than datasets they have to interpret first. EO data can be of high value for flood protection, but only when the products made from it match what users need (Bremmer, 2016).

EO-based services aim to bridge this gap by packaging satellite data into user-friendly products such as flood hazard maps and risk atlases. Rather than requiring users to process raw imagery themselves, these services deliver clear indicators and visualizations that stakeholders can directly use for spatial planning, infrastructure decisions, and long-term flood risk management. This way, EO data becomes accessible to a much broader group of users than the technical community that originally produces it.

Entrepreneurship can play an important role in turning EO satellite data into practical flood risk management services (Denis et al., 2017). With the increasing availability of free and open EO satellite data and the decreasing costs of satellites, the EO sector has changed considerably. These developments have lowered the barriers for new companies to enter the market and have created opportunities for startups to develop EO-based services for both public and private users. By combining technical expertise with an understanding of user needs, entrepreneurs can help to bridge the gap between raw EO data and useful flood risk management services.

2.4.1. Flood risk management measures

The services at this level exist to support concrete flood risk management measures, so it is worth setting out what those measures are. Flood risk management consists of three types of measures: prevention, response, and recovery. Prevention measures aim to reduce flood risk before an event occurs. Response and recovery measures focus on managing the impacts during and after an event.

On Bonaire, prevention requires a combination of measures (De Boer et al., 2023; Metselaar et al., 2025). Flooding is caused by problems in different parts of the island at the same time, so measures

are needed across the whole island, from the rural areas higher up to the urban area of Kralendijk and the coast. Higher up, planting more vegetation in the kunukus (rural areas), controlling erosion, and restoring water retention structures such as dams and tankis (water reservoirs) can reduce runoff and slow the flow of water towards Kralendijk. Closer to the coast, protecting and restoring the urban salinas (salt marshes) helps to buffer rainwater and trap sediment before it reaches the sea. In the urban area, improving drainage and maintaining rooien (channels) and culverts prevents blockages and helps water flow away during heavy rainfall. Spatial planning regulations are also needed, to keep construction out of vulnerable areas such as salinas and former riverbeds. EO satellite data can support these prevention measures by helping to identify vulnerable zones, which is useful for planning infrastructure and managing risk.

Response measures limit the impacts during an event. Early warning systems can alert residents in time to act. For tsunamis, the KNMI already runs a warning procedure based on notifications from the Pacific Tsunami Centre. Emergency response plans that set out evacuation routes and crisis coordination are essential for a fast reaction. Temporary measures such as sandbags or flood barriers can protect specific objects during storm surges or extreme rainfall (HKV Lijn in Water, 2024).

Recovery measures restore the situation after a flood, such as clearing debris and repairing damaged infrastructure. The HKV report recommends designing critical infrastructure so it can be restored quickly and rebuilt in a more climate-robust way. Ecological recovery matters too. Extreme rainfall on Bonaire washes sediment into the sea and damages coral reefs, so maintaining the upstream system of rooien, dams, and salinas serves both prevention and recovery (HKV Lijn in Water, 2024). Financial support or insurance can help affected households and businesses recover (Hudson et al., 2019; Mysiak & Dionisio Pérez-Blanco, 2016). Finally, analysis after a flood using EO satellite data can show the extent and impact of the flooding, which helps to improve measures for future events (Schumann & Brakenridge, 2018). Which of these measures a service supports depends on who uses it and who pays for it, which brings the chain to its final link.

2.5. The customer level: users and funding

The final link of the value chain is the customer level, where the products made from EO data are used to make decisions and where the question of who pays for them arises. The customers for flood risk management services are diverse: governments responsible for spatial planning and crisis management, nature organisations protecting ecosystems, and private actors such as insurers and banks whose exposure depends on flood risk. What these customers have in common is that few can carry the cost of a service alone, which makes the funding arrangements between them central to whether a service can be sustained.

2.5.1. Public-private partnerships and insurance

Funding and sustaining flood risk management is rarely something the public sector can do alone, which is why public-private partnerships (PPPs) are often used. In a PPP, the public and private sectors collaborate and share the burden. The public sector focuses on crisis management and protecting communities, while the private sector has its own stake, since floods cause economic losses and damage to infrastructure. By working together, they can share financial risks, technical knowledge, and information such as weather and climate forecasts, which can strengthen flood risk monitoring (Khoshnoud et al., 2025; Mysiak & Dionisio Pérez-Blanco, 2016).

Insurers are a key private actor in this context. They manage the financial risks of flood damage by providing protection after disasters, and they can encourage property owners to reduce their own risk by taking preventive measures (Hudson et al., 2019). However, in high-risk areas insurance can become unaffordable or unavailable. Collaboration between insurers and governments through PPPs can help here: when governments invest in preventive measures such as dams and well-maintained infrastructure, the risk goes down, which helps keep insurance affordable.

This is relevant for EO-based flood services in two ways. First, PPPs offer a funding model in which the cost of a service does not fall on one party alone, which matters in a setting where no single customer may be able to pay for it. Second, insurers are a potential customer for EO-based risk information, since better flood prediction and damage data could help them assess risk and set premiums.

2.6. Existing EO flood services

Having set out the three links of the value chain, it is possible to see how the EO flood services that already exist fit into it. Several EO-based flood services already exist, ranging from global systems to services made specifically for the Dutch Caribbean. Looking at them together shows what is already available and where the gaps are.

At the global level, two free services provide flood information anywhere in the world. The Copernicus Emergency Management Service runs the Global Flood Awareness System (GloFAS), which gives information about upcoming and ongoing floods using satellites, models, and in-situ measurements (Copernicus Emergency Management Service, n.d.). Google Research developed Flood Hub, which uses two AI models to forecast floods: one predicts how much water flows in a river, the other predicts which areas will flood and how high the water will rise, up to seven days ahead (Nearing et al., 2024). Both are useful, but they are built for large river systems and broad coverage. That makes them less suited to a small island like Bonaire, where flooding comes from local rainfall and runoff rather than large rivers.

Other services were made specifically for the Dutch Caribbean. In late 2025, Climate Adaptation Services (CAS) and Nelen & Schuurmans developed the Climate Effect Atlases for the islands, financed by the Ministry of Infrastructure and Water Management (IenW). These are interactive maps of climate risks such as flooding, heat, drought, and sea-level rise, and they combine open satellite data with local knowledge to help governments and organisations make decisions (Climate Adaptation Services, n.d. International Panel for Deltas, Coastal Areas and Islands (IPDC), 2025).

The startup Spheer, together with the Dutch Caribbean Nature Alliance, built an AI tool that combines satellite data with artificial intelligence so users can monitor their land and water ecosystems (Spheer, 2024). Deltares developed CARIB-FATE, a digital service that maps pollution sources and how they spread in coastal waters, which supports the protection of coral reefs and biodiversity (Deltares, 2025). Finally, the Dutch startup Fastflood offers a platform that simulates floods quickly and can support early warning, free for individual users and subscription-based for organisations (FastHazard B.V., 2026).

Together, these services show that EO-based flood information for Bonaire is no longer absent. But the picture is fragmented. The global systems are not made for the island, and the Caribbean services each focus on a single aspect, such as climate risk mapping, ecosystem monitoring, or pollution. None of them brings the different data sources and local knowledge together in one service that covers the full range of flood risk management needs on Bonaire, and many depend on project funding to keep running. This leaves room for services that are better integrated and aimed at the specific needs of the island.

2.7. Research gap

The literature reviewed in this chapter shows that EO data has clear potential for flood risk management. It can map flooded areas, support forecasting, and provide social and economic value, especially when satellite data is combined with elevation and in-situ measurements. The literature also shows that this potential is not realised automatically. Raw data only becomes useful through a service that processes and interprets it, and the value chain depends on every link, from data providers to service providers to customers.

Most existing research, however, looks at the technical side of EO, such as sensors, data processing, and flood modelling, or at general use cases in large, well-instrumented regions. Less attention is given to the step that turns EO data into practical services, and to the role entrepreneurs play in that step. The literature on EO entrepreneurship suggests that falling costs and open data have lowered the barriers to entry, but it says little about what happens after market entry, or about the conditions under which such services are actually adopted and sustained.

This gap is especially clear for a context like Bonaire. As a small island that is formally part of a high-income country but faces capacity constraints more typical of lower-income regions, Bonaire does not fit the settings in which most EO research is carried out. It is unclear which flood risk management needs exist there, which EO-based services could meet them, and what opportunities and challenges entrepreneurs would face in developing them. This study addresses that gap by examining how EO

data can be translated into entrepreneurial flood risk management services on Bonaire.

3

Methodology

This chapter explains the research design and methods used in the study. It describes how data was collected and analysed to understand customer needs, the use of Earth Observation (EO) data, and the feasibility of EO-based flood risk management services on Bonaire.

3.1. Research design

This thesis is set up as a qualitative exploratory case study. The design fits the research question, which asks how EO data can be translated into entrepreneurial flood risk management services on Bonaire. This question is open rather than confirmatory, and it concerns a topic that has been little studied. The aim is therefore to understand needs, opportunities, and challenges, rather than to test a hypothesis or measure technical performance.

A case study was chosen because flood risk management depends on local geography, governance, and stakeholders, which cannot be understood in the abstract. As Hollweck (2015) notes in a review of Yin's work, case study research is a methodological approach for investigating a contemporary phenomenon in depth and within its real-life context, which is exactly what this study aims to do. Studying one case in depth, rather than comparing several, makes it possible to examine these factors together and in detail, including the relationships between the actors involved. The specific characteristics of Bonaire that make it a relevant case are described in the introduction and the theoretical background.

The study is exploratory because little research exists that combines EO data, flood risk management, and entrepreneurship in a small island context. Exploratory research is suitable when a phenomenon is not yet well understood and the aim is to gain insight and identify what matters (Stebbins, 2001). This is why the study focuses on understanding the needs of potential users and the challenges of developing an EO-based service, rather than on measuring technical performance.

3.2. Data collection

Data collection consisted of two parts: a theoretical background developed from document review, and a round of semi-structured interviews with relevant stakeholders. A theoretical background was developed by reviewing relevant documents, including scientific articles and climate and flood risk reports. The academic literature was identified through Scopus and Consensus using search terms such as "Earth observation," "flood risk management," and "small islands," in different combinations. The grey literature was drawn from institutions active in flood risk and climate adaptation in the Dutch Caribbean, including the KNMI, HKV, Deltares, and Witteveen+Bos. Together, these sources provided the conceptual foundation for the study, helped to analyse how flood risk management is currently organised in the Dutch Caribbean, and formed the basis for the design of the interview questions.

This study applies the power-interest grid of Bryson (2004), which positions stakeholders by their power to influence flood risk management and their interest in it. Bryson's original grid treats interest as a matter of degree, from low to high. Here the interest axis is read as directional as well, ranging from

opposed through neutral to supportive, because some actors have an interest that runs counter to flood risk management rather than simply a low one. The placement of each stakeholder draws on both the desk study and the interviews: the desk study provided an initial mapping from policy documents and literature, which was then refined using the interviews. An initial mapping was made during the desk study, based on policy documents, reports, and literature. This mapping identified the main stakeholder groups and guided the purposive sampling of interview participants, by showing which groups needed to be covered. The interviews were then used to develop the analysis further, since they gave a more detailed understanding of each stakeholder's role, power, and interest.

A total of 21 semi-structured interviews were conducted, partly on Bonaire and partly in the Netherlands. Participants were selected through purposive sampling, based on this stakeholder analysis. The aim was to cover the different links of the value chain and the main stakeholder groups: research institutes and EO companies on the supply side, Dutch government actors involved in flood risk and water management, and potential customers on Bonaire such as the local government, nature organisations, and actors from the tourism and banking sectors. Participants were approached by email, and some through contacts made during the EU Satellite Conference on Bonaire. Most interviewees also suggested further relevant contacts, who were then approached as well. Not all targeted groups could be reached: several insurers and real estate developers were approached but were unavailable during the research period, and the large-scale data providers were not interviewed because the study focused on the service provider and customer links, where the main gap was expected.

A large part of the data collection took place during a visit to Bonaire from 10 April to 1 May 2026, which included attendance at the EU Satellite Conference, organised by the Cabinet of the special envoy for the BES islands. Being on the island was useful for more than practical reasons. Conducting the interviews in person made the conversations more open and made it easier to ask follow-up questions. The visit also gave a better feeling for the local context, such as how people experience flood risk in daily life and how the different actors relate to each other. This helped with interpreting the interviews, because it made it easier to understand the answers within the situation on Bonaire. Participants based in the Netherlands were interviewed online. The participants covered a range of stakeholders involved in flood risk management on Bonaire, although the large-scale satellite data providers were not included. Table 3.1 gives an overview of the participants by stakeholder type. Full summaries of each interview are provided in Appendix A.

Before each interview, participants were informed about the purpose of the study and how their input would be used, and gave their consent to participate and to be recorded. The study was conducted in line with the requirements of the TU Delft Human Research Ethics Committee (HREC). To protect the privacy of participants and the organisations they represent, all interviews are reported anonymously and referred to by stakeholder role rather than by name, as listed in Appendix A. The interviews were conducted in Dutch and English, and quotes used in this thesis were translated into English by the author where necessary.

The interviews were semi-structured, and the questions were designed based on the principles of The Mom Test (Fitzpatrick, 2013). This approach recommends asking about concrete past experiences and current practice rather than hypothetical interest. Instead of asking participants directly whether they would use a certain service, the questions focused on their current situation, the problems they experience, and how they deal with these problems today. This helps to avoid overly positive answers and makes it easier to identify real needs rather than assumed ones. Each interview therefore started from the participant's own work, with questions about recent projects and real situations, and followed up on the topics they raised.

A core set of questions was used across most interviews, supplemented with questions tailored to each participant's role. The questions were grounded in the concepts introduced in the theoretical background. The value chain determined which questions were asked to whom: EO companies were asked about their role as service providers, while potential customers were asked about their needs. The flood risk management categories of prevention, response, and recovery shaped the questions about experiences and measures, and the literature on public-private partnerships informed the questions about collaboration and funding.

The core questions covered four themes: the participant's experience with flooding on Bonaire, their

Table 3.1: Overview of interview participants by stakeholder type

Code	Stakeholder type
A.1	National meteorological institute
A.2	Consultant in water management
A.3	Developer of flood maps for the Caribbean
A.4	National meteorological institute
A.5	International nature conservation organisation
A.6	National representative of Dutch government
A.7	Local nature organisation
A.8	Research institute (water management)
A.9	Public Entity Bonaire
A.10	Local nature organisation
A.11	Public Entity Bonaire
A.12	Research institute (water management)
A.13	Bank on Bonaire
A.14	Dive school
A.15	Ministry of Infrastructure and Water Management 1
A.16	Ministry of Infrastructure and Water Management 2
A.17	Public Entity Bonaire
A.18	Environmental NGO
A.19	Earth observation startup
A.20	Geospatial data company
A.21	Tourism organisation

current sources of information and use of EO tools, the measures and collaborations they were involved in, and their view on responsibility for flood risk management. These themes connect to the three sub-questions. Questions about experiences and information needs relate to the needs of potential customers (SQ1) and the suitability of EO data and features (SQ2), while questions about measures, funding, and collaboration relate to the opportunities and challenges for entrepreneurs (SQ3). For the EO companies, which sit on the supply side of the value chain, a more detailed set of questions was added about their business model, funding, and experience of developing services for the islands. The full interview protocol is provided in Appendix C.

3.3. Data analysis

The interview data were analysed using a hybrid deductive-inductive thematic analysis (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006). Thematic analysis is a method for identifying, organising, and interpreting patterns of meaning across qualitative data (Braun & Clarke, 2006). The approach was deductive in its starting point, since the theoretical framework was developed beforehand and the interview questions were derived from it. It was inductive in its coding, since the codes emerged from reading the transcripts rather than from a predefined coding scheme set before analysis.

The analysis was carried out in ATLAS.ti, and the coding proceeded through three phases: open, axial, and selective coding (Williams & Moser, 2019). These phases are associated with grounded theory, but they were used here as thematic coding techniques. The study did not adopt a grounded theory design, as it proceeded from an a priori framework and aimed to identify themes rather than to generate a new theory through theoretical sampling and saturation.

