

Grenada's Water Sector: Managing water and wastewater to meet water needs while protecting the purpose of the country's ecosystems

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Executive Summary

Grenada has made great strides in distributing clean, potable water to its people however water demand continues to increase and natural sources are not enough to meet the need. Grenada's economy relies on water and water usage. As big economic drivers like tourism and agriculture continue to expand with increasing population, water demand only continues to grow. With increasing water use, there is increased wastewater but Grenada's water sector lacks proper and adequate management. Grenada's current water sector system is insufficient to support the country's water needs and environmental and public health are at risk in the face of climate change and other global stressors.

This case study began with the decision space where important stakeholders relevant to Grenada's water sector were mapped. The map reflected realistic parameters for decision-making within the water sector. The main stakeholders to note are the many managing bodies of the water sector including the National Water and Sewerage Authority (NAWASA), the Environmental Health Department, Fisheries departments, and the Physical Planning unit; the tourism industry and tourist; the agriculture industry; the general population; and Grenada's coastal environment. The goal statement was formed after considering each stakeholder: A future where water needs are met, water and wastewater are well managed, and the purpose of Grenada's ecosystems are protected.

The wicked problem and the system were understood with a conceptual model. The wicked problem is unique to the water sector in Grenada. It is a social planning problem with no true solution, only a range of better or worse solutions. The challenges in the system are the changing climate, meeting water demand needs, economic instability, and inadequate water management, especially regarding wastewater treatment. The conceptual model highlights how the challenges are connected through feedback loops.

After a thorough understanding of the system, fragilities were easily identified. The main fragilities of the system are fragmented government organization, economic instability, sensitive ecosystems, fecal/chemical pollution, coastal settlement and infrastructure, dependence on water, economic dependence on the agriculture industry, and economic dependence on the tourism industry. The exogenic hazards were climate change, economic disruption, and extreme weather events. The endogenic hazards were identified from the fragilities including decision-making, inadequate wastewater treatment, and overconsumption of water. These endogenic hazard scenarios were then used to develop a spectrum of possible futures. The spectrum for each scenario includes four futures:

collapse, continue, discipline, and transformation. The collapsed future for each hazard would be the worst-case scenario and result in a degraded environment and water scarcity. The transformative future would be where the hazards were monitored and mitigated for a reality most closely resembling the goal statement.

Using the spectrum of possible futures, interventions were then carefully developed with the goal statement in mind. The interventions were split into three categories; cross-sector coordination, increased wastewater treatment, and water reuse. Each category had interventions to address the various hazards that would make moves toward the goal statement. Table 3 shows each intervention discussed and its pros and cons.

Table 3: Interventions addressing the hazards and possible future scenarios and their main pros and cons.

Intervention	Pros	Cons
Cross sector coordination	coordinated approach, water quality standards and monitoring, infrastructure improvements, barriers to management are removed	requires funding, needs specialized personnel, large scale shift within government organization
Increase wastewater treatment plants	centralizes and increase wastewater treatment, decreases current poorly designed infrastructure, decreases wastewater contamination	very expensive, requires major installation around the country
Improve current treatment plants and wastewater infrastructure	decreases wastewater contamination and poorly designed infrastructure, increases wastewater treatment, uses current infrastructure	expensive
Wastewater to drinking water	supplements water supply, decreases wastewater effluent discharges and wastewater contamination	expensive, needs innovative technology and treatment, needs comprehensive water reuse education
Non potable water reuse	supplements water supply, reduces cost of drinking water treatment, decreases effluent discharges, decreases wastewater contamination	expensive, needs water reuse education

After, the pros and cons of each intervention were analyzed and led to the final recommendations which are recommended to Grenada's government.

Recognizing that:

- Climate change is changing water resources
- Grenada's government has a fragmented approach to managing the water sector
- Water supply is not meeting water demand
- Wastewater is not adequately treated or managed

Acknowledging that:

- There are many stakeholders with interest in the water sector
- Addressing water and wastewater management will not be easy to accomplish
- Grenada is aware of many of its current water sector issues

The following interventions are recommended to Grenada's government for implementation:

- Improving cross-sector coordination to better manage the water sector
- Improve current treatment plants and wastewater infrastructure
- Implementing nonpotable water reuse to supplement the water supply

1 Introduction

1.1 Water and wastewater

Safe and accessible water is not only important for public health but can also increase economic growth and poverty reduction (WHO, 2023). In 2010, the United Nations (UN) General Assembly recognized water and sanitation as a human right – explicitly stating that “everyone has the right to sufficient, continuous, safe, acceptable, physically accessible and affordable water for personal and domestic use” (WHO, 2023).