In the open coding phase, the transcripts were read carefully and relevant concepts were labelled. This produced a broad set of about 340 initial codes describing distinct ideas in the data. Many of these were then merged, which reduced the set to about 140 codes. During axial coding, the codes were compared and the relationships between them were explored, which grouped them into seven categories: data gaps and monitoring needs, early warning systems, infrastructure and water management, EO data capabilities and limitations, flood risks and impact, entrepreneurial opportunities and barriers, and governance and institutional challenges. In the selective coding phase, these categories were consoli-

dated around three central themes that connect to the research questions: customer needs, EO data usability, and entrepreneurial challenges. This is also where the central finding of the study took shape, namely that the main barrier on Bonaire is not the availability of EO data but the lack of a service that turns it into something usable. In the results, the findings are presented along the value chain rather than theme by theme, so that the needs at each level can be discussed together. This made it possible to compare the findings across the different stakeholder groups.

3.4. Validity and reliability

To strengthen the validity, multiple interviews were conducted with stakeholders from different groups. This made it possible to compare perspectives and to see which themes recurred across the different sectors. The interviews were recorded and transcribed, so that no important information would be lost. After each interview, the transcript was sent back to the participant, so they could check it and correct or add anything if needed. This form of member checking helps to ensure that the data reflects what the participant actually meant, rather than the researcher's interpretation of it.

Reliability is supported by using the same three-phase coding process for all interviews, which made the findings of the different stakeholder groups easier to compare. Because interviews can be subject to bias, the findings were also triangulated against the literature and policy documents reviewed for the theoretical background. The interview questions were also designed using the principles of The Mom Test, which focus on current practice and concrete past behaviour rather than hypothetical interest, to reduce the risk that participants gave socially desirable or speculative answers. Comparing the interview findings across different stakeholder groups, and against these documents, made it possible to see which themes recurred across sources rather than relying on any single perspective.

It is also important to reflect on the role of the researcher. The researcher may have influenced the interviews, for example through the way questions were asked or which follow-up questions were chosen. The researcher's background shaped the study as well. Being Dutch and speaking the language was an advantage in part of the research. Most interviews could be conducted in Dutch, which made the conversations more natural for many participants, and it helped in understanding the administrative relationship between Bonaire and the Netherlands. At the same time, the researcher is not from the Caribbean and does not speak Papiamentu, the local language of Bonaire. This created some distance from the local context and may have limited access to perspectives that are shared more openly with someone from the island. The findings should therefore be read as the interpretation of an outside researcher, informed by the fieldwork on Bonaire but not from an insider's position.

4

Results

This chapter presents the findings of the study, based on the 21 semi-structured interviews and analysed through the hybrid deductive-inductive thematic analysis described in Chapter 3. It is organised in two parts. The first part maps the actors involved in flood risk management on Bonaire through a stakeholder analysis, using the power-interest grid to show where interest in EO-based services is strongest and where the power to fund and adopt them lies (Section 4.1). The second part turns to what these stakeholders expressed in the interviews, organised around the EO value chain introduced in Chapter 2, which runs from data providers through service providers to customers (Section 4.2). For each link in the chain, the chapter describes the needs that stakeholders raised. It then presents the barriers and market conditions that shape the development of EO-based flood risk management services on Bonaire (Section 4.3). The findings are presented along the value chain rather than theme by theme, so that the needs expressed at each level can be discussed together and compared across stakeholder groups.

4.1. Stakeholder analysis

Where the value chain shows the roles through which EO data becomes a useful service, the stakeholder analysis looks at the actors involved in flood risk management on Bonaire and how much power and interest they have. A stakeholder analysis helps to understand who is affected by a problem and what they need or expect. According to Bryson (2004), this matters because initiatives often fail when stakeholder interests are ignored.

This study uses the power-interest grid, one of the techniques described by Bryson. The grid places stakeholders along two axes: their interest in the issue and their power to influence it. This results in four groups: players (high power and high interest), subjects (high interest but low power), context setters (high power but low interest), and the crowd (low power and low interest) (Bryson, 2004). As set out in Chapter 3, the interest axis is read here as directional rather than only a matter of degree, ranging from opposed through neutral to high, because some actors have an interest that runs counter to flood risk management rather than simply a low one. The placement of each stakeholder draws on both the desk study and the interviews: an initial mapping was made during the desk study, based on policy documents and literature, and refined using the interviews. The result is shown in Figure 4.1.

The grid is useful here for two reasons. First, flood risk management on Bonaire involves many actors with different degrees of power and interest, and none of them can address flood risk alone. Second, the grid helps to identify opportunities and barriers for entrepreneurs: stakeholders with high interest but low power may signal demand for flood risk services, while those with high power but low or opposed interest can enable or block their adoption. Some of these stakeholders are also part of the value chain described above, such as the EO data providers at the start and the service providers in the middle, while others are the potential customers at the end. Mapping them by power and interest therefore shows not only who is involved, but also where along the value chain the interest in EO-based services is strongest and where the power to fund and adopt them lies.

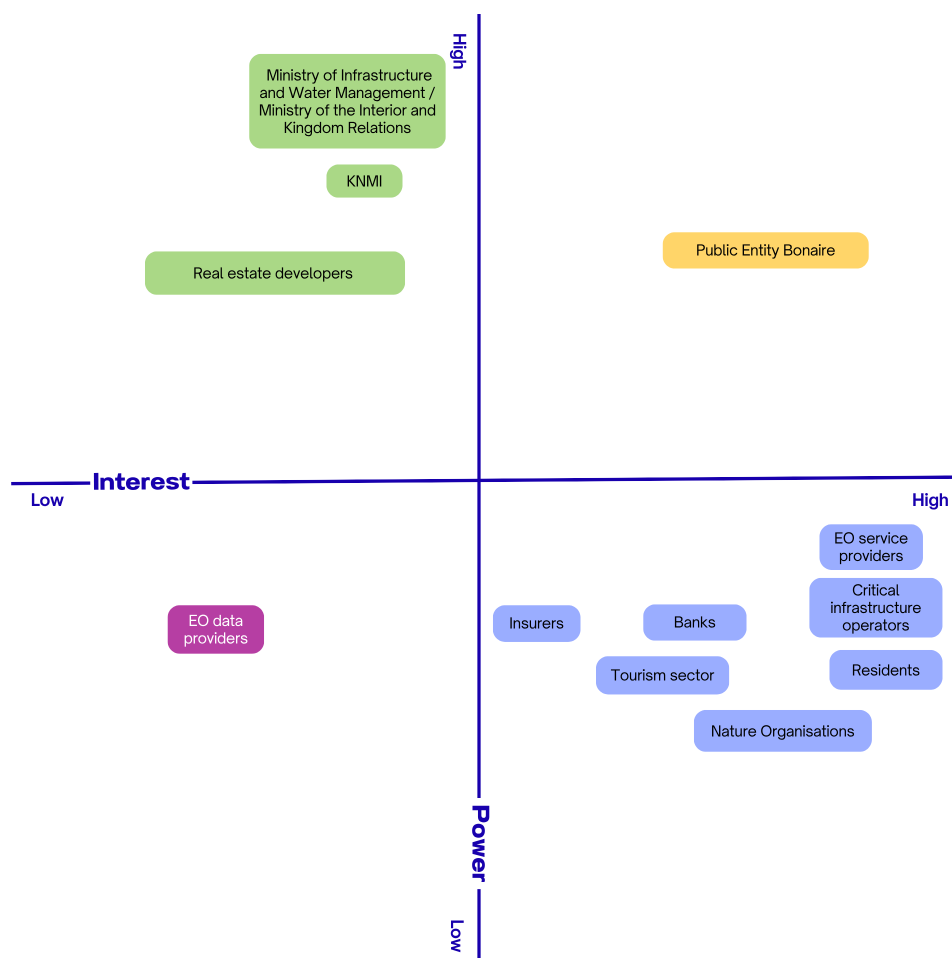


Figure 4.1: Power-interest grid of stakeholders in flood risk management on Bonaire. The interest axis ranges from opposed (left) through neutral to high (right); the power axis from low (bottom) to high (top).

High Power - High Interest

Public Entity Bonaire (OLB): The local government is responsible for flood risk management through spatial planning, maintenance of drainage systems, and crisis management during flood events (De Boer et al., 2023). It also oversees permits and regulations related to flooding. The local government has high power, as it can develop policies and plans to manage infrastructure and the dam network. However, its ability to implement these plans is constrained by financial dependence on the Dutch government (A.9, A.17).

High Power - Low or opposed Interest

Ministry of Infrastructure and Water Management (IenW) and Ministry of the Interior and Kingdom Relations (BZK): Because Bonaire is a special municipality without a province or water board, these two ministries carry responsibilities that elsewhere sit at intermediate administrative layers, which places significant power at the national level. The Ministry of Infrastructure and Water Management is responsible for water and flood protection, while the Ministry of the Interior and Kingdom Relations coordinates the relationship with the special municipalities and is central to structural funding (Ministries of Agriculture, Nature and Food Quality, Infrastructure and Water Management and Interior and Kingdom Relations of The Netherlands, 2020; Waterschap Rijn en IJssel, 2023). National funding of concrete measures, such as the restoration of dams and salinities, was also described in the interviews, where a recurring point was that one-off restoration is financed nationally while structural maintenance falls to the OLB (A.16). Their interest, however, is distant rather than opposed: neither ministry has a stake in flooding occurring, but flood risk on Bonaire competes with many other national priorities. The January 2026 court ruling shows that action followed legal pressure rather than their own initiative (Rechtbank

Den Haag, 2026). This distinguishes them from actors such as real estate developers, whose interest runs counter to flood management rather than merely being low.

KNMI: KNMI is legally responsible for weather forecasting and early warning systems on Bonaire. It has high power, since it can develop the early warning systems that flood risk management depends on, although it is financially dependent on the Ministry of Infrastructure and Water Management. Its interest is more limited, because Bonaire is only a small part of its wider responsibilities and flood risk on the island is not its main focus (KNMI, 2024).

Real estate developers: Real estate developers decide which sites are developed and how, which gives them substantial influence over where flood risk is created. This power is real but conditional: it is channelled through the OLB, which tests every building application against the Ruimtelijk Ontwikkelingsplan Bonaire and issues the permit. Developers therefore do not decide autonomously, but their influence grows where enforcement is weak and where projects proceed through development agreements with the island. Their interest, however, is not merely low but partly opposed to flood risk management. Because they sell properties on, the flood risk transfers to the buyer rather than remaining with them (A.17). At the same time, flood measures work against their commercial interest: they restrict buildable land, which is scarce and most valuable along the low-lying coast, and they add cost through drainage and elevation requirements, for which there is currently no obligation on private developers (A.10). This places them left of neutral on the interest axis: an actor with the power to shape flood exposure but a limited or countervailing incentive to reduce it.

Low Power - High Interest

Residents: Residents, particularly those living in low-lying areas in and around Kralendijk, are directly exposed to flood risks. Their interest is high, since flooding can damage their homes and cut off their access to essential services such as the hospital, the harbour, and the airport. Their power is low to medium. They cannot directly influence flood policy, but they can make small changes to their own homes, and they can exert some influence through their right to vote (A.9).

EO service providers: Companies and startups that develop EO-based tools. They have low power on Bonaire, since they are external actors without a formal role in local policy or decision-making. However, their interest is high, though of a different kind than that of the other stakeholders: rather than being affected by flooding themselves, they have a professional and commercial interest in providing the services that could address it. Their position in the value chain makes them central to translating EO data into usable tools, but only if there is local demand and funding to support them.

Nature organisations: Organisations involved in managing and protecting Bonaire's ecosystems. They have low power, since they are not formal decision-makers and depend on permits and funding from the government. However, they have a high level of interest, because flooding and sediment runoff directly damage the coral reefs and mangroves they work to protect. They are also among the more active users of EO data, mostly through basic tools, which makes them both interested stakeholders and potential customers (A.10, A.7).

Banks: Banks finance property purchases through mortgages. Their power over flood risk management is low, since they do not decide on flood measures or policy. However, they do influence who can buy property and under what conditions. Their interest is high, because flooding could affect the value of the properties they finance and the ability of owners to repay their loans (A.13).

Insurers: Insurers can financially protect property owners against flood damage. Their interest is high, since their business depends on the risks that flooding creates. Their power, however, is more limited, because they cannot directly influence the measures taken against flooding, although they do play a financial role once flooding has occurred (A.20).

Critical infrastructure operators: Several actors operate infrastructure and services that are essential to Kralendijk. These include the utility company WEB Bonaire (water and electricity), the hospital, the harbour, and the airport. They have low power, since their focus is on running their own operations rather than influencing policy. However, their interest is high because they are located in low-lying areas and are vulnerable to flooding, which can disrupt critical infrastructure and essential services. The hospital, for example, closed for two days during the November 2022 flooding, when the surrounding area flooded and the building became difficult to reach ((De Boer et al., 2023), A.18).

Tourism sector: The tourism sector is one of the most important parts of the economy of Bonaire, and much of it depends on the natural environment, such as the reefs and the coast. Its power is low, since it consists of many separate businesses rather than a single decision-maker, which makes it hard to act as one voice in policy. Its interest is high, because flooding and the damage it causes to infrastructure and nature can directly affect tourism activities and the income that depends on them. This interest is mostly long-term and partly split, however: the sector depends on the reefs and coast that flooding threatens, yet concrete flood measures such as coastal building restrictions can also sit uneasily with short-term commercial interests (A.21). On balance the interest remains high, but it is not uniform across the sector.

Low Power - Low Interest

EO data providers: The organisations that collect and supply raw satellite data, such as the operators of the Copernicus programme or commercial satellite companies. They have low power over flood risk management on Bonaire, since they are large external actors with no formal role in local decisions. Their interest in Bonaire specifically is also low, since the island is only a small part of the global area their satellites cover. They are nonetheless the starting point of the value chain, as the data they provide is what service providers and customers build on.

The power-interest grid shows that flood risk management on Bonaire involves many stakeholders, but few combine high power with high interest. Only the Public Entity Bonaire falls in this category. The other powerful actors are disengaged from flood risk, but in two different ways. For lenW, BZK, and KNMI, it is a matter of competing priorities: they have no stake in flooding occurring, but it is not their main focus. For real estate developers, the interest runs actively counter to flood management, since measures restrict scarce buildable land and add cost.

The groups most affected by flooding or most engaged with it sit in the opposite position, with high interest but limited power. These include residents, operators of critical infrastructure, the tourism sector, nature organisations, banks, and insurers, along with the EO service providers central to delivering solutions. Finally, the large-scale EO data providers sit in the low power, low interest quadrant. This distribution has a direct consequence. Because the actors able to fund and adopt services are either indifferent or actively opposed, flood considerations do not enter decisions on their own, but only where the OLB steers them there through spatial planning and permitting. The adoption of EO-based services therefore depends not only on the technical potential of the data, but on whether these competing interests can be aligned.

4.2. Needs and applications

Where the stakeholder analysis in Section 4.1 mapped the actors involved in flood risk management and their relative power and interest, the remainder of this chapter turns to what those stakeholders expressed in the interviews. The thematic analysis of the transcripts produced seven themes, summarised in Table 4.1. These themes structure the sections that follow: the needs at each level of the value chain (Sections 4.2.1-4.2.3) and the barriers and market conditions that shape the development of EO-based services (Section 4.3). The findings are presented along the value chain rather than theme by theme, so that the needs expressed at the data, service provider, and customer levels can be discussed together. Because the presentation follows the value chain, the code tables in the following subsections group codes by value-chain level and therefore cut across the seven themes; a code may appear at more than one level.

Table 4.1: Overview of Themes Identified in the Thematic Analysis

Theme	Codes (<i>n</i>)	Quotations	Section
Governance and institutional challenges	43	110	4.3
EO data capabilities and limitations	45	100	4.2.2
Infrastructure and water management	35	99	4.2.3
Entrepreneurial opportunities and barriers	39	84	4.3
Flood risks and impact	28	73	4.2.3
Data gaps and monitoring needs	18	45	4.2.1
Early warning systems	19	40	4.2.3

Note. The seven themes are the categories from the axial coding phase (Section 3.3). *Codes (n)* is the number of distinct codes in each theme and *Quotations* is its groundedness (the number of coded quotations). Because a code or quotation can belong to more than one theme, the values are not mutually exclusive and do not sum to the project total. A further 11 codes (quotations = 18) were not assigned to a theme; these are listed separately in Appendix D.1.