Wastewater is used water and contains human waste, food scraps, oils, soaps, and chemicals (USGS, 2018). Wastewater can be domestic, industrial, and commercial (Riffat, 2012). Domestic wastewater is produced by residential, nonindustrial businesses, and institutional sources (Riffat, 2012). Industrial wastewater contains substances from raw materials, intermediate products, byproducts, and end products from manufacturing and production processes (Riffat, 2021). Finally, commercial wastewater is similar to domestic sources but has additional contributions from washing and other operations (Riffat, 2021). Although the environment can cope with small amounts of pollution, as seen today, large amounts of pollution can overwhelm the Earth's life support system (USGS, 2018).

Treating wastewater should be prioritized for both environmental and public health (USGS, 2018). Untreated wastewater released into the environment causes negative impacts on fish and wildlife populations, beach closures and other recreational restrictions, limitations on fish and shellfish harvesting, and the contamination of drinking water (USGS, 2018). When water and wastewater are properly managed, communities benefit from better health and other positive improvements in their

lives (WHO, 2023).

Water is socially vital – and an economic good that requires a coordinated, participatory management approach as well as a commitment to good governance with accountability and transparency (Government of Grenada, 2020). Water contributes to economic and social development, and it should be considered when balancing competing water uses with its role in the ecosystem (Government of Grenada).

1.2 Study area

Grenada, an island nation with several isles located at 12.1 degrees north and 61.5 degrees west, is the southernmost country in the east end of the Caribbean Sea, north of Trinidad and Tobago (Figure 1).

Grenada and its two smaller islands, Carriacou and Petite Martinique (Figure 2), have a population of about 110,000 people (Atis et al., 2021). The islands are mountainous inland and gradually decline into the coastline (Atis et al., 2021). Coral reefs, seagrass beds, and mangrove swamps surround the islands and provide rich marine and coastal biodiversity with beaches ideal for turtle nesting sites (Atis et al.,