4.2.1. Data level

This section discusses the needs at the data level of the value chain. Since the large-scale satellite data providers were not interviewed, these needs were identified mainly by the users and knowledge institutions that work with the data. They concern what is needed at the level of data availability and quality. The codes that carried this level are summarised in Table 4.2.

Table 4.2: Codes at the Data Level of the Value Chain

Code	Quotations	Documents
Lack of local climate data	20	10
Limitation: ground validation needed	11	5
Need for groundwater and water storage research	3	3
Insufficient knowledge what is located underground	2	2
Coral dike hydrology	1	1
Low update frequency sufficient for planning	1	1
Subsurface hydrology poorly understood	1	1

Note. *Quotations* is the groundedness of each code across all 21 interviews and *Documents* the number of interviews in which it occurs (full codebook in Appendix D.1). A code may also occur at other value-chain levels.

The need mentioned most often was for ground data to validate satellite observations (*Limitation: ground validation needed*; 11 quotations, 5 interviews). A national meteorological institute (A.4) explained that ground stations are essential to check whether EO data is correct: "The truth is at the in-situ ground stations. EO data cannot do without the ground stations yet." The same participant noted that in the Netherlands satellite imagery matches ground measurements well because there is a weather station every 50 kilometres, while on the BES islands there are few ground measurements and most is done from the satellite, which makes EO products less reliable. A local nature organisation (A.10) added that they always combine satellite data with field observations, since the field check gives them confidence in the patterns they see on the map.

This validation need was reinforced by a shortage of local measurements more generally (*Lack of local climate data*; 20 quotations, 10 interviews), the most grounded code across the analysis. A participant from the national meteorological institute (A.1) pointed out that rainfall varies locally: "In the past there was only one weather station on Bonaire, while most rain falls in the north." The OLB (A.11) confirmed this, explaining that rain showers can be very local on Bonaire, which is why a network of measurement stations is so important.

A second need is for basic registration data, which satellite observations cannot capture on their own. The developer of flood maps for the Caribbean (A.3) explained that the Netherlands has extensive

base registrations, while these are largely missing on Bonaire: "In the Netherlands there are extensive base registrations, but these are largely missing on Bonaire. Think of data on buildings or damage." A consultant in water management (A.2) added that the elevation model does not capture everything, and that there is less known about local watercourses, drainage, and culverts.

A related need concerns knowledge of the subsurface (*Insufficient knowledge what is located underground* and *Need for groundwater and water storage research*; 2 and 3 quotations). A local nature organisation (A.7) explained that the future resilience of Bonaire is uncertain, partly because too little is known about what lies underground, including groundwater extraction and possible storage capacity. The OLB (A.17) described why this matters on Bonaire: the porous coral dike along the west coast allows seawater to move hundreds of metres inland through subsurface flows, which standard satellite data cannot capture (*Coral dike hydrology*). A tourism organisation (A.21) added that for the tourism sector, detailed and locally specific climate data and risk maps are not always available or easy to access, which makes it harder to assess risks and take timely measures.

The interviews also showed what update frequency would be sufficient (*Low update frequency sufficient for planning*). Stakeholders did not call for real-time monitoring in all cases. For spatial planning, the OLB (A.11) noted that one or two updates of the information per year is enough, so the right update frequency depends on the use case.

4.2.2. Service provider level

This section discusses the needs at the service provider level, the link in the value chain where raw data is turned into usable products. These needs were expressed by both users and the companies that develop EO tools. Table 4.3 summarises the codes at this level.

Table 4.3: Codes at the Service Provider Level of the Value Chain

Code	Quotations	Documents
Difficulty converting raw EO data into usable information	7	4
EO data insufficient - needs numerical models	6	3
EO primarily useful for past and present analysis	4	3
Need for integrated tool	2	2
Integration of EO and elevation data	1	1
Making EO accessible to non-technical users	1	1
Multimodal data combination	1	1
Need for transparency in climate models	1	1

Note. *Quotations* is the groundedness of each code across all 21 interviews and *Documents* the number of interviews in which it occurs (full codebook in Appendix D.1).

The need mentioned most often was the gap between raw satellite data and usable information (*Difficulty converting raw EO data into usable information*; 7 quotations, 4 interviews). An EO startup (A.19) explained that users without a background in remote sensing can only benefit from EO data if the technology is made easy to use, so that they can work with a tool without first having to learn remote sensing (*Making EO accessible to non-technical users*). Users described the same gap. The OLB (A.11) said that turning raw data into information is the main barrier to wider use: "Turning raw data into information is a challenge. The knowledge to program it is missing." A local nature organisation (A.10) added that more advanced tools often take too much time to learn for what they give back, so they end up using basic tools like Google Earth instead.

A second need is for tools that combine different data sources (*Need for integrated tool* and *Multimodal data combination*). Several participants described EO data as one layer in a larger picture rather than a complete service on its own. The OLB (A.17) explained that combining layers is useful: "If you can combine everything in one tool and overlay them, you can act faster." An EO startup (A.19) mentioned that their platform increasingly combines satellite imagery, aerial photos, and elevation data, and a geospatial company (A.20) explained that their digital twin platform is built around the same idea of combining multiple data sources for disaster risk management.

A third need is for information about how reliable the outputs are and on what assumptions they rest

(*Need for transparency in climate models*, grounded in the broader *Forecast uncertainty and model limitations*; 16 quotations, 6 interviews). A national meteorological institute (A.4) and the developer of flood maps for the Caribbean (A.3) both stressed that maps and forecasts are only useful when users can judge how reliable they are. A geospatial company (A.20) made the same point operationally, arguing that outputs should carry an uncertainty estimate so that unreliable areas, for example those obscured by cloud cover, can be flagged rather than trusted. An international nature conservation organisation (A.5) captured the underlying need: "I would mainly want to know which assumptions have been made when building a model. Then I can better judge what the model is and is not suitable for."

Besides these needs, some participants described concrete services they had developed or used at this level. A consultant in water management (A.2) explained how they combined satellite-based elevation data with KNMI climate scenarios to build first risk profiles for Bonaire (*Integration of EO and elevation data*), and that the more detailed AHN elevation model, which was flown in later, improved the accuracy of these flood maps. A research institute focused on water management (A.8) added that EO data is mainly useful for understanding past and present conditions, while numerical models are needed to simulate future scenarios, so that EO and modelling complement each other (*EO primarily useful for past and present analysis* and *EO data insufficient - needs numerical models*). An EO startup (A.19) described mangrove monitoring as one of the most successful applications of their pilot on Bonaire.

4.2.3. Customer level

This section discusses the needs at the customer level, where the focus is less on data and more on infrastructure and communication. Four needs came up across the interviews: groundwater and water storage, drainage infrastructure, early warning communication, and awareness and education. Table 4.4 summarises the codes at this level, which draw on the infrastructure, early warning, and awareness themes.

Table 4.4: Codes at the Customer Level of the Value Chain

Code	Quotations	Documents
Insufficient drainage infrastructure	20	9
Heavy rainfall as primary flood driver	17	9
Urban development blocking natural drainage	12	8
Lack of spatial planning regulations for private developments	8	6
KNMI is responsible for early warning	8	5
Low EO awareness among stakeholders	7	2
Breakdown of traditional water management systems	6	4
Early warning system absent or in development	6	6
Human interpretation required in early warning	5	2
Need for restoration of dams	4	4
Informal flood warning communication systems	3	3
Need for EO training and education	3	2
Need for public awareness on flood risks	3	3
Climate atlas not used for implementation but for overview	2	2
Vulnerability of digital warning systems during disasters	2	1
Flood risks not in business model	1	1
Limited stakeholder input on extreme events	1	1

Note. *Quotations* is the groundedness of each code across all 21 interviews and *Documents* the number of interviews in which it occurs (full codebook in Appendix D.1).

The first need concerns groundwater and water storage (*Breakdown of traditional water management systems*; 6 quotations, 4 interviews). Several participants explained that flood risk on Bonaire is closely linked to the breakdown of the traditional water management system. The OLB (A.17) described how a network of dams, rooien, and salin as historically captured and retained rainwater, but has since been poorly maintained and in some cases even used to dump waste. A local nature organisation (A.10) explained why this happened: "Agriculture has largely disappeared for over fifteen years. Since

then, water is pumped from the sea and converted through reverse osmosis. The dams have fallen into disrepair as a result.” Because the dams no longer retain water (*Need for restoration of dams*), rainwater now runs directly to the sea.

The second need concerns drainage infrastructure (*Insufficient drainage infrastructure*; 20 quotations, 9 interviews, the most grounded code at this level). A local nature organisation (A.10) described this as the most urgent gap on the island: “What is really missing are measures in the infrastructure: drainage along the road, through sewers or ditches. There are examples on Bonaire where this happens, but in many places not.” The same participant noted that this is partly because there are no requirements for private developers to include drainage in their projects (*Lack of spatial planning regulations for private developments*). The OLB (A.9) showed the consequences during the 2022 flood event, when underground drainage no longer worked because it had been built over or blocked (*Urban development blocking natural drainage*): “During that flood it turned out that a drainage channel ended in someone’s backyard, but a concrete wall had been placed in front of it. Then the water has nowhere to go.” Around 70 to 80 millimetres of rain fell in one night while the ground was already saturated (*Heavy rainfall as primary flood driver*), and several homes in the Savanna neighbourhood were partly flooded.

The third need concerns early warning communication (*Early warning system absent or in development*; 6 quotations, 6 interviews). The national crisis coordinator (A.6) explained that there is currently no formal early warning system on Bonaire, and that communication mostly runs through informal channels (*Informal flood warning communication systems*): “There is a WhatsApp group with the KNMI. The KNMI sends a warning when it makes an extreme weather forecast for Bonaire.” The same participant pointed out the limits of this approach, since network coverage is not reliable everywhere and tourists from cruise ships may not receive any alert. A local nature organisation (A.7) added that the OLB has a disaster communication app, but that it depends on internet coverage which often drops out during emergencies (*Vulnerability of digital warning systems during disasters*), and that an earlier siren exercise was chaotic because many people did not know how to respond. A national meteorological institute (A.4) noted that more measurement stations are needed for early warning, and that warning cannot be fully automated because human judgement is needed before making decisions that concern people’s safety (*Human interpretation required in early warning*).

The fourth need concerns awareness and education (*Low EO awareness among stakeholders and Need for EO training and education*; 7 and 3 quotations). The OLB (A.11) explained that EO is still seen as something distant: “It is still a far-from-my-bed show, the satellites.” The same participant stressed that the first challenge is simply that people understand EO exists at all, and suggested focusing on education, for example by introducing satellite data in schools. Awareness is also a barrier for using existing tools (*Climate atlas not used for implementation but for overview*): the OLB (A.11) knew the Climate Effect Atlas but had not yet used it, explaining that the problem is not the atlas itself but the knowledge to work with it, which staff have to acquire on their own.

This limited awareness is not restricted to the government. A dive school (A.14) showed how distant flood risk feels for parts of the private sector (*Flood risks not in business model*). The business had not experienced flood damage, did not use any tools to assess flood risk, and did not include it in its business model, describing it as a distant concern. A tourism organisation (A.21) described a similar pattern in the tourism sector. Although climate risks such as extreme rainfall, drought, and coastal erosion increasingly come up in conversations with partners, flood risk is not yet a structural part of most businesses’ operations or investment decisions. The participant saw it mainly as a long-term risk and noted that they could inform themselves better about what is happening on Bonaire. The OLB (A.9) added that awareness among residents is also important, since people need to understand that drainage channels must be kept open and that natural risks have to be taken into account.

This limited awareness also affects the data itself (*Limited stakeholder input on extreme events*). A national meteorological institute (A.1) explained that when they presented climate scenarios on Bonaire to gather input, they received little response on extreme rainfall, even though this is the variable that matters most for flood risk. They linked this to the fact that climate adaptation is still relatively new on the island, which makes it harder to gather input from local stakeholders. The same low awareness that holds back the use of tools therefore also makes it harder to collect the local input needed to improve the data behind them.

4.3. Barriers and market conditions

In this section, the barriers and market conditions are discussed and grouped into four themes: funding and market size, governance and institutions, data and technical limitations, and adoption by users. The codes underlying each group are summarised in Table 4.5.

Table 4.5: Codes Underlying the Barriers and Market Conditions

Code	Quotations	Documents
<i>Funding and market size</i>		
Need for more financial resources	8	6
Dependence on project-based financing	5	5
Insurance gap on Bonaire	4	3
Tool needs to be manually modified to local context	2	1
Blended finance for climate adaptation	1	1
Innovation funding for EO startups	1	1
Mismatch between loan timeframes and long-term climate risks	1	1
Pilot without follow-up	1	1
Small user base limits investment	1	1
Regional scale lowers EO service costs	1	1
<i>Governance and institutions</i>		
Limited institutional capacity	18	11
Fragmented institutional responsibilities	10	8
Inefficiency and lack of decisiveness local government	10	2
Lack of spatial planning regulations for private developments	8	6
Comply or explain principle not applied	1	1
Permit delays climate adaptation and housing projects	1	1
<i>Data and technical limitations</i>		
Forecast uncertainty and model limitations	16	6
EO data insufficient - needs numerical models	6	3
EO primarily useful for past and present analysis	4	3
Lack of historical data	2	2
Lack of global coordination of satellite infrastructure	2	1
Data ownership disputes KNMI-Curacao	1	1
Historical aerial imagery valuable	1	1
Need for satellite imagery of flood events	1	1
<i>Adoption by users</i>		
Low EO awareness among stakeholders	7	2
Competition with ArcGIS	1	1
Functionality gap with existing tools	1	1
Limited user time and capacity	1	1
Mismatch with ecologist workflows	1	1
Remote collaboration challenges	1	1

Note. *Quotations* is the groundedness of each code across all 21 interviews and *Documents* the number of interviews in which it occurs (full codebook in Appendix D.1). A code may recur across sections.

Funding and market size

The challenge mentioned most often concerns funding (*Need for more financial resources* and *Dependence on project-based financing*; 8 and 5 quotations). Several participants pointed out that climate adaptation on Bonaire is financed through projects rather than structural budgets, which makes it hard to sustain a service over time. A recurring problem is that pilots are not followed up (*Pilot without follow-up*), and that EO tools developed elsewhere often need to be adapted to the local context of Bonaire before they can be used (*Tool needs to be manually modified to local context*). An EO startup (A.19) experienced this directly: during their pilot, several islands used a cheap test licence, but once the company moved to a regular pricing model, the platform was no longer actively used. A geospatial

company (A.20) described funding continuity as the biggest obstacle for services like this: "Even if people pay for a pilot, this is something that needs continuous updating. You need new satellite images, you need someone to do the processing, you need to host all of the data. Who's going to maintain it?" They stressed that this is a question of funding and ownership rather than a technical problem. An environmental NGO (A.18) described the same pattern more broadly, comparing it to the Netherlands, where the legally established Delta Programme guarantees structural funding for water safety: "What we keep seeing is that the problems are structural, but the funding stays project-based." The same NGO noted that the Netherlands has made money available to develop the islands' climate plans, but not to guarantee funding for carrying them out.

Two conditions in the market could help to address this funding problem. First, the regional scale of EO data lowers costs (*Regional scale lowers EO service costs*). A geospatial company (A.20) noted that satellite imagery covers areas far larger than a single island, which makes a service more cost-effective when several governments share it: "A satellite image covers way more than one island, so you are a lot more cost effective if you can do these economies of scale and have multiple governments interested." This provider was piloting a digital twin platform on another Caribbean island under a government-to-government agreement funded by the Dutch government, and saw a similar process as a possible model for Bonaire. Second, public innovation funding offers an entry point (*Innovation funding for EO startups*). An EO startup (A.19) explained that they started after winning national innovation funding, which allowed them to develop their first prototype, and that they were later invited to the islands through a European programme for space-sector startups. A bank on Bonaire (A.13) added that flood risk is not yet reflected in financial decisions, since most business loans run for fifteen years or less while flood risk plays out over much longer periods (*Mismatch between loan timeframes and long-term climate risks*). Insurers were mentioned as a possible future customer (*Insurance gap on Bonaire*): a geospatial company (A.20) suggested they could become paying customers if better flood prediction helped them lower their exposure and price their premiums.