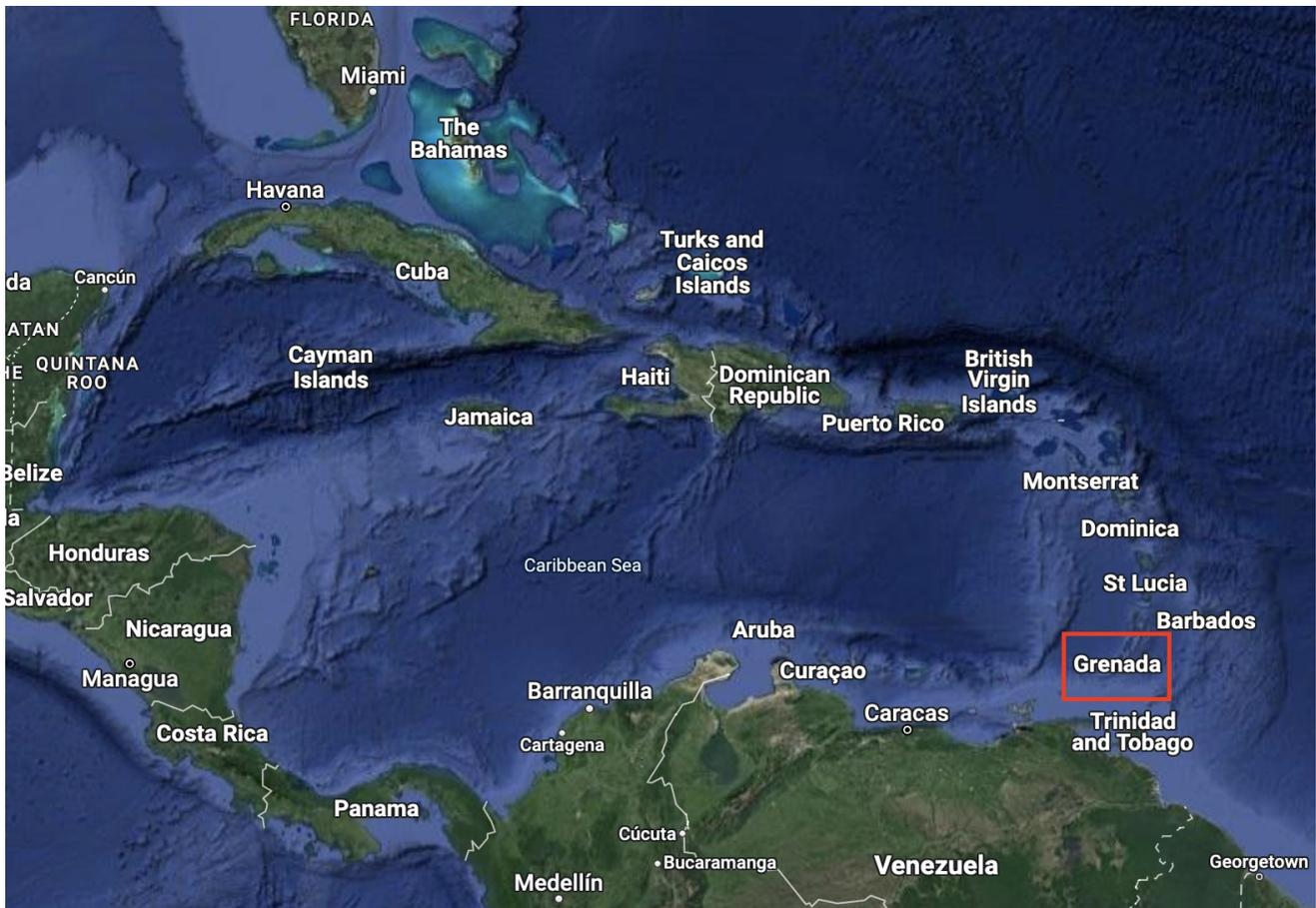
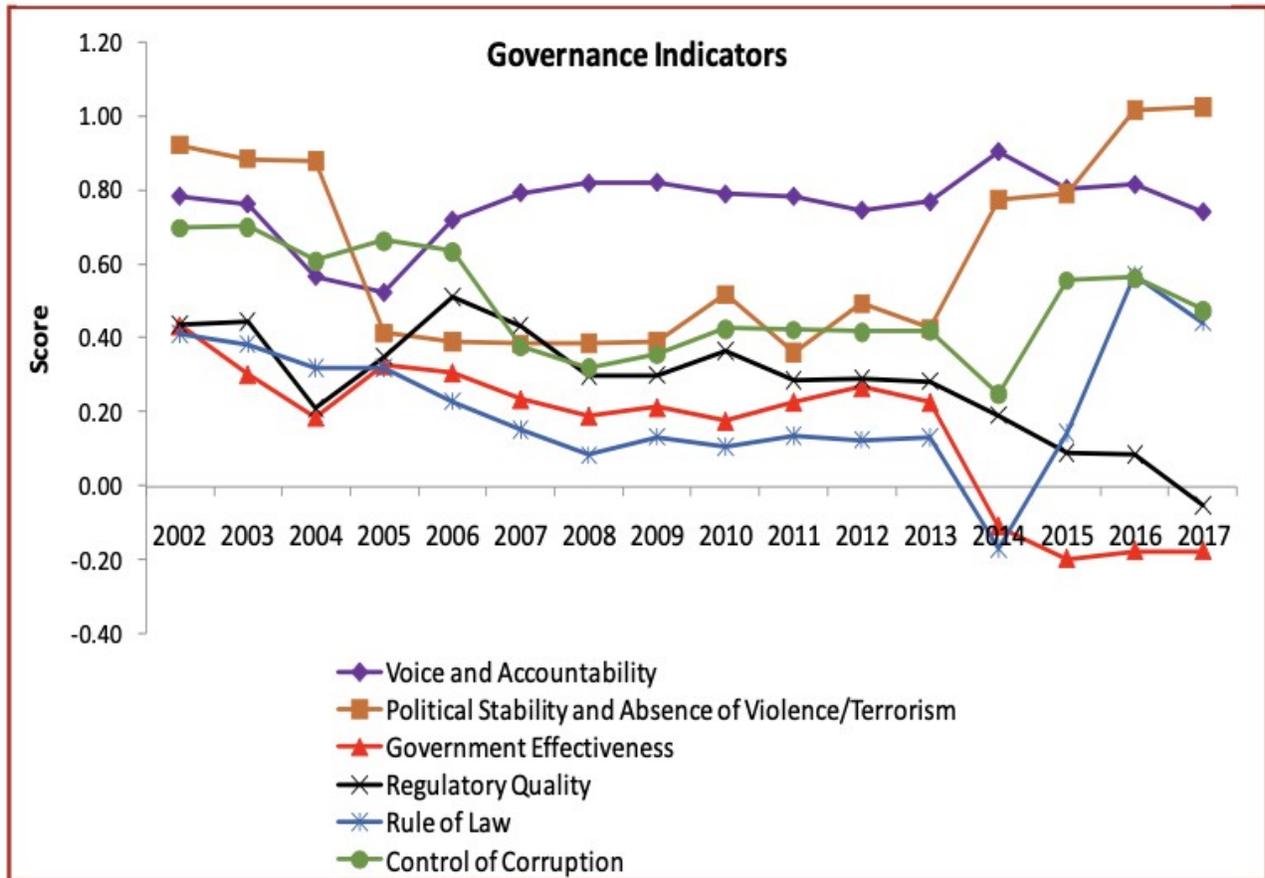


Figure 1: Map of the Caribbean showing Grenada's location, sourced from Google.



Figure 2: Map of Grenada (MOF, 2020).

2021). Grenada depends on these marine resources for employment, food security, and coastal protection especially since most of the economic and social infrastructure is located along the coasts (Atis et al., 2021). The country's economic prosperity relies on fisheries as well as the eco-tourism industry (Atis et al., 2021). But Grenada is highly affected by global climate change and its variety of ecosystems, coastal, marine, forest, and freshwater, are all being challenged (Government of Grenada, 2019). A climate-resilient health system is prioritized in Grenada's National Sustainable Development Plan (NSDP) which includes improving critical health-determining sectors such as water and sanitation



Source: World Bank

Figure 3: Graph of governance indicators in Grenada (Government of Grenada, 2019).

(Government of Grenada, 2019). Grenada is governed under a parliamentary democracy system, but as seen in Figure 3, Regulatory Quality and Government Effectiveness are two governance indicators that have deteriorated in recent years (Government of Grenada, 2019).

Institutional problems from the current fragmented and uncoordinated approach need to be addressed (Government of Grenada, 2020). This is vital because the lack of institutional capacity, shortage of human resources, unsatisfactory environmental regulations, the necessity of improvements to efficiency and effectiveness of water, sanitation, and wastewater services all affect economic and social development as well as increasing impacts of natural disasters (Government of Grenada, 2020).

This case study focuses on Grenada and its water sector from direct consumption and use of water to treatment and disposal of sewage and industrial effluent and associated infrastructure. It investigated many recent documents such as reports from Grenada's own government, the Intergovernmental Panel on Climate Change (IPCC), and other relevant organizations to find that there is a fragmented and siloed approach to water and wastewater management in Grenada, which to their credit, these reports recognize. However, because of this, a lot of these reports have conflicting interpretations of the current state of the water sector, but one commonality is that they all focus on water distribution and freshwater

sources. Unfortunately, many of these reports only briefly brush over wastewater management and lack important information and depth on the topic.

1.3 Case Study Template

The Mitigation and Adaptation Research Institute (MARI) Case Study Template (Plag, 2021) was used to carry out this case study. This template was developed for the Conservation Leadership program at Old Dominion University, where students learn to address wicked problems while integrating natural, physical, and social sciences.

Following the template, research of the background information and answering questions on who and what was being studied happened first. Then the decision space was mapped, where the stakeholder map and understanding of our wicked problem was developed. Next, fragilities and hazards that can affect the system were identified. Foresight was then developed once the potential hazards and their impact on the future were understood. Possible futures were then explored, both desirable and undesirable. Using transformation knowledge, interventions that could lead the systems toward a more desirable future were developed. Finally, after weighing the pros and cons of the interventions, recommendations were formulated to help the stakeholders meet the goal statement.

2 Societal Context and Decision Mapping

2.1 Societal Context

Over the last 10 years, Grenada has improved access to potable water – about 98% of the population has access to improved water supply and most domestic users are now also metered (Government of Grenada, 2020). The majority of homes on the mainland of Grenada are piped to the potable water supply. Only a few villages are not piped, and they use treated spring water during the wet season and government-supplied water trucks in the dry season (Government of Grenada, 2020).