Governance and institutions

Another challenge concerns governance (*Inefficiency and lack of decisiveness local government, Limited institutional capacity, and Fragmented institutional responsibilities*; 10, 18, and 10 quotations). Several participants described the local government as slow to act, which makes it difficult to move from plans to implementation. A local nature organisation (A.7) noted that many reports and studies exist, but that actual implementation lags behind, partly due to a lack of decisiveness within the local government. A geospatial company (A.20) explained that trust is needed before people adopt a service, and that this depends on local engagement: people are more willing to use a platform once they see their own data reflected in it. They added that projects rarely work without a local champion who takes ownership of them, since responsibility often falls away when political cycles change. A local nature organisation (A.10) added that there are no requirements for private developers to include drainage in their projects, and that permit procedures are slow because the underlying laws are unclear or do not exist (*Permit delays climate adaptation and housing projects*), which has delayed their own dam project by two years. The OLB (A.11) also pointed to a large maintenance backlog in the road network, where delayed repairs become more expensive every year. An environmental NGO (A.18) linked this to the principle of comply or explain (*Comply or explain principle not applied*), which means that national policy should in principle also apply to the BES islands unless there is an explicit reason it does not, but which in practice often leaves the islands behind. The same NGO referred to the Bonaire climate case, in which the court ruled in January 2026 that the Netherlands is not doing enough to protect Bonaire from climate change.

Despite these governance challenges, participants also pointed to current policy developments that place flood risk higher on the agenda. The OLB (A.17) mentioned the upcoming revision of the zoning plan, in which flood risk and suitable building locations are taken into account. Several participants (A.16, A.17) referred to the development of a climate plan for Bonaire, which includes the restoration of dams and rooien, better maintenance, and preventing construction in risk areas.

Data and technical limitations

A third group of challenges is technical. The lack of historical data is a recurring problem (*Lack of historical data*), and it takes two forms. The first is historical meteorological data. A consultant in water management (A.2) explained that this data is difficult to access, since records from before 2010,

when the BES islands were part of the Netherlands Antilles, are poorly archived. The OLB (A.11) and a ministry participant (A.16) both added that there is an ongoing discussion between the Dutch and Curaçao meteorological services about the ownership, quality, and digitalisation of this data (*Data ownership disputes KNMI-Curacao*). The second is historical imagery of past flood events (*Historical aerial imagery valuable* and *Need for satellite imagery of flood events*). The OLB (A.11) explained that data from the past helps to understand how water behaves: "You also need data from the past, how it used to be and how it used to happen. Combining photos with satellite data from past events gives you good information about what water does." Without this kind of imagery, knowledge of past flooding stays anecdotal and is difficult to use for planning. Several participants also pointed out the limits of EO itself. A research institute focused on water management (A.8) noted that EO is mainly useful for understanding past and present conditions, while numerical models are needed for future scenarios (*EO primarily useful for past and present analysis* and *EO data insufficient - needs numerical models*). A national meteorological institute (A.4) added that the global coordination of satellite infrastructure is limited (*Lack of global coordination of satellite infrastructure*), which affects what data is available for small islands like Bonaire.

Beyond these limits of what EO can observe, several participants pointed to the uncertainty of the forecasts and models themselves (*Forecast uncertainty and model limitations*; 16 quotations, 6 interviews, the most grounded code in the EO-capabilities theme). A national meteorological institute (A.1) explained that the global climate models used for Bonaire have a coarse resolution of around 100 by 100 kilometres, so that a small island is barely represented and its rainfall is difficult to capture; the institute manages this spread by combining several models and scenarios. The same institute (A.4) noted that short-range weather forecasts carry a comparable uncertainty, because the initial state is only known within the limits of the available measurements: "At $t = 0$ we think we know what it looks like, but we are limited in our measurements and measuring points. The model can end up far off." A research institute focused on water management (A.8) added that all forecasts are ultimately based on probabilities, so outcomes can differ from what was predicted, and that a coarse global model can generate false alarms when it does not resolve conditions near the coast. These limits reinforce that EO and models are most dependable for the past and present, and that future-oriented outputs must be read together with their uncertainty.

Adoption by users

A final group of challenges concerns adoption. An EO startup (A.19) explained that local users were often enthusiastic but had very little time available (*Limited user time and capacity*): some ecologists had "maybe only four hours a month, half of which was spent in meetings." The same participant noted that their step-by-step way of working did not always match how ecologists usually work, since ecologists tend to plan a whole study before collecting data (*Mismatch with ecologist workflows*). A local nature organisation (A.10) added that advanced tools often take too much time to learn for what they give back, so they fall back on basic tools like Google Earth (*Functionality gap with existing tools*). Organisations that already use software such as ArcGIS may also not switch to a new platform unless it clearly offers more (*Competition with ArcGIS*). Finally, the geographical distance between Bonaire and service providers in the Netherlands makes collaboration harder (*Remote collaboration challenges*), and several participants stressed that working on location is more effective than working remotely (A.19, A.20).

5

Discussion

This chapter interprets the findings of the study and relates them to the value chain framework introduced in Chapter 2, the stakeholder analysis presented in Chapter 4, and wider literature. The discussion is organised around four themes that emerged across the findings. The first is the set of potential customers and the applications that would serve them, for which the service-provider role is the missing link in the value chain. The second is awareness and capacity as a barrier to adoption. The third is the importance of continuity and funding over technical capability. The fourth is the influence of governance and trust. Together these themes explain why the technical potential of EO data has not yet translated into a working service on Bonaire: the data and applications exist, but the service provider, the demand, the funding, and the governance needed to sustain them do not yet come together. Building on these four themes, the chapter closes with a set of recommendations for the actors best placed to fill this gap.

5.1. Potential customers and applications

This section looks at the customer end of the value chain in two steps. It first identifies the potential customers for an EO-based flood risk management service on Bonaire, and how they differ in their role and their engagement. It then turns to the applications such a service could offer, and how these match the needs of those customers.

5.1.1. Potential customers

The interviews pointed to five potential customer groups for EO-based flood risk management services on Bonaire. They differ along two dimensions that shape how a service could reach them. The first is their role: some would use a service directly, while others would pay for it without using it themselves. The second is their current engagement: some are already involved with EO, while others could benefit but are not yet active, and their demand remains uncertain. These two dimensions cut across each other, so the groups are best understood by where they fall on both.

The direct users are the nature organisations and terrain managers and the local government, and both are already engaged. Nature organisations and terrain managers already use EO data, mostly through basic and freely available tools such as Google Earth and the elevation map from the Dataroom Caribbean Netherlands (A.10). Their awareness is relatively high, which makes them the most realistic first users, although their capacity to pay is limited. The OLB, as the local government, plays a central role in crisis management, spatial planning, and infrastructure maintenance (A.9, A.17). Its awareness varies within the organisation, and while it is a clear user, its ability to pay depends on funding from the national government.

The national ministries occupy a different position: they would pay for a service rather than use it. IenW and BZK do not use EO tools themselves, but they finance them, which makes them customers whose decisions shape what tools become available locally (A.15, A.16). Their role in the value chain is not to apply a service but to fund it, which is why their limited interest, identified in the stakeholder analysis,

matters so much for whether services are sustained. This split between the parties that use a service and the party that pays for it is central to the funding question discussed in Section 5.3.

Insurers and the real estate development sector are potential rather than active, and could be either users or payers. Insurers were named as a possible customer group by other stakeholders rather than by insurers themselves. In the Netherlands they increasingly use climate maps to assess portfolio risks, but on Bonaire this is much less developed (A.3), and none were available for an interview, which suggests a market that is not yet active. The real estate development sector could use flood risk information before building, but awareness in this group is currently low, and it too should be seen as a potential rather than a confirmed customer.

5.1.2. Applications

The customer groups just described sit at the customer end of the value chain, where the service provider is the link that converts data into value. The Sentinel Benefits Study (EARSC, 2024) found that committed individuals, or champions, at service providers and users are one of the strongest predictors of whether EO services are actually adopted. On Bonaire, this intermediary role is largely missing, which helps to explain why the data that does exist remains underused. As one participant from the OLB put it, turning raw data into information is the main challenge, and the knowledge to do so is missing (A.11). When the needs of these groups are translated into possible EO applications, most of them sit at this service provider level. These applications were not proposed by stakeholders as a finished list; they follow from the needs that stakeholders expressed, combined with the EO capabilities described in the theoretical background. What they have in common is that they do not require new satellite data, but a service that processes and combines existing data for the local context. They also map onto the three flood risk management categories from the theoretical background, prevention, response, and recovery, although not evenly.

Most of the applications fall under prevention. A first group concerns water management and infrastructure, and would mainly serve the local government and nature organisations. The results showed a need for an integrated overview that combines elevation, water flows, and infrastructure, both above and below ground. EO data is well suited to this, since elevation models and satellite imagery can show height differences and drainage paths across the whole island at once, which is difficult to capture with ground surveys alone. This rests in particular on the new LiDAR-based elevation model for Bonaire, with a resolution of 0.5 metres and a vertical accuracy below 15 centimetres. On a low-lying island where small differences in elevation determine whether an area floods, this level of detail is what makes island-wide analysis of water flows realistic, where the earlier 30-metre global model was too coarse. A related application follows from the need to restore the traditional water management system: because many dams and rooien are silted up or built over, satellite imagery and elevation data could help to detect which structures no longer function and where water accumulates, so that restoration can be prioritised. Technically, this combines optical imagery with the elevation model: silted-up or built-over structures show up as deviations from the surrounding surface, and the DEM reveals where water accumulates instead of draining away. The same data could support an assessment of drainage capacity, which stakeholders described as the most urgent infrastructure gap.

A second group of prevention applications concerns planning, and is most relevant for the government and the real estate development sector. The need to understand flood risk before decisions are made points to flood risk models and scenarios, which some participants already build by combining elevation data with rainfall scenarios. For Bonaire, this kind of application is not only hypothetical: the Climate Effect Atlas already provides flood risk maps for the island. The results showed that uptake is uneven, however. Some stakeholders use it, while others know it but have not yet applied it, often because they lack the knowledge to do so (A.11). This illustrates the wider pattern found in this study, that the barrier is rarely the existence of a tool, but the awareness and capacity to use it. With the upcoming revision of the zoning plan, EO could further support spatial planning by showing which areas are most exposed, which is relevant for decisions about where to build and where to locate critical infrastructure such as the hospital, the airport, and the port. For the real estate development sector, the same risk information could help developers assess flood risk before building, although awareness in this group is currently low. Ecosystems form a further prevention application that would serve nature organisations: because mangroves act as natural coastal protection, monitoring their development is directly

relevant for flood prevention, and an EO startup described mangrove monitoring as one of the most successful applications of its pilot on Bonaire (A.19). This works by comparing optical imagery of the same area over time, so that changes in the extent and condition of mangrove stands become visible from successive images without fieldwork at every site.

A smaller number of applications relate to response, and would mainly serve the local government and residents. The interviews consistently described the absence of a formal early warning system, with warnings instead running through informal channels such as a WhatsApp group with the KNMI (A.6). Yet at the other end, the KNMI is in fact developing a formal system: through its Early Warning Centre it has built a prototype multi-hazard dashboard for the BES islands that combines weather models, satellite data, and seismic and tsunami information (Kruiver et al., 2024). What is missing is the layer in between: a formal system that actually reaches local users. The dashboard currently runs internally in the KNMI weather control room, with a version for local stakeholders only planned as a next step, so the parties on the island are largely unaware that it exists. That it did not come up in the interviews is itself telling, and echoes the wider awareness gap found in this study: the barrier is often not whether a tool is being built, but whether it reaches and is known to local users. The dashboard already includes rainfall-relevant layers, such as weather models and satellite imagery of cloud cover that indicates rain, and the wider hazard of extreme rainfall and flash floods is explicitly recognised. What it does not yet provide is an operational warning targeted at flooding on the island, which is still a next step rather than an existing function.

Furthermore, recovery was almost absent. Although stakeholders discussed recovery activities such as the restoration of dams and *saliñas* after the November 2022 rainfall, they did not link these to EO data. Both IenW (A.16) and the OLB (A.17) described this restoration, but from different perspectives: the ministry co-financed the repair work, while the OLB carried it out and stressed that structural maintenance afterwards falls to the local government. This is an interesting gap, since EO-based damage assessment is a well-established application elsewhere (Schumann & Brakenridge, 2018). The results also showed that damage information is largely missing on Bonaire, which is exactly the kind of gap such an application could fill. Part of the explanation seems to be that the focus of climate adaptation on Bonaire is deliberately on prevention. As the OLB explained, the aim is to reduce risks beforehand so that damage stays as limited as possible (A.17). Responsibility for damage itself is also unclear. The OLB stated that compensating residents is not its task (A.9). Both IenW and the OLB noted that the Dutch disaster compensation law does not fit the Caribbean context well (A.16, A.17). Recovery is therefore seen less as a matter of data and more as a question of prevention and liability, which may be why stakeholders did not connect it to EO. The fact that they do not yet see EO as a recovery tool suggests that this is an underused space, particularly for damage assessment that could support insurers and infrastructure owners. For an entrepreneur, recovery may therefore be a less crowded entry point than prevention, where more applications already exist.

These applications also make clear what value such a service would hold, and the value differs by customer. For the direct users, it is operational: nature organisations would be better able to monitor the reefs and mangroves whose degradation by sediment is their central concern, while the OLB would gain faster and better-grounded decisions on spatial planning and drainage, precisely where its own capacity now falls short. For the ministries, who would pay rather than use, the value is different: EO could show whether the measures they finance, such as dam and *saliña* restoration, actually reduce risk over time, which is information they currently lack. For the potential customers, the value is commercial: if the insurance market develops, better flood prediction and damage data would help insurers price risk, and developers could weigh flood exposure before building. In each case, however, the value lies in supporting a decision rather than replacing it, which is consistent with the finding that EO works as one input among others.

Taken together, these applications show that EO could support flood risk management across all three categories, but almost always as one input among others rather than as a stand-alone solution. The entrepreneurial opportunity on Bonaire therefore lies less in collecting data and more in processing and interpreting it for the local context.

5.2. Awareness and capacity

A second theme that runs through the interviews is that the barriers to EO adoption on Bonaire are not only technical or financial, but also about awareness and capacity. Even where data and tools exist, they are often not used, because potential users do not know that EO exists, do not know how to apply it, or do not have the time and skills to do so. This was one of the most consistent findings across the study, mentioned by the local government, the private sector, and an external data provider alike.

The most basic form of this barrier is that many potential users cannot picture what EO can do for them. The results showed that EO is often seen as something distant from daily practice, and that awareness is low not only among residents but also among groups such as developers and real estate development companies. The private sector illustrated this clearly: a dive school saw flood risk as a distant concern and used no tools at all, while a tourism organisation viewed it mainly as a long-term risk and noted that it could inform itself better. A geospatial company added that this awareness gap is not unique to Bonaire, but common across the region, which means that reaching potential users requires active outreach rather than waiting for demand to appear.

The level of awareness, however, was not the same across all groups, or even within them. Nature organisations and terrain managers stood out as relatively aware, since they already use basic EO tools such as Google Earth, elevation data, and historical aerial imagery in their daily work. This is likely because they are confronted directly with the consequences of flooding, such as sediment damage to coral reefs, and therefore have a stronger interest in understanding how water moves across the island. Within the local government, awareness also varied. While EO was often described as something distant, some participants from the OLB were clearly familiar with its possibilities: one could point to concrete uses such as mapping water flows and building risk scenarios for dams (A.11), while another already worked with historical aerial imagery and the Climate Effect Atlas and saw the value of combining EO with in-situ measurements (A.17). The contrast with the private sector is notable, where a dive school and a tourism organisation saw flood risk as a distant or long-term concern. This suggests that awareness is closely linked to how directly a person experiences or works with the effects of flooding, and that it can differ from one individual to another within the same organisation. This individual variation echoes the role of champions described in the Sentinel Benefits Study (EARSC, 2024), where committed individuals are a key factor in whether EO services are taken up. A second form of the barrier is that, even when tools exist, the knowledge to use them is missing.

These findings align closely with the literature on the EO downstream sector. Lupi et al. (2024) found that the largest demand-side barrier to the growth of EO services is limited awareness among potential users about what EO can offer, and that the strongest success factor on the supply side is the availability of skilled personnel and the capacity to absorb and apply new knowledge. Bonaire shows both sides of this pattern. On the demand side, awareness is low across most user groups, and on the supply side, the local capacity to process and apply EO data is limited. This suggests that the barriers on Bonaire are not unique to a small island, but a sharper version of a pattern seen in larger EO markets as well.

The implication for entrepreneurs is that developing a good tool is not enough. Because awareness and capacity are themselves barriers, a service is only likely to be adopted if it is accompanied by education and local engagement. The variation in awareness also points to where an entrepreneur might start: nature organisations and the individuals within government who already understand EO are the most realistic first users, since they are aware of the technology and motivated by the problem. This connects to the finding, discussed in the next section, that trust and a local presence are preconditions for adoption. An entrepreneur entering this market would therefore need to invest not only in the technology, but also in building awareness and supporting users.

5.3. Continuity and funding

A third theme is that the main obstacle to EO-based services on Bonaire is not technical, but financial and organisational. Across the interviews, participants who had actually developed or piloted EO services pointed to the same problem: building a tool is feasible, but keeping it running over time is not. A geospatial company described funding continuity as the biggest obstacle for services like this. It was explicit that this is not a technical challenge, but a question of who pays for the ongoing data processing, hosting, and maintenance, and who owns the service in the long term. An EO startup experienced

the same pattern, when its pilot lost users once a commercial pricing model was introduced. This finding refines the picture given in the entrepreneurship literature. Denis et al. (2017) argued that falling satellite costs and the growing availability of free and open data have lowered the barriers to entering the EO market, creating opportunities for new firms. The case of Bonaire shows that this is true, but incomplete. Entering the market is indeed easier than before, since data and tools are increasingly accessible. The harder problem has shifted further down the line, to keeping a service alive once the initial funding ends. On Bonaire, the barrier is therefore not access to data or technology, but continuity.

Several structural factors make this continuity problem worse. The market is small, since the user base on a single island is too limited to support a standard commercial pricing model. Much of the funding comes from government, which means that services depend on political priorities and can stall when these shift. The scale of this dependence is considerable. A study commissioned by Greenpeace estimated the investment needed for climate adaptation on Bonaire at between 1.2 and 1.8 billion US dollars, against an annual budget for the Public Entity Bonaire of around 105 million dollars (Grant Thornton Impact House & Greenpeace, 2026). As set out in the theoretical background (Section 2.1.2), Bonaire cannot draw on the international climate finance available to the Small Island Developing States it resembles, which leaves national funding as the main route. These figures concern physical adaptation measures rather than an EO service specifically, but they illustrate the financial environment in which such a service would have to survive: one where local resources fall far short of the need, and where structural support depends largely on the Dutch state. An environmental NGO made the same point by comparing Bonaire to the Netherlands, where the legally established Delta Programme guarantees structural funding for water safety. On Bonaire the problems are structural while the funding stays project-based, and the result is that even successful pilots struggle to become lasting services.

At the same time, the interviews pointed to conditions that could ease the continuity problem. The regional scale of EO data is one: because a single satellite image covers far more than one island, serving several islands at once is more cost-effective than serving Bonaire alone. A geospatial company was piloting a digital twin platform on another Caribbean island under a government-to-government agreement funded by the Dutch government, and saw a similar process as a possible model for Bonaire. Public innovation funding is another: an EO startup had been able to develop its first prototype after winning national innovation funding, and was later brought to the islands through a European programme for space-sector startups. These routes do not solve the continuity problem on their own, but they suggest that neither public funding nor a commercial model is sufficient by itself.

These public routes ease the continuity problem, but they do not resolve it, because the continuity problem is not only a matter of too little funding, but of who could pay for a service at all. It is worth distinguishing funding from a business model. Public funding, whether project-based or structural, makes a service possible, but it does not make it a business. For an entrepreneur, a service that depends entirely on public money is not a venture but a subsidised project that ends when the subsidy ends, which is precisely the continuity problem in another form. A durable service needs customers who pay for it because it is worth something to them, not only because it serves a public task.

Here the findings expose a deeper obstacle. The parties that would use such a service are not the parties best able to pay for it. As the stakeholder analysis showed, the actors with the most interest in flood risk, such as nature organisations and the OLB, have the least capacity to pay, while the actors with resources, the national ministries, engage as funders rather than users. The value of a service and the ability to pay for it therefore sit with different parties. This mismatch, rather than market size alone, is what makes a purely commercial model difficult on Bonaire.

This mismatch points back to the public-private partnerships discussed in the theoretical background (Mysiak & Dionisio Pérez-Blanco, 2016). A partnership is a way of connecting the party that benefits from a service, the party that uses it, and the party that pays for it, when these are not the same. It also resolves the question of access: payment can be decoupled from use. The existing services discussed in the theoretical background already show this model, where the cost is carried on one side while use is free or low-cost on the other. The Climate Effect Atlas, for instance, is financed by IenW and freely available to its users, and Fastflood is free for individuals while charging organisations. For an EO service on Bonaire, the same logic would mean that a paying party, whether a ministry, an insurer, or a partnership between them, carries the ongoing cost, while the high-interest but low-budget users such as nature organisations and the OLB reach the service at little or no cost. Such an arrangement,

combining public funding in the early stages with paying customers as the market develops, is a more realistic route to a lasting service than either public funding or a commercial model on its own. Partnerships of this kind have not yet emerged on Bonaire, where flood insurance is barely developed, but they point to how the cost of an EO service could eventually be spread beyond government alone.

5.4. Governance and trust

A fourth theme concerns the institutional context in which any EO-based service on Bonaire would have to operate. Even if a service is technically sound, and aimed at a real need, its success depends on governance and trust. Several findings point to this, and together they show that the institutional setting is as important as the technology itself.

A recurring observation was that the local government is slow to move from plans to implementation. Many reports and studies exist, but actual measures lag behind, partly because of limited decisiveness and capacity within the local government. This connects to the stakeholder analysis in the theoretical background. The power-interest grid showed that the actors with the most power, in particular IenW and BZK, have only a medium interest in flood risk on Bonaire (Bryson, 2004). Because the parties that could act do not always treat it as a priority, funding and decision-making tend to be slow. This slow progress is reinforced by a gap in responsibility between the national and local government, which both sides described from their own perspective. From the national side, a participant from IenW explained that while the ministry co-finances one-off restoration projects, such as the repair of dams and *salifías*, the structural maintenance afterwards is the responsibility of the OLB (A.16).

From the local side, the OLB confirmed that it carries out this restoration. However, it stressed that regular maintenance has to come from the local budget, which is under pressure, and that the central government contribution has not kept pace with the island's rapid growth (A.11, A.17). The result is that each level sees the other as responsible: the ministry treats implementation and maintenance as a local task, while the local government looks to the ministry for the funding and support to carry it out. This gap reflects a structural pattern rather than a one-off disagreement over a single task. Under the comply-or-explain principle, national policy should in principle extend to the BES islands unless there is explicit reason otherwise, yet in practice it often does not reach them (A.18). Seen against the absent administrative layer described in Chapter 2, this is unsurprising. Where no province or water board carries national policy down to the island level, there is no structure to ensure that it arrives, and the responsibility for closing that distance is itself left unclear. This mirrors what a geospatial company described as responsibility falling through a crack when no one takes ownership, and it helps to explain why measures that are agreed on paper are often not carried out in practice. The Bonaire climate case, in which the court ruled in January 2026 that the Netherlands had failed to adequately protect the island, illustrates the same pattern: national responsibility towards the island was established only once a court compelled it (Rechtbank Den Haag, 2026).

Trust emerged as a second governance-related condition. A geospatial company stressed that trust is a precondition for adoption, and that it grows when users see their own local data reflected in a tool. The same participant argued that projects rarely succeed without a local champion who takes ownership and drives adoption forward. Without someone locally responsible, a service falls away when political cycles change. This connects to the concept of social capital from the theoretical background. Petzold and Ratter (2015) argue that small islands often have strong local networks and relations of trust, but that this social capital only leads to action when it is linked to higher-level actors such as governments and companies. A local champion is exactly this kind of link: someone who can mobilise local trust and connect it to the resources and knowledge of outside service providers. The finding that some individuals within the OLB are already aware of EO's possibilities suggests that such champions may already exist on Bonaire.

These governance findings also help to explain a tension that runs through the whole study. On the one hand, the stakeholders with the most interest in flood risk, such as nature organisations, residents, and parts of the tourism sector, have limited power and few resources to pay for services. On the other hand, the stakeholders with the power and resources, mainly IenW and BZK, have a more distant interest. EO-based services therefore cannot rely on demand from end users alone, but depend on high-power actors being willing to fund them. This reinforces the earlier finding that continuity depends on public

funding, and it suggests that an entrepreneur on Bonaire would need to work with government actors and local champions rather than approaching the market as a purely commercial opportunity.

Finally, the governance context is currently shifting in ways that may be favourable. The upcoming revision of the zoning plan will require flood risk to be assessed at new developments, and a climate plan for Bonaire is being developed. Together with the attention generated by the climate case, these developments place flood risk higher on the agenda than before. For an entrepreneur, this means that the institutional window for EO-based flood services may be more open now than in the past, provided that the funding and ownership questions can be resolved.

5.5. Recommendations

The central finding of this study is that the missing link on Bonaire is the service provider: the actor who turns raw EO data into usable products. The recommendations below therefore do not argue for that role in the abstract, but set out how it could be filled in practice and what would be needed to sustain it. They are organised by the two groups whose action matters most: the entrepreneur who could build such a service, and the government actors without whom it is unlikely to last. Because awareness and capacity, not the technology, are the binding constraint, a final step then sets out where to begin: not with the tool, but with the users closest to the problem.

For the entrepreneur

At its core, the service the entrepreneur could build is an integrated tool for the most urgent local needs: a service that combines elevation, water flows, and infrastructure, both above and below ground, integrated with local infrastructure data, ground measurements, and local knowledge. This would directly serve the water management and drainage needs that stakeholders described as most urgent, with the OLB and nature organisations as first users. What matters is not new satellite data, but a service that processes and combines existing data for the local context and presents it in a form non-technical users can act on.

The entrepreneur should also consider a regional rather than an island-specific service, because a service built for Bonaire alone faces a market too small to pay its own way. A regional service, covering several Caribbean islands at once, is likely to be more viable, since a single satellite image already covers far more than one island and the main costs of processing and hosting can then be shared. The EO companies interviewed pointed to this as the most cost-effective route, and one provider was already piloting a platform on another Caribbean island under a government-to-government agreement. This remains a plausible direction rather than a proven one: whether a regional model works in practice is itself a question for the comparative research set out in Section 6.6.

Finally, the entrepreneur should work through a local champion, since adoption depends on trust, and trust depends on local ownership. The findings suggest that projects rarely succeed without someone locally who takes ownership and drives adoption, and that responsibility otherwise falls away when political cycles change. Identifying and working through such a champion, possibly one of the individuals already aware of EO within the OLB, would be a precondition for a service that lasts, provided the OLB gives that person the room to take it on.

For the government

The most important action at the national level is to make funding structural rather than project-based, since the findings indicate that the main obstacle is not building a service but keeping it running. Climate adaptation on Bonaire is financed largely through one-off projects, so services rarely outlive their pilot. This falls in particular to BZK, as the ministry that coordinates the relationship with the special municipalities and is central to their structural funding, and to IenW, as the ministry responsible for water and flood protection, which could bring the logic of the Delta Programme, where water safety funding is structurally secured in the European Netherlands, to bear on Bonaire.

Behind the funding problem lies a structural one that BZK, as the coordinating ministry for the special municipalities, is best placed to address. Since Bonaire has neither a province nor a water board, the administrative layer that in the European Netherlands translates data and knowledge into water management is absent, which is widely regarded as a design flaw in the 2010 arrangement (Nijpels,

2023). Responsibility for flood measures falls between the national government, which finances one-off restoration, and the OLB, which carries structural maintenance, so that neither fully takes ownership. Rather than leaving this coordinating, knowledge-translating function in the gap between the two, BZK should designate a clear owner for it and apply the comply-or-explain principle more consistently, so that national policy reaches the island rather than leaving it behind. This does not require recreating a water board, but without a named owner, even a well-funded service risks stalling once a project ends.

At the island level, the OLB has two concrete levers within its own spatial-planning and permitting mandate. The upcoming revision of the zoning plan is an opportunity to require flood risk to be assessed at new developments and to steer building away from the most exposed low-lying areas. Alongside this, introducing drainage requirements for private developers, which currently do not exist, would address the infrastructure gap that stakeholders described as the most urgent on the island. Both levers, however, depend on a firmer basis for permitting itself. Participants noted that permit procedures are slow because the underlying rules are unclear or absent, which leaves flood risk without a formal role in the decision. Strengthening that basis, by setting clear criteria against which applications are tested, would give both the zoning plan and any EO-based risk information a concrete point of entry into permitting decisions.

Where to begin

Taken together, these recommendations describe what a viable service would look like, but they leave open where to start. The starting point is not the tool. The single most important first step is to build awareness and capacity among the users who are already closest to the problem, because awareness and capacity, not technology or data, are the central barrier on Bonaire. The integrated tool described above is the goal, not the entry point: without this groundwork it would simply join the tools that already exist but go unused, such as the Climate Effect Atlas, which some know and use, while others know of it without applying it, and others are unaware of entirely. The first move is therefore for the service provider, working with the OLB, to start with the nature organisations and the individuals aware of EO within the OLB, strengthening their ability to use the data that is already available, and to accompany any service with education and local engagement rather than treating these as an afterthought.

There is a reason to act now. The upcoming revision of the zoning plan will require flood risk to be assessed at new developments, a climate plan for Bonaire is being developed, and the January 2026 court ruling has placed flood risk higher on the political agenda than before. This combination opens an institutional window that may not stay open indefinitely, and it is for the entrepreneur that this timing matters most: the moment to build the capacity and trust that adoption depends on is while that window is open.

6

Conclusion

This chapter answers the research questions of the study. It first goes through the three sub-questions one by one: the needs of potential customers, the EO data and features that fit those needs, and the opportunities and challenges for entrepreneurs. It then puts these together to answer the main question of how EO data can be translated into entrepreneurial flood risk management services on Bonaire. The chapter closes by reflecting on the limitations of the study and setting out directions for future research.

6.1. The needs of potential customers

The first sub-question looks at the demand side: what potential customers on Bonaire actually need.

What are the needs of potential customers regarding flood risk management services on Bonaire?

The interviews identified four groups of potential customers: nature organisations and terrain managers, the local and national government, insurers, and the real estate development sector. Their needs are practical and sit at the customer end of the value chain. The focus is less on data and more on infrastructure, communication, and capacity. Nature organisations and the local government are the most active potential users. They need an integrated overview of elevation, risk zones, and infrastructure to support decisions about water management and spatial planning.

Across the interviews, four needs came up repeatedly: restoring water storage through dams and salinías, improving drainage infrastructure, a faster and more reliable early warning system, and more awareness of how to use EO. Insurers and the real estate development sector were named as potential customers by others rather than by themselves. Their awareness of EO is currently low, so they are a possible rather than an active market. Across all groups, EO is seen as a supporting tool rather than the main solution, since the underlying problems are mostly about physical infrastructure and institutional capacity.

6.2. Suitable EO data and service features

The second sub-question builds on these needs and turns to the supply side: which EO data and features could actually meet them.

Which types of Earth Observation data and service features are most suitable for addressing these needs?

The needs identified in this study point to a number of possible EO applications, most of which fall under flood prevention. These include an integrated tool that combines elevation, water flows, and infrastructure. Others are tools to detect which dams, rooien, and drainage channels need restoration, flood risk models and scenarios for spatial planning, and mangrove monitoring. A smaller number relate to the response phase, in particular early warning systems and tools for evacuation planning.

Recovery applications, such as damage assessment after a flood, were almost entirely absent from the interviews, even though they are well established in the literature. What these applications have

in common is that they do not need new satellite data. Instead, they need a service that processes and combines existing data for the local context. The most suitable features are therefore not about the data itself. They are about making EO accessible and reliable for non-technical users, and about combining satellite data with local infrastructure data, ground measurements, and local knowledge.