Grenada's freshwater supply is strongly dependent on the seasonal weather patterns through the wet and dry seasons (Government of Grenada, 2019). Potable water is currently sourced from 23 surface and six groundwater supply sources on the mainland (Government of Grenada, 2019). Carriacou and Petite Martinique mostly rely on harvesting rainwater to meet potable water demands (Government of Grenada, 2019). Their water is supplied through 33 community rainwater catchments and 45 communal cisterns but Grenada has recently built two reverse osmosis desalination plants on Carriacou to supplement water needs (Government of Grenada, 2019). These sources provide a max of 31,800 m³/day in the dry season and 54,600 m³/day in the wet season but in the dry season, water demand is 54,600 m³/day, and in the wet season, 45,500 m³/day. (Government of Grenada, 2019). The demand for water is more than both seasons can provide and is expected to increase with population growth and expansion of tourism and agriculture (Government of Grenada, 2019).

The tourism industry is the largest consumer of potable water besides domestic demand (Government

of Grenada, 2019). Demands on water supply are rising because of increased usage from the tourism industry and the increasing adverse effects of climate change including silting of dams, damage to distribution lines during intense rainfall, and increasingly intense dry seasons (Government of Grenada, 2019).

Agriculture water needs are predominantly met with rainfall but are still estimated at about 15% of the total demand (Government of Grenada, 2019). Water is pumped from the downstream rivers for large operations and used from the potable water supply for small backyard-type gardening (Government of Grenada, 2019). Water from livestock also comes from the treated public water supply (Government of Grenada, 2019).

Climate change poses a serious risk to the economy and livelihoods. A recent climate screening revealed that 13.5% of the 2018 national budget for Grenada was at risk of negative effects of climate change (Government of Grenada, 2019). The tourism industry is also highly dependent on the attractiveness and resiliency of the natural coastal environment and is at risk with climate change caused sea level rise, storm surge, and droughts (Government of Grenada, 2019). The agriculture industry, which contributes to the well-being and livelihood of the nation, is also very sensitive to climate change (Government of Grenada, 2019). It will likely be impacted by excessive rainfall, droughts, uneven distribution of rainfall, and extreme weather events (Government of Grenada, 2019). This can also lead to soil erosion and land degradation from flooding, and saltwater intrusion leading to loss of crops and threatening food security (Government of Grenada, 2019). Some areas are already experiencing acute land erosion and serious flooding (Government of Grenada, 2019). Water scarcity has already caused serious problems and current harmful environmental practices like deforestation and destruction of wetlands are affecting watersheds and water production (Government of Grenada, 2019). Longer and more severe dry seasons, increased temperatures, and heavy rainfall events cause interruptions to water supply and tend to affect low-income households (Government of Grenada, 2019). Since most of the population and human activity is mostly concentrated on the coastline, the coral reefs and other marine ecosystems must be prioritized for their coastline protection (Government of Grenada, 2019).

However, with all this water use, there is little effort currently being made to adequately treat the generated wastewater before discharging it into public waterways (Government of Grenada, 2019). The current wastewater system is severely inadequate and substantial leakage is polluting surface water, the ocean, and groundwater (Atis et al., 2021). This is causing contamination, sanitation issues, and risks to human and environmental health (Atis et al., 2021). Currently, common disposal methods include septic tanks, self-contained treatment systems, pit latrines, and sullage disposal (Atis et al., 2021). Sullage is used water, such as kitchen or bath water, that does not contain human waste, also known as gray water (Atis et al., 2021). In rural communities, open defecation into rivers and drains may still be practiced (Atis et al., 2021). Many dense housing developments around the island discharge untreated wastewater into rivers and tributaries (Atis et al., 2021). Heavy rainfall and flooding cause significant

Table 1: Main stakeholder groups and their level of interest and influence. Interest and decision-making authority (influence) are briefly explained for each stakeholder.

Stakeholder	Level of Interest	Interest	Level of Influence	Decision Making Authority
Government of Grenada	High	Social, economic, and environmental health	High	Water sector regulators
General Population	Mid	Direct user	Mid	Support the prioritization the water sector
Environmentally Focused Organizations	High	Environmental health	Low	Education and outreach relevant to the water sector
Tourism Industry	High	Direct user, eco-tourism	High	Economically significant user of the water sector
Agriculture Industry	High	Direct user	Mid	Economically significant user of the water sector
Tourists	Mid	Social and environmental expectations	Mid	Determine success of tourism industry
Grenada's Coastal Environment	High	Fulfil its purpose	Low	Changes to social, economic, and environmental resource availabiltiy

amounts of wastewater from pit latrines and septic tanks to overflow, and through runoff, release into the ocean (Atis et al., 2021). Leakages and runoff also pose a risk to the island’s freshwater supply and sewage has been found to seep into and contaminate the groundwater (Atis et al., 2021).

Table 1 summarizes Grenada’s water sector societal dynamics. The table shows the main stakeholders and their role in the system. The Government of Grenada and other statutory bodies are prioritizing socioeconomic development and growing environmental concerns. Grenada’s Government has the highest decision-making authority as they have the power to regulate and monitor the water sector and environment. The general public, tourism industry, and agriculture industry are all direct users of water and have mid to high influence in decisions made about the water sector. Tourists have social and environmental expectations and can influence the success of the tourism industry depending on whether their expectations are met. There are many environmentally focused organizations interested in Grenada and the management of water and wastewater. These organizations range from local conservation groups to intergovernmental organizations looking to provide aid for climate resiliency. They are highly interested in environmental health but have less influencing power. Lastly, Grenada’s unique coastal ecosystem’s purpose is to function as an ecosystem. Grenada’s coastal environment cannot present an argument but will respond to climate change, overconsumption, and pollution in negative ways. Its influence may be low but its response to changes can be valued and used for decision making.

2.2 Decision Space

The decision space is where the stakeholders are mapped in detail based on their interest, influence, and understanding of the roles of the stakeholders. The rules and regulations that govern the stakeholder's decisions are considered, understood, and mapped. This is important to maintain the realistic parameters that the stakeholders make decisions within and to identify the stakeholders to whom recommendations should be made. Mapping the decision space takes a participatory modeling approach, meaning system dynamics and context are considered while including all interested parties in the decision-making processes (Plag, 2021). Essentially, the decision space develops parameters, agreed upon by all stakeholders, for the decision makers to work in and make informed recommendations.

2.2.1 Stakeholder Map

There are many stakeholders relevant to Grenada's water sector. Figure 4 maps these stakeholders on a scale of interest and influence. Currently, Grenada's sewage management is regulated by several entities starting with the National Water and Sewerage Authority (NAWASA), which is a statutory body (Atis et al., 2021). Within Grenada's government structure, the Ministry of Agriculture, Forestry, and Lands, and the Ministry of Health, Social Security, and International Business – Environmental Health Department also play a role in water and wastewater management (Government of Grenada, 2019). NAWASA oversees the operation, maintenance, and monitoring of the sewage systems, and the Environmental Health Department and the Fisheries Division regulate wastewater management, mostly regarding water pollution and monitoring quality (Atis et al., 2021). There is also the Physical Planning Unit which regulates development activities (Atis et al., 2021). These stakeholders are concentrated in the high interest, high influence section of the map as they have the most influencing power over water sector management.

The map also includes economic stakeholders including the tourism industry, tourists, and the agriculture industry; the general population, many environmentally focused organizations and a few others who have varying interests and influence. Notably, Grenada's coastal environment also has a high interest stake in the management of the water sector. "The purpose of a system is what it does," (Beer, 2002). Therefore, the coastal environment has a right to be and serve the purpose of a coastal environment.

2.3 Goal Statement

Each stakeholder should have their perspective towards a future they would like to reach considered when developing a goal statement. Common objectives between stakeholders were used to develop an individual statement that considered all stakeholders' influence and interests. The final goal statement formed was agreed upon by all with minimal sacrifice and reasonable compromise.

Iteration 1: Using a participatory approach, Grenada's participatory approach to properly manage the water sector.

Grenada's Water Sector: Stakeholder Map

Abbreviations

NAWASA: National Water and Sewerage Authority
GIDC: Grenada Investment Development Corporation
GWP-C: Global Water Partnership-Caribbean
GSDTF: Grenada Sustainable Development Trust Fund Inc.
GFC: Grenada Fund for Conservation
GRENCODA: Grenada Community Development Agency
IAGDO: Inter Agency Group of Development Organizations
SPECTO: St. Patrick's Environmental and Community Tourism Organization
FoE Grenada: Friends of the Earth Grenada
G-WASP: Grenada Water Stakeholder Platform
MOH: Ministry of Health, Social Security, and International Business
MOA: Ministry of Agriculture, Forestry, and Lands
MOF: Ministry of Finance, Planning, Economic, and Physical Development

Legend

Red: government entities and statutory bodies
 Green: economic contributors
 Blue: environmentally focused organizations

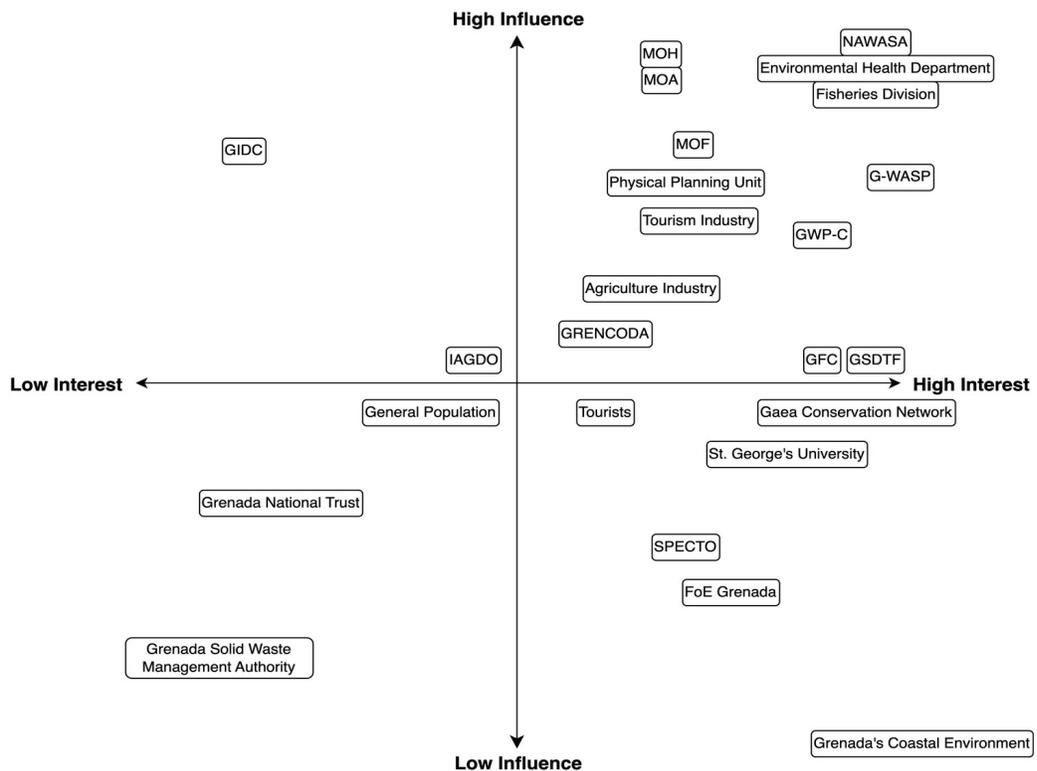


Figure 4: Stakeholder map indicating the interest and influence of all stakeholders. The vertical axis represents the amount of influence each stakeholder has and the horizontal axis represents the amount of interest each stakeholder has. These stakeholders are mapped based on their interest and influence in Grenada's water sector.

Iteration 1 did not focus on a future or explicitly consider Grenada's unique ecosystem and therefore did not meet all stakeholder interests.

Iteration 2: *A future where water and wastewater are appropriately managed, and the purpose of Grenada's ecosystems is protected.*

Iteration 2 lacked a focus on meeting water needs which was important to all stakeholders.

Iteration 3: *A future where water needs are met, water and wastewater are well managed, and the purpose of Grenada's ecosystems are protected.*

Iteration 3 considered all stakeholders and their interests and was the agreed upon goal statement.

3 Wicked Problem and Conceptual Model

3.1 Wicked Problem

This case study aims to assess the current situation and potential future of Grenada's water and wastewater management while prioritizing ecosystem health in the face of climate change impacts. Social planning problems such as this are considered "wicked problems" as defined by Rittel et al. (1973). It is important to note that, for a wicked problem, there is no set of solutions to pick from. Every wicked problem is unique to itself, and no two wicked problems are the same – accordingly, their solutions will always be tailored to the specific situation. Possible solutions to these problems are not true-or-false, but better or worse (Rittel et al., 1973). Furthermore, different stakeholders have their own perspectives on the problem and the framing of the problem shapes the possible solutions.