6.3. Opportunities and challenges for entrepreneurs

The third sub-question takes the entrepreneur's perspective: if the needs and the possible applications are clear, what makes it hard or promising to actually build such a service.

What are the opportunities and challenges for entrepreneurs developing EO-based flood risk management services on Bonaire?

The clearest opportunity lies in the service-provider role. Turning data into usable products is the weakest link in the value chain and the one with the clearest unmet need, so an entrepreneur who can fill it addresses a real demand. Further opportunities lie in serving several islands at once to get around the small local market, in drawing on public innovation funding in the early stages, and in the current policy momentum created by the zoning plan revision and the climate plan.

However, the challenges are substantial, and most are not technical but financial and institutional. A central problem is that the value of a service and the ability to pay for it lie with different parties. The groups with the most interest in flood risk, such as nature organisations and the local government, have the least capacity to pay, while the actors with resources are more distant from the risk. This means funding is not simply a matter of finding money, but of designing a business model in a market where the users cannot carry the cost alone. Related to this, funding for climate adaptation is mostly project-based rather than structural, which makes it hard to keep a service running once a pilot ends. The local market is small, governance is slow, and responsibility for funding and maintenance is split between the local and national government, so neither side fully takes it on. Awareness of EO is low among most user groups, and adoption depends on trust and on a local champion who can drive it forward. Together, these challenges show that the main barrier is not building a tool, but sustaining it: keeping it funded, embedded, and used over time.

6.4. Answering the main research question

Bringing the three sub-questions together, the study can now answer the main research question:

How can Earth Observation (EO) data be translated into entrepreneurial flood risk management services on Bonaire?

The answer lies less in the data and more in the service that turns it into something usable. Satellite data is increasingly available, and the needs of potential customers are real and clearly expressed. What is missing is the link that connects the two: the service provider. This is the central finding of the study. On Bonaire, the bottleneck is not the satellite data or the technology, but the translation of that data into accessible, reliable products that local users can act on.

An entrepreneur can therefore translate EO data into flood risk management services by taking on this service provider role. In practice, this means turning raw data into tools that non-technical users can understand and trust. It also means integrating satellite data with local infrastructure data, ground measurements, and local knowledge, and combining the tool with education and local engagement so that it is actually used. Most of these services would support flood prevention, with a smaller role in response and an underused space in recovery.

The study also shows that this is unlikely to succeed as a purely commercial venture aimed at Bonaire alone. The local market is too small, funding is mostly project-based, and adoption depends on trust and institutional support. A more realistic path is a service that spans several islands, is supported by public funding in its early stages, and is carried locally by a champion who can build the trust needed for adoption. EO data can support flood risk management on Bonaire, but only when it is embedded in a service, a funding structure, and a local context that allow it to be used in practice.

6.5. Limitations

This study has two main limitations that should be taken into account when interpreting the findings.

The first concerns the stakeholder groups that could not be interviewed. Insurers and the real estate development sector were both identified as potential customer groups, but neither was available during the research period, and the large-scale satellite data providers were not interviewed either. This is a limitation because these groups carry weight in the analysis: insurers and developers are discussed as the actors with both the resources and a commercial reason to pay for a service, and are therefore central to the business-model and public-private partnership argument, while the data providers occupy the first link of the value chain. The severity is uneven across the findings. It is most serious for the business-model argument, since the claim that insurers could become paying customers rests entirely on how other stakeholders perceive them, rather than on input from insurers themselves, and the willingness to pay of both insurers and developers remains untested. It is less serious for the data-provider link, because a geospatial company that collects and processes its own data did take part, so that perspective is partly represented, and because the study deliberately focused on the service-provider and customer links where the main gap was expected. The effect is that the conclusions about who could sustain a service financially should be read as plausible directions rather than established demand. If the study were repeated, these groups would be approached earlier and through more channels, with more time reserved for scheduling, and the willingness to pay of insurers and developers would be tested directly.

The second limitation follows from the study's focus on a single island. As explained in Chapter 3, studying one case in depth was a deliberate choice, but it means the findings cannot be directly generalised. Bonaire's specific combination of high-income status and limited local capacity, its particular hydrology, and its governance relationship with the Netherlands all shape the results, so how far they transfer depends on how similar another setting is. Bonaire is also not a typical island: its position within the Kingdom of the Netherlands means it cannot draw on the international climate finance available to Small Island Developing States, as set out in Section 2.1.2, which makes its funding situation unusual. The concrete effect on this study is that its conclusions are calibrated to this one configuration. The recommendation to serve several islands regionally, for instance, assumes that other Caribbean islands face similar needs and constraints, which this single-island design could not test. The findings should therefore be read as grounded in Bonaire, and as hypotheses rather than established results for other islands. If the study were repeated, a comparative design covering at least one further island would make it possible to separate what is specific to Bonaire from what holds more widely, and to test the regional model directly rather than infer it.

6.6. Future research

These limitations point to several directions for future research, of which three stand out. The most direct next step is to move from identifying needs to testing them in practice, by studying an EO-based service as it is developed and adopted on Bonaire. This study concluded that the service-provider role is the missing link, but that conclusion rests on what stakeholders said they needed, not on observing a service in use. Following a service over time, from its introduction with a local partner through its actual use by organisations such as the OLB or the nature organisations, would show whether the demand identified here translates into adoption, and which factors, such as the presence of a local champion or the funding arrangement behind it, determine whether it lasts. This would test the central claim of this research rather than assume it, and would turn the needs mapped here into evidence about what a working service actually requires.

A second direction is comparative research across several Caribbean islands. Several of this study's conclusions, most importantly the recommendation to serve islands regionally rather than one at a time, rest on the assumption that other islands face needs and constraints similar to Bonaire's, which a single-island design could not test. Comparing Bonaire with islands that differ in their governance status, such as the other Dutch Caribbean islands or independent states in the region, would show which findings are specific to Bonaire and which hold more widely, and would establish whether a shared regional service is realistic in practice or only in principle. This matters because the regional model is central to the case for a financially viable service, yet it currently rests on inference rather than evidence.

A third direction is to reach the stakeholder groups that could not be included here, in particular insurers, real estate developers, and the large-scale providers of satellite data. The business-model argument of this study depends on the idea that actors with resources and a commercial interest, such as insurers, could become paying customers, but this rests entirely on how others described them. Interviewing these groups directly, or surveying their willingness to pay, would show whether the demand this study inferred on the supply and payment side actually exists, and would clarify the conditions under which a service could be funded by paying customers rather than by public money alone.

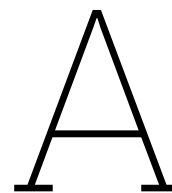
Two further directions are worth noting more briefly. Research into recovery applications would be valuable, since EO-based damage assessment was largely absent from the interviews even though it is well established elsewhere, which suggests an underexplored area where a service could add value. Finally, the governance obstacles identified here, in particular the slow decision-making and the unclear division of responsibility between the national government and the OLB, deserve study in their own right, since they reach beyond EO but are central to whether any flood risk management service is adopted and sustained.

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Summary of interviews

A.1. National meteorological institute 1

The institute uses global climate models (CMIP6) in combination with statistical downscaling to create local climate scenarios for Bonaire. Due to the low resolution of global models, small islands are difficult to model accurately. A major challenge is the lack of long-term and reliable precipitation data, making it difficult to analyse extreme precipitation events. These extremes are crucial for assessing flood risks.

Bonaire is expected to become drier, but with more intense rainfall. This could lead to an increase in flood risks. Earth Observation is used indirectly via reanalysis datasets, but high resolution remains a challenge. Collaboration with local stakeholders is still in development, partly due to limited capacity and because climate adaptation on Bonaire is relatively new.

A.2. Consultant in water management

Consultant conducted a desk study on risk profiles for flooding on the BES islands. The focus was on creating an initial overview of different types of flooding, such as heavy rainfall, coastal flooding, and sea level rise. KNMI climate scenarios and available elevation data were used as the main inputs. Instead of developing new models, the approach mainly combined existing information to identify risks and gaps in knowledge.

At the time of the study, detailed elevation data was still limited. Newer high-resolution data has since become available and improves the level of detail in flood maps. However, this does not strongly change the overall picture of which areas are most vulnerable at the island.

An important limitation remains the lack of detailed local data, especially about drainage systems, water infrastructure, and long-term rainfall records. This makes it difficult to model flooding processes in detail. The results of the report are mainly used to support ongoing climate adaptation processes, such as climate tables and the development of adaptation strategies. It becomes clear that different types of flooding differ in how often they occur and how large their impact is, which is important when deciding on priorities for adaptation measures.

Another challenge is the division of responsibilities between the Dutch national government and local authorities. This makes it more complex to decide who is responsible for taking action and implementing measures. Overall, the next step is less about improving the risk analysis and more about selecting and implementing suitable adaptation measures, while continuing to improve data and monitoring over time.

A.3. Developer of flood maps for the Caribbean

The interview describes the development of a Climate Effect Atlas for the Caribbean Netherlands. The main goal of this atlas is to bring together different sources of climate-related information into one central and accessible platform. This helps to reduce fragmentation of knowledge and provides a

shared understanding for policymakers and other users. The atlas is not based on one single dataset, but combines information from multiple knowledge institutions. The development of the atlas is an ongoing process. In the case of Bonaire, it is still relatively new and continues to be expanded based on user needs and available data. The focus is on connecting existing projects and ensuring that relevant maps and data are made accessible. Compared to the Netherlands, data availability and usage are still developing, which influences how quickly the atlas can grow.

The maps are publicly accessible and are mainly intended to support decision-making, for example in spatial planning or the development of climate adaptation strategies such as heat plans. They help to identify where certain risks are located and where action may be needed. However, due to privacy regulations, it is not possible to track exactly who uses the maps or how they are used in practice. Several challenges are identified in the development of the atlas. These include limited financial resources, gaps in basic data, and the need for better data infrastructure, such as reliable base maps and statistics. It is also important to clearly define what type of information is needed, so that maps are relevant for the local context instead of simply copying approaches used in the Netherlands.

Collaboration takes place with various stakeholders, including governments, knowledge institutions, and local organisations. However, limited local capacity and frequent staff changes make collaboration more challenging. Overall, the atlas aims to act as a bridge between knowledge development and practical use, by making climate information more accessible and easier to apply in local decision-making.

A.4. National meteorological institute 2

The interview describes how Earth observation (EO) data and ground measurements are used in weather monitoring and applications. EO data is considered very valuable, but it cannot replace ground stations. Ground measurements are still needed to verify whether satellite data is accurate. In places like the Netherlands, where many ground stations are available, weather predictions are more reliable than in the Caribbean Netherlands, where fewer measurements exist.

On the BES islands, EO data plays a larger role because of the limited number of ground stations. However, this also means that predictions, especially for extreme rainfall, are more uncertain. Extreme events such as heavy rainfall are often linked to larger weather systems like hurricanes, which can be observed from satellites, but local impacts remain harder to measure accurately without in-situ data.

Early warning systems for flooding are currently not fully formalised. Communication often happens through a mix of official channels and informal methods, such as Whatsapp groups. There is a need for more measurement stations and more structured systems. At the same time, early warning cannot be fully automated, because human interpretation is needed to assess impacts and uncertainties before decisions are made.

The use of EO data by private companies is possible, but it is not seen as something that can fully replace public responsibilities. Weather and safety are considered core government tasks. Collaboration between public and private sectors is possible, but governments need to maintain control over critical data and systems.

Different types of elevation data (DTM) are also discussed. Methods such as LiDAR and radar each have advantages and limitations. LiDAR provides higher resolution but can contain noise, while radar has lower resolution but can better capture larger-scale patterns. These datasets are important for understanding flood risks, but they also contain uncertainties.

Finally, numerical weather models remain essential for forecasting. Although AI-based models are developing quickly and can perform well in some cases, they are not yet widely used in operations because they are less transparent and perform less well for extreme events. These extremes are especially important for applications such as flood prediction.

A.5. International nature conservation organisation

It is important to distinguish the two types of flood risks on Bonaire. The first type is flooding caused by heavy rainfall and the second type is flooding from the sea, such as coastal flooding or sea level

rise.

Nature-based solutions are considered useful, but only when they are suitable for the specific situation. For example, mangrove restoration is not always seen as a solution for every flooding problem. It can take a long time before mangroves provide enough protection, and in some locations it is not possible to plant them at all.

Several challenges are identified, including a lack of clear legislation, limited capacity, fragmented responsibilities, and issues with data quality. In addition, model inputs are sometimes outdated, and funding is often focused on short-term visible results instead of long-term maintenance.

For Bonaire, important future wishes include developing an integrated water management plan, restoring historical dams, improving rainwater harvesting, promoting circular water use, and strengthening data and modeling capabilities.

A.6. National representative of Dutch Government on Bonaire

This interview highlights that responsibilities are divided between the local government (OLB) and national actors. The local government is responsible for disaster management plans, while the national representative mainly becomes involved when support is requested. In such cases, requests are assessed on whether they are reasonable, proportional and clearly defined before being approved.

The interview indicates that there is currently no fully developed early warning system on Bonaire. Communication mainly takes place through informal channels, such as a WhatsApp group with the KNMI, which shares weather warnings. Several challenges for implementing a formal warning system are mentioned, including limited network coverage, occasional power outages and the presence of tourists who may not receive alerts. There are ongoing efforts to explore alternatives, such as cell broadcast systems.

Flood response measures are described as relatively basic and similar to those used elsewhere, such as placing sandbags, evacuating people from low-lying areas and protecting critical infrastructure like hospitals. It is noted that some important facilities, such as the hospital and airport, are located in low-lying areas, which increases their vulnerability.

An important theme is the lack of capacity on the island. There are limited personnel available for crisis management, and this affects both short-term response and long-term planning. For example, there is only one crisis coordinator within the local government, which creates risks if that person is unavailable. It is also difficult to attract and retain qualified staff due to the island's small population and the challenges of relocation. As a result, long-term projects often receive less attention, and external support is frequently requested.

The interview also shows that collaboration with private parties or discussions around insurance are currently limited in this context. Instead, the focus is mainly on public governance, coordination and operational response.

A.7. Local nature organisation 1

This interview gives a perspective from a local nature organisation involved in ecosystem management on Bonaire. It suggests that heavy rainfall is currently seen as a more immediate and less predictable flooding risk than sea-level rise. This is mainly related to increasing urbanisation, limited drainage infrastructure and the large amount of paved surfaces, which prevents water from infiltrating into the ground. As a result, rainwater runoff can quickly lead to flooding in certain areas.

Coastal flooding is also mentioned as a risk, especially during extreme events such as hurricanes. In these situations, wave direction and storm conditions can change, which has already caused damage along parts of the coastline in the past. This shows that both rainfall flooding and coastal flooding are relevant, but they differ in how often they occur and how predictable they are.

The interview indicates that there is currently no fully developed early warning system on Bonaire. Although there is a local app for disaster communication, its effectiveness is limited because internet coverage is not always reliable and there is no consistent siren system. Earlier tests with warning

systems also showed that people were not always sure how to respond, which suggests that awareness and preparedness are also important issues.

In terms of data use, Earth observation has been explored, but it is not always considered reliable without validation from local measurements. There seems to be a gap between satellite data and what is actually happening on the ground, which makes it more difficult to directly use this information for decision-making.

Another important point is the gap between knowledge and action. Many studies and reports are available, but actual implementation is described as limited. This is mainly linked to governance challenges, such as slow decision-making, limited attention for environmental topics and inefficiencies within the local government.

These issues also affect maintenance of infrastructure and the ability to reduce problems like sediment flowing into the sea. Overall, the interview suggests that besides technical challenges, institutional issues play a large role in managing flood risks on Bonaire.

A.8. Research institute focused on water management 1

The modelling work for Bonaire within the project is mainly based on numerical models rather than solely on Earth observation data. Earth observation is used to support the models, for example for validation, land-cover inputs, and observing sediment in coastal waters.

However, for analysing future policy scenarios, numerical modelling is required. The modelling approach combines different components, including hydrological models on land, hydrodynamic models in the sea, and particle tracking. Together, these are used to simulate how water and materials flow from land into the ocean, such as how rainfall runoff transports sediments and nutrients into coastal waters and how this affects coral reefs.

Earth observation is mainly useful for understanding past and current conditions, while numerical models are needed to simulate future developments and the effects of human interventions. Artificial intelligence may support tasks such as data cleaning, summarising information, and filling data gaps, but it is not currently seen as a replacement for numerical models, mainly due to challenges related to transparency and trust.

There is a strong need for long-term collaboration and maintenance of modelling systems. Many research projects on Bonaire produce data, but this information is often fragmented and not always integrated into a broader system. Involving local stakeholders is important to validate model inputs and improve the realism of the simulations.

Commercial opportunities for this model are considered limited, as this type of modelling how water flows from land to the sea on an island is typically seen as a government responsibility. However, operational services based on Earth observation, such as Sargassum early warning systems, may have commercial potential when they provide continuous monitoring and adapted to the local context.

A.9. Public Entity Bonaire 1

This interview provides insight into how the local government (OLB) deals with flood risks on Bonaire in practice. It shows that heavy rainfall events have recently had a significant impact, especially during periods where the ground is already saturated. In such cases, large amounts of rain in a short time can lead to flooding, even if this was not fully expected beforehand.

Different types of flooding are discussed, including rainfall flooding, tsunamis and coastal flooding. Tsunamis are seen as having the highest potential impact because many critical facilities, such as the hospital, airport and emergency services, are located in low-lying coastal areas.

However, heavy rainfall is considered more likely to occur, although generally less dangerous. The interview describes how the crisis response works during extreme rainfall. When a severe event occurs, a crisis team is activated to assess the situation and decide on actions. These actions mainly focus on practical solutions, such as clearing drainage systems, strengthening dams, pumping water and communicating with the public. In some cases, evacuation of vulnerable people may also be considered.

An important challenge mentioned is the difficulty of managing water due to outdated or incomplete drainage infrastructure. Some drainage channels no longer function properly because they are blocked, poorly maintained or built over. This can cause water to accumulate in certain areas. In addition, the availability of equipment, such as water pumps, can be limited during extreme events, which makes it harder to respond effectively.

The use of tools and data for flood risk management is currently limited. There is little active use of modelling or monitoring tools, mainly due to time constraints and lack of capacity. Instead, the organisation relies largely on warnings from the KNMI. There is, however, a clear interest in having better tools or maps to identify risk areas in advance. Regarding early warning systems, the responsibility is mainly placed at the national level, with the KNMI providing official warnings. These warnings are communicated locally through channels such as social media, radio and television. However, there is a need for faster and more reliable communication systems, such as cell broadcast alerts, to reach people more effectively during emergencies.

The interview also highlights challenges related to insurance and financial resilience. Many residents have limited financial resources, which makes it difficult to insure against flood damage or invest in preventive measures. This limits the role that insurance can currently play in managing flood risks.

Finally, future needs are described in terms of improving infrastructure, developing better spatial planning and increasing awareness among residents. There is also a need for better data, such as accurate elevation maps and integrated information systems, to support decision-making.

A.10. Local nature organisation 2

Extreme rainfall is described as an important and increasing problem on Bonaire. Due to more construction and a lack of proper drainage, water flows into the streets more often. This leads to economic damage, traffic disruption, damage to roads and cars, and environmental impacts such as sediment and nutrients flowing into the sea.

Bonaire is not well prepared for heavy rainfall. The main challenges are outdated infrastructure, missing drainage systems, limited government capacity, weak regulations, and issues with permits. In the past, dams played an important role in managing water, but many of them have fallen into disrepair as agriculture declined and desalination became more important for water supply.

The nature organisation aims to work on restoring dams and improving water management, especially for nature restoration and protecting mangroves. However, progress is limited by permit procedures and institutional barriers. At the same time, it is noted that government activities are sometimes carried out without a clear plan or permits.

Earth observation is mainly used in a practical way, for example through Google Earth, historical aerial images, and elevation data such as AHN. There is a need for detailed and useful information, but advanced tools are often too complex or time-consuming to use. An important issue is the gap between raw data and information that can be easily applied at the local level.

A.11. Public Entity Bonaire 2

This interview highlights that heavy rainfall is seen as one of the main flood risks for Bonaire. It is expected that rainfall will become more intense in shorter periods, which increases the likelihood of flooding. At the same time, there has been limited investment in water infrastructure in recent decades.

In the past, water management was closely linked to agriculture, and systems of dams and drainage channels were well maintained. These systems helped to slow down and filter water before it reached the sea. However, due to rapid and largely unplanned population growth, many of these systems have been damaged or removed. Housing developments have been built on or near former drainage routes and dams, which increases the risk of flooding in residential areas.

Earth observation is considered useful for gaining a better understanding of water flows and the physical layout of the island. Satellite data can help identify elevation differences, built areas and drainage paths, which can support the redesign of water routes and infrastructure. It can also be used to assess whether existing drainage systems need to be restored or improved. In addition, combining satellite data with

historical information can help to better understand how water behaved during past flood events. This can support the development of risk scenarios and emergency plans, for example by analysing how much water dams can handle under different rainfall conditions.

At the same time, several challenges are mentioned in using satellite data. The main issue is not the availability of data, but the lack of local capacity and knowledge to process and interpret it. Turning raw data into useful information requires technical skills and expertise, which are currently limited. There is also a general lack of awareness about the possibilities of satellite data. It is seen as something distant and not yet fully integrated into daily practice. Increasing knowledge and awareness, for example through education, is therefore considered important.

Potential users of this type of information include not only the government, but also developers, construction companies and infrastructure planners. However, awareness among these groups still needs to increase.

The Climate Effect Atlas is known, but not yet widely used, mainly due to a lack of knowledge about how to apply it in practice. More training or guidance could help improve its use.

Finally, the interview points to financial and institutional challenges. There is a significant backlog in infrastructure maintenance, partly due to rapid population growth and limited funding from the Dutch government. Current budgets are still based on outdated population numbers, which creates pressure on existing systems. It is also mentioned that funding from the ministry has not fully kept pace with these developments, raising questions about how measures based on Earth observation and other data will be financed and implemented.

A.12. Research institute focused on water management 2

The interview focused on the institute's approach to early warning systems and climate adaptation, with reference to projects in the Caribbean region. Early warning systems are developed together with governments and local stakeholders, and are used operationally rather than only as research models. The interviewee stressed that all forecasts involve some level of uncertainty, which system operators need to understand when making decisions. Earth Observation data plays a supporting role in the institute's work. A range of data sources is used, including precipitation, water quality, and algal bloom detection. These are combined with hydrological, hydrodynamic, and water quality models. A challenge in the Caribbean context is the limited availability of data, which makes it difficult to properly calibrate and validate models. This contrasts with regions such as the Netherlands, where the data infrastructure is more developed.

A.13. Bank on Bonaire

The interview was held with a representative from a bank operating on Bonaire. The bank does not use specific tools to assess flood risk when issuing loans or mortgages. The interviewee acknowledged that sea level rise is expected over the coming decades, but noted that most business loans are short term, up to fifteen years, which limits how strongly this risk currently influences risk assessments. When dealing with collateral located on the waterfront, the bank assesses flood risk on a case by case basis, taking into account variations in coastline height and sediment type. Inland flooding was described as rare. In flood prone areas, most buildings are built on raised foundations, which keeps water out during heavy rainfall. The bank also indicated that it does not hold any collateral on properties that are known to flood. The interviewee emphasised that risk is never fully eliminated, but that the bank is willing to accept flood risk as part of its assessment process.

A.14. Dive school

The interview was conducted with a dive school on Bonaire. The business has not experienced any flood damage and has not had problems with heavy rain. The interviewee was not familiar with tools for assessing flood risk and only checks a local weather forecast website. The dive school does not have flood insurance and does not include flood risk in its business model, describing it as a distant concern. The main practical issue for the business is the poor condition of the unpaved road to its location. Potholes get deeper during rain and the road is not maintained. According to the interviewee,

this falls under a broader infrastructure plan funded by the Netherlands, but no action has been taken for over a year. The interviewee also noted that floods are rare on Bonaire and that the main issue is that water cannot drain away.

A.15. Ministry of Infrastructure and Water Management 1

The interview was held with a policy officer, working on the use of satellite applications. The Climate Effect Atlas for Bonaire was a central topic. The interviewee explained that the climate scenarios behind the atlas have not yet been fully translated into local flood risk assessments, partly because of limited funding. Scenarios are also updated regularly, which can be confusing for people and can affect the credibility of the information. Sea level rise was seen as the main long-term flood risk for Bonaire, especially because there is little coastal protection in the south.

EO tools are not yet widely used to monitor flood risks on Bonaire. The interviewee mentioned that more data is needed, such as elevation data, sea level data, and information on the condition of mangroves. This data should be collected in a structured way and be accessible for different users. The interviewee also suggested that mangrove restoration could be linked more directly to flood risk management, which is currently not the case in adaptation planning.

A.16. Ministry of Infrastructure and Water Management 2

The interview was held with four policy officers, working on climate adaptation and the Climate Effect Atlas for the BES islands. Flood risk on Bonaire was discussed from a risk analysis perspective, including coastal flooding, extreme rainfall and tsunamis. The interviewees pointed out that data availability is a major limitation. Historical precipitation data for Bonaire mostly comes from Curaçao, and there is ongoing discussion about the ownership and quality of this data.

A central topic was the role of the ministry in flood related projects. The ministry finances restoration of dams and salinas, while structural maintenance is the responsibility of the Public Entity Bonaire. The interviewees described this as a recurring challenge, since one off restoration projects do not solve the underlying need for ongoing maintenance. Spatial planning was also raised as an issue, including the location of critical infrastructure such as the hospital and the construction of villas in flood prone coastal areas.

The Climate Effect Atlas for the BES islands was described as a growth model. Compared to the European Netherlands, less data is available, no structured user group exists, and basic information often needs to be collected before maps can be developed. The interviewees stressed that the way maps are used is at least as important as the maps themselves. The Greenpeace climate case was mentioned as an example where one extreme scenario was used to make a point, which raised questions about how realistic such a scenario is.

EO data is already used within the atlas for long time series, although historical datasets for Bonaire are still limited. The interviewees also mentioned that the existing damage compensation law does not fit the Caribbean context well and that the focus of the ministry is on reducing risks beforehand rather than compensating damage afterwards.

A.17. Local government 3

The interview was held with a nature policy advisor at the local government on Bonaire. A central theme was the use of historical aerial imagery for spatial planning. Images from the 1950s to the 1990s are used to identify where salinas and water buffer areas were originally located, and to inform decisions about where new development should be avoided. Restoration of salinas such as Salina di Vlijt was discussed as a priority, particularly in areas where increasing construction has heightened flood risk. The interviewee noted that property developers frequently submit plans for sites that are already flood prone or expected to become more vulnerable in the future.

The interviewee described a complex hydrological situation that makes Bonaire different from many other locations. Along the west coast, a coral dike formed by storm and coral deposits runs parallel to the road. The porous limestone underneath allows seawater to move hundreds of metres inland. When extreme rainfall coincides with elevated sea levels, as occurred in 2004 and 2022, water rises

both from above and from below, leading to major flooding. Old septic tanks compound this problem, since wastewater can rise to the surface during flood events.

EO data plays a supporting role in the interviewee's work. Aerial imagery from 1961 is actively used by Wageningen students to identify the location of historical dams and rooien, which then informs restoration plans. The interviewee also uses the Climate Effect Atlas, and expressed a clear need for high-quality satellite imagery of specific flood events such as the one in November 2022. Resolutions of one to five metres were considered sufficient for civil engineering and spatial planning purposes, although higher resolutions would be welcome where available. The interviewee also expressed interest in integrating EO data with in-situ measurements in a single tool, since this would allow faster decision making and a better understanding of how water moves on the island.

Several structural challenges were raised. Funding for dam and rooi restoration is project based rather than structural, which limits ongoing maintenance. Capacity at the local government is a recurring constraint, and integrating water management with agriculture was suggested as a way to share responsibility with landowners. The interviewee also pointed to the fragmentation of research outputs on Bonaire, noting that the volume of available studies can make it difficult to maintain an overview. EO based tools that combine multiple data layers could help to address this, but require investment in local capacity and awareness.

A.18. Environmental NGO

The interview was held with a representative of an environmental NGO that was involved in legal action against the Dutch state on climate adaptation for Bonaire. The interviewee identified sea level rise as a major long term threat for Bonaire, especially for the southern part of the island and the capital. Under some climate scenarios, the hospital, the police station, and the airport fall within high risk areas. The hospital is also vulnerable to heavy rainfall, since the surrounding area floods quickly and the building becomes difficult to reach.

A recurring theme was the impact of urban development on natural drainage. The interviewee gave several examples of areas where water previously flowed naturally to the sea but where new construction has blocked or redirected these flows. New buildings near the airport were highlighted as a concern, since they are being placed close to wetlands and salinías. The breakdown of the historical system of dams was also discussed. Although the underlying knowledge to restore this system exists, financing is mostly project based rather than structural, which limits long term progress.

A.19. Earth observation startup

The interview was held with the founder of a Dutch startup that develops Earth Observation tools for non technical users. The company is a few years old and started after winning public innovation funding. The interviewee explained that the company became involved on the BES islands after being invited to a matchmaking event for European space sector startups. This led to a pilot project with a regional nature alliance, which acted as a single entry point representing multiple islands. The pilot focused mainly on vegetation monitoring.

After the pilot ended, the company moved from a low cost test licence to a regular pricing model. At that point, only a few users continued to engage actively, and uptake dropped further once paid licences were introduced. The interviewee described this drop off as a structural challenge for EO services targeting small island markets, since the user base is often too small to support a standard commercial pricing model without continued public or institutional funding.

A second adoption barrier was time. Several local users were enthusiastic about the tool but had only a few hours per month available for the project, much of which was spent on meetings. The interviewee also noted that the iterative way of working that suits the tool, where users start small and learn as they go, does not always match the traditional research workflow that some users prefer. On the technical side, the interviewee mentioned that small islands are relatively easy to process compared to large areas in the Netherlands. The main constraint is the limited availability of high quality reference imagery for training the AI models. In the Netherlands, annual aerial photos are available, while for the BES islands the company often had to rely on whatever was available at a single point in time. High

resolution satellite imagery has only recently become available for these islands.

The company does not develop tools for flood monitoring directly, but provides vegetation and landscape information that can support flood related analyses. The interviewee saw operational EO services such as continuous monitoring or early warning systems as the most promising area for commercial flood related applications, while acknowledging that more complex flood modelling typically falls within the scope of public institutions.

A.20. Earth observation service provider

The interview was held with a representative of an international geospatial data provider. The company is currently developing a digital twin platform for disaster risk management, including flood risk and coastal erosion. The platform is being piloted on another Caribbean island under a government to government agreement, with the Dutch government providing the funding. The interviewee expressed interest in following a similar process for Bonaire, since satellite imagery covers areas far larger than a single island, which makes a regional approach across multiple islands more cost effective than an island specific one.

A central theme was the role of funding and ownership in sustaining EO services. The interviewee described continuity as the biggest obstacle for services like this, noting that it is an operational rather than a technical challenge. Even when a pilot is funded, continued satellite imagery, data processing, hosting, and maintenance need to be paid for over the long term. Ownership at the end user organisation is equally important, but political cycles often mean that responsibility falls through the cracks when leadership changes. Private companies could contribute to funding, but only if there is a clear business case. Insurers were mentioned as a plausible example, since better flood prediction could inform their premium calculations.

Local engagement was also stressed as essential. The interviewee emphasised the need for a local champion to drive adoption forward, since without someone locally who takes ownership and advocates for the service, projects rarely succeed. Trust was identified as a precondition for adoption, and local validation data plays a key role in building it.

In terms of data, the platform uses multispectral satellite data. Open source data from Sentinel and Copernicus is used for long term baselining, while commercial daily imagery is needed for monitoring sudden events such as floods. AI is being integrated into the platform to lower the barrier of entry for non technical users, but the interviewee acknowledged that this raises questions of trust and bias, which they address through transparency, quality metrics, and trusted training data.

A.21. Tourism organisation

The interview suggests that climate change and flooding are becoming more relevant topics for the tourism sector on Bonaire, although they are not yet fully integrated into day-to-day business decisions. The respondent emphasised that Bonaire's tourism sector strongly depends on the island's natural environment, particularly its coastal areas, coral reefs, and marine ecosystems. This makes environmental protection important not only from an ecological perspective, but also for maintaining the island's attractiveness as a destination.