Grenada has many water bodies including lakes, waterfalls, rivers, and streams which all provide habitats for indigenous fauna (Government of Grenada, 2020). These freshwater bodies and estuaries present opportunities for eco-tourism and education (Government of Grenada, 2020). The water flow from the mountains to the reefs creates the near-shore coastal water ecosystem which includes mangroves, beaches, littoral forests, coral reefs, seagrass beds, rocky shores, rivers, estuaries, and wetlands (Government of Grenada, 2020). Human activity has severely compromised the ecosystem health of the coastal waters from mangrove clearance, overfishing, and pollution (Government of Grenada, 2020). Grenada struggles to identify new economic growth opportunities with strong growth trends and to transform the economy, Grenada will need to tap into traditional economic growth drivers and new sectors of potential growth (Government of Grenada, 2019). Grenada's economic space in the sea is 75 times larger than its landmass and can be used to grow its economy (Government of Grenada, 2019). This includes maximizing on established tourism and fishing industries as well as increasing recreational and aquaculture industries (Government of Grenada, 2019). However, developing these economic growth pathways will require addressing marine pollution and climate change (Government of Grenada, 2019).

Current climate variability and impending climate changes in temperature and rainfall patterns already have and will continue to affect the supply of potable water (Government of Grenada, 2019). Potable water wells near the coast are at major risk of sea level rise and saltwater intrusion (Government of Grenada, 2019). Grenada does not have a formal or consistent environmental monitoring program and therefore there is no available information about the quality of freshwater sources or ways to assess the health of the watershed (Government of Grenada, 2019). However, raw surface water has been characterized by high coliform counts which indicates fecal contamination which is especially high during the wet season (Thompson, 2019). When wastewater is improperly managed, drinking water is likely dangerously contaminated and/or chemically polluted (WHO, 2023). Fortunately, current drinking water treatment removes fecal contamination before consumption, but it is clear that cross-sector coordination is critical for water, land, coastal areas, and public health concerning sewage management (Thompson, 2019; Atis et al., 2021). However, Grenada currently lacks support for cross-agency and intragovernmental collaboration as well as human, financial, and technical resources (Atis

et al., 2021). There is inadequate management and leadership with regard to safely treated wastewater, but the country's sustainable economic, social, and environmental development heavily relies on immediate interventions that will support proper and effective management of wastewater (Atis et al., 2021). Especially with increasing tourism, urbanization, and population, the impacts on Grenada's marine and coastal environment are also increasing (Atis et al., 2021). Large amounts of untreated wastewater have become a major threat to assets that both tourism and the economy rely on but also environmental and public health (Atis et al., 2021). Grenada's topography does allow for the safe application of septic and soak-away options which the Environmental Health Department has standard designs for (Atis et al., 2021). However, poor design, construction, and placement of septic tanks and pit latrines have been overlooked since the Physical Development Department has done limited monitoring and enforcement (Atis et al., 2021). Inadequate and poorly managed water and wastewater increases preventable health risks since contaminated water and poor sanitation are vectors of diseases like cholera, dysentery, hepatitis A, and typhoid (WHO, 2023).

Grenada's current aging infrastructure is only just managing the growing needs of the people and economy (Government of Grenada, 2019). Infrastructure investments must consider climate resiliency, long-term commitments, and address infrastructure gaps including water and sanitation services (Government of Grenada, 2019). Infrastructure development is very challenging in the face of climate change because of impacts from sea level rise, extreme weather events, and the increasing need to reduce carbon emissions (Government of Grenada, 2019).

3.2 Conceptual Model

To achieve the desired future, the system must first be understood. Conceptual models enable a full understanding of a system and its main feedback loops. In Figure 5, Grenada's water sector system is outlined. The model highlights potable water, wastewater, safely treated wastewater, climate change, risk, and potential water reuse flows as well as other integral connections within the system.

Starting with freshwater sources, this model shows how potable water is distributed between the general population and the economy. Once the water undergoes a variety of uses, it is turned into wastewater. However, as we can see in the model, many of the wastewater flows make it into the environment including the freshwater sources used for drinking water. Only a few flows become safely treated wastewater, which unfortunately means that currently, there is only a small potential for water reuse. Climate change impacts can be seen affecting freshwater sources, as well as agriculture and exacerbating wastewater pollution. Most notably, public health and environmental health risks are directly connected to the ecosystems, general population, and economy.

Under the IPCC's Sustainable Development Goals (SDG), monitoring of Safely Treated Household Wastewater in Grenada 2020 Country Estimate was completed