Flooding caused by heavy rainfall is currently experienced as a localized issue, especially in parts of Kralendijk where roads and businesses can be temporarily affected. However, these events are not yet seen as a structural threat to the tourism sector. Climate risks are therefore mostly perceived as a longer-term concern, rather than an immediate operational challenge.

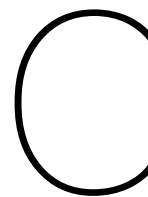
The 2022 flooding event did increase awareness of weather-related risks among tourism stakeholders. During this event, the main priorities were visitor safety, communication with guests, and restoring services as quickly as possible. The sector was able to recover relatively quickly through cooperation between tourism businesses, emergency services, and government actors. A key limitation mentioned by the respondent is the lack of easily accessible, locally specific climate and flood risk information. Although information is available through government agencies, meteorological services, and research projects, it is not always detailed or accessible enough for tourism businesses to use in planning. This suggests that improved access to localized risk data could support more proactive adaptation and

strengthen the long-term resilience of the tourism sector.

B

Use of AI

AI tools, including ChatGPT and Claude, were used as supportive aids during the research and writing phases of this study. They assisted in improving grammar and readability, structuring text, formatting references, and brainstorming about the analysis and interpretation of the interview data. All content generated with AI was critically reviewed, verified against original sources, and edited by the author. The research, analysis, and conclusions presented in this thesis are the author's own work.



Interview protocol

The interviews were semi-structured. A core set of questions was used across most interviews, supplemented with questions tailored to each participant's role. The questions below are grouped by theme. Not every question was asked in every interview, and follow-up questions were added during the conversation depending on the participant's answers. Most interviews were conducted in Dutch and the questions have been translated into English.

Opening and context

- Can you describe a recent project where your organisation was involved with flood risk or climate adaptation on Bonaire?
- What was your role in this project?
- What did your organisation do in concrete terms?

Experience with flooding

- Which type of flooding is the biggest risk for Bonaire?
- Can you take me step by step through the last time there was a threat of flooding?
- What was the biggest challenge at that moment?
- Were you affected by the November 2022 flooding? What happened in concrete terms?
- How did you deal with it at the time, and who made which decisions?
- Have things changed since then in how you deal with this kind of risk?

Current information and decision-making

- To what extent do you use Earth Observation tools to monitor flood risk?
- How do you currently get information about weather, climate, or flood risk?
- Do you use maps, data, or forecasts in your planning? If so, which ones?
- Are you familiar with the Climate Effect Atlas?
- What are the biggest frustrations or limitations with the information you have now?

Measures and the future

- Which concrete measures have recently been taken to make Bonaire more resilient to flooding?
- Have you seen changes in recent years in how Bonaire deals with flood risk? Can you give an example?
- Are you worried about sea-level rise or increasing flooding for the future?
- Have you been involved in discussions about early warning systems?

Collaboration and stakeholders

- Are you involved in collaborations between public and private parties? How do you see these collaborations?
- What is the biggest challenge in this collaboration?
- Which organisations have you worked with most around climate or water?
- Who do you think is actually responsible for flood risk management on Bonaire?

Additional questions for EO companies

For the EO companies, which sit on the supply side of the value chain, additional questions were asked about developing and running an EO service.

- How did you end up working on the BES islands? Was that a deliberate choice or coincidence?
- What is the business model behind your service? Who pays for what, and is that sustainable?
- What role does public funding play in your business model? Is that a healthy dependency or a vulnerability?
- What have been the biggest obstacles in setting up an EO service for the Caribbean, compared to the Netherlands or other markets?
- How did you map the needs of users? Did that work the way you expected?
- What have been the biggest surprises in what clients actually needed, compared to what you expected?
- What have been the biggest technical challenges in working with data for a small island like Bonaire?
- How do you handle the in-situ validation challenge?
- What happens now that the pilot is over?

D

Codebook

This appendix presents the full set of codes that resulted from the thematic analysis of the 21 interviews, in order to make the analysis transparent and reproducible (Section 3.3). The codes were generated inductively through open coding and then grouped into seven themes during axial coding. Table D.1 lists every code under its theme, ordered by groundedness, together with the number of quotations it codes and the number of interviews in which it occurs.

Codes were merged where they captured the same idea, which reduced an initial set of about 340 codes to the final set reported here. A code may belong to more than one theme, in which case it appears under each, the per-theme totals therefore overlap. The eleven codes that were not assigned to a theme are listed separately at the end of the table.

Table D.1: Codes by Theme, with Groundedness

Code	Quotations	Documents
<i>Governance & institutional challenges</i> ($n_{\text{codes}} = 43$, quotations = 110)		
Limited institutional capacity	18	11
Fragmented institutional responsibilities	10	8
Inefficiency and lack of decisiveness local government	10	2
Lack of spatial planning regulations for private developments	8	6
Dependence on project-based financing	5	5
Environmental modelling is government responsibility	5	2
Insurance gap on Bonaire	4	3
Collaboration with local government (OLB) and partners	3	3
Dependence on private sector during crises	3	1
Lack of understanding by Dutch government	3	2
Dependence on Dutch national government	2	2
Fragmented research and knowledge	2	2
Integrated water management needed	2	2
Lack of global coordination of satellite infrastructure	2	1
Limited local political interest in climate issues	2	2
Need for collaboration OLB and ministries	2	2
Public-private partnership possible in EO development	2	2
Insufficient legislation	2	2
Absence of water management institutions	1	1
Awareness for spatial planning	1	1
Blended finance for climate adaptation	1	1
Comply or explain principle not applied	1	1
Credibility challenges in climate communication	1	1
Data ownership disputes KNMI-Curacao	1	1
Difficulty communicating uncertainty to the public	1	1

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Table D.1 (continued)

Code	Quotations	Documents
Dutch government is responsible	1	1
Dutch ministry intervention limited by autonomy principle	1	1
Flood risk perceived as long-term issue	1	1
Geographical distance as barrier to collaboration	1	1
Importance of local knowledge to working here	1	1
Informal building practices increase flood vulnerability	1	1
Informal collaboration networks are important on Bonaire	1	1
Insufficient investment for infrastructure	1	1
International collaboration in weather monitoring	1	1
Knowledge gap on suitable adaptation measures	1	1
Lack of awareness for different types of floods	1	1
Lack of knowledge about user needs	1	1
No formal flood risk strategy	1	1
Permit delays climate adaptation and housing projects	1	1
Regional collaboration across Kingdom	1	1
Risk reduction over insurance	1	1
Urgent need for climate adaptation action	1	1
Wet tegemoetkomende schade not fit for Bonaire	1	1
<i>EO data capabilities & limitations</i> ($n_{\text{codes}} = 45$, quotations = 100)		
Forecast uncertainty and model limitations	16	6
Limitation: ground validation needed	11	5
High spatial resolution needed for small islands	8	6
EO data insufficient - needs numerical models	6	3
EO data for assessing drainage infrastructure condition	4	2
EO primarily useful for past and present analysis	4	3
EO useful for long timespans	3	3
Need for public awareness on flood risks	3	3
Adaptation requires island-specific approaches	2	1
Climate atlas not used for implementation but more for overview	2	2
EO data for emergency planning	2	2
Global datasets insufficient for local island contexts	2	2
Lack of global coordination of satellite infrastructure	2	1
Radar advantages for extreme weather monitoring	2	1
Shift from photos to satellite data	2	2
Trade-off between radar and lidar data	2	1
AI requires clear object definitions	1	1
AI training data limitations	1	1
Bonaire technically manageable	1	1
Climate tools depend on accurate elevation data	1	1
EO data for flood risk modelling and scenarios	1	1
EO indirect support for flood models	1	1
EO limitations under cloud conditions	1	1
GIS layer overlay for analysis	1	1
High resolution imagery now available for BES	1	1
Historical aerial imagery valuable	1	1
Incomplete climate risk scenarios for Bonaire	1	1
Integration of EO and elevation data	1	1
Interpretation matters more than the map	1	1
Limited access to high resolution data	1	1
Low update frequency sufficient for planning	1	1
Multimodal data combination	1	1
Need for transparency in climate models	1	1
Outdated datasets reduce model reliability	1	1
Reliability of global tool unsure	1	1
Scenario planning for infrastructure failure	1	1

continued on next page

Table D.1 (continued)

Code	Quotations	Documents
Small island advantage for EO processing	1	1
Stakeholder validation improves model realism	1	1
Use of climate scenarios	1	1
Use of freely available EO tools	1	1
Use of optical satellites	1	1
Use of reanalysis/EO data due to data gaps	1	1
Use of regional climate models	1	1
Use of seasonal climate forecasts	1	1
Use of statistical downscaling	1	1
<i>Infrastructure & water management</i> ($n_{\text{codes}} = 35$, quotations = 99)		
Insufficient drainage infrastructure	20	9
Urban development blocking natural drainage	12	8
Lack of spatial planning regulations for private developments	8	6
Breakdown of traditional water management systems	6	4
Flood risk linked to low-lying urban development	6	5
Critical infrastructure vulnerable to flooding	4	4
EO data for assessing drainage infrastructure condition	4	2
Need for restoration of dams	4	4
Flooding accelerates infrastructure degradation	3	1
Need for spatial flood risk mapping	3	3
Integrated water management needed	2	2
Need to move vulnerable buildings on higher parts	2	2
Rapid population growth increasing infrastructure pressure	2	1
Insufficient legislation	2	2
Absence of water management institutions	1	1
Awareness for spatial planning	1	1
Bonaire not spatially designed for rainfall events	1	1
Building of sewers and ditches	1	1
Combining water management with agriculture	1	1
Coral dike hydrology	1	1
Flood impacts on hospital	1	1
Groundwater contamination from septic tanks	1	1
Informal building practices increase flood vulnerability	1	1
Insufficient investment for infrastructure	1	1
Lack of coastal protection infrastructure	1	1
Loose goats erosion impact	1	1
Natural water filtration system	1	1
Need for building dams	1	1
Need for infrastructure and drainage planning	1	1
Need for integrated spatial planning	1	1
Need to retain water on land	1	1
Permit delays climate adaptation and housing projects	1	1
Scenario planning for infrastructure failure	1	1
Subsurface hydrology poorly understood	1	1
Watershed management as flood adaptation strategy	1	1
<i>Entrepreneurial opportunities & barriers</i> ($n_{\text{codes}} = 39$, quotations = 84)		
Need for more financial resources	8	6
Difficulty converting raw EO data into usable information	7	4
Low EO awareness among stakeholders	7	2
Environmental modelling is government responsibility	5	2
AI limitations for extreme weather prediction	4	2
AI useful for summarizing and harmonizing fragmented datasets	4	3
Insurance gap on Bonaire	4	3
Need for EO training and education	3	2
Need for public awareness on flood risks	3	3

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Table D.1 (continued)

Code	Quotations	Documents
Bridging role between EO providers and users	2	2
Construction sector as potential EO user	2	2
Lack of flood risk assessment tools	2	2
Lack of global coordination of satellite infrastructure	2	1
Lack of knowledge about risks for insurances and cost of damage	2	2
Limited affordability of flood insurance	2	2
Public-private partnership possible in EO development	2	2
Tool needs to be manually modified to be adapted to local context	2	1
Uncertainty about insurability of flood risks	2	2
Assess risks case by case	1	1
Blended finance for climate adaptation	1	1
Competition with ArcGIS	1	1
Credibility challenges in climate communication	1	1
DCNA as gateway customer	1	1
Difficulty communicating uncertainty to the public	1	1
Flood risks not in business model	1	1
Functionality gap with existing tools	1	1
Innovation funding for EO startups	1	1
Iterative vs traditional research methods	1	1
Lack of awareness for different types of floods	1	1
Limited user time and capacity	1	1
Mismatch between loan timeframes and long-term climate risks	1	1
Mismatch with ecologist workflows	1	1
No insurance for flood risks	1	1
Pilot without follow-up	1	1
Regional scale lowers EO service costs	1	1
Remote collaboration challenges	1	1
Risk acceptance in business decisions	1	1
Risk consideration business/floods	1	1
Scientific uncertainty in climate risk assessment	1	1
Small user base limits investment	1	1
<i>Flood risks & impact</i> ($n_{\text{codes}} = 28$, quotations = 73)		
Heavy rainfall as primary flood driver	17	9
Mangrove restoration as flood risk reduction	10	5
Coastal flooding and sea level rise	7	6
Flood risk linked to low-lying urban development	6	5
Critical infrastructure vulnerable to flooding	4	4
Flooding accelerates infrastructure degradation	3	1
Flooding damages coral ecosystems through sediment runoff	3	2
Flooding causes economic disruption	2	1
Inland flooding on Bonaire viewed as localized and limited	2	2
ABC islands different climate	1	1
Different interests tourism/measures	1	1
Ecological impacts of flooding	1	1
Expectation of increasing future flood risk	1	1
Flood risk perceived as long-term issue	1	1
Heavy rainfall is less predictable	1	1
Hurricane low frequency high impact	1	1
Importance of knowing the extremes for flood risks	1	1
Lack of awareness for different types of floods	1	1
Link between warming and increased rainfall intensity	1	1
Low flood risk awareness	1	1
Low perceived flood risk based on past experience	1	1
No historical flood damage	1	1

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Table D.1 (continued)

Code	Quotations	Documents
No prior flood damage	1	1
Port and maritime operations vulnerable to extreme weather	1	1
Risk assessment based on coast line variations	1	1
Sediment in sea damages ecosystem	1	1
Tourism sector important economic value	1	1
Tsunami high impact low risk	1	1
<i>Data gaps & monitoring needs</i> ($n_{\text{codes}} = 18$, quotations = 45)		
Lack of local climate data	20	10
Need for groundwater and water storage research	3	3
Need for spatial flood risk mapping	3	3
Lack of historical data	2	2
Need for integrated tool	2	2
Resolution requirements for spatial planning	2	1
Insufficient knowledge what is located underground	2	2
Add development of mangroves to EO tool	1	1
Atlas can be improved	1	1
Data needs to be up to date	1	1
Importance of knowing the extremes for flood risks	1	1
Integration of meteorological services in early warning systems	1	1
Lack of high-resolution reference imagery	1	1
Limited stakeholder input on extreme events	1	1
Making EO accessible to non-technical users	1	1
Multilingual access (Papiamentu)	1	1
Need for more environmental and climate data	1	1
Need for satellite imagery of flood events	1	1
<i>Early warning systems</i> ($n_{\text{codes}} = 19$, quotations = 40)		
KNMI is responsible for early warning	8	5
Early warning system absent or in development	6	6
Human interpretation required in early warning	5	2
Development of cell broadcast emergency systems	3	2
Informal flood warning communication systems	3	3
Vulnerability of digital warning systems during disasters	2	1
Absence of structural siren system	1	1
Early warning communication with local authorities	1	1
Early warning system inaccurate for earthquake and tsunami	1	1
Emergency services play central role in flood response	1	1
Existing disaster app is not user friendly	1	1
Limited public preparedness for emergencies	1	1
Not sure if early warning for tsunami	1	1
Operational EO services can support commercial early warning systems	1	1
Other islands are preparing an early warning system	1	1
Regional coastal models improve early warning accuracy	1	1
Resource shortages during emergencies	1	1
Standard emergency response measures for flood risks	1	1
Use of digital disaster communication tools	1	1
<i>Ungrouped codes</i> ($n_{\text{codes}} = 11$, quotations = 18)		
Need for centralization of environmental knowledge	6	3
Awareness of climate effect atlas	2	2
Focus on preventive measures	2	2
Agroforestry as climate adaptation strategy	1	1
Challenges in translating analysis into actionable measures	1	1
EO suitability depends on object size	1	1
Institutional delays in implementing warning systems	1	1
Need for in-situ measurements	1	1

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Table D.1 (continued)

Code	Quotations	Documents
Need for stakeholder participation	1	1
No user group on Bonaire	1	1
Use of weather forecast for flood risks	1	1

Note. Codes are organised under the seven themes from the axial coding phase (Section 3.3), ordered by total groundedness; ungrouped codes are listed last. *Quotations* is the groundedness of each code (number of quotations it codes), and *Documents* is the number of interviews in which it occurs. Within each theme, codes are ordered by groundedness. Because a code can belong to more than one theme, some codes appear under multiple themes, and the per-theme totals therefore overlap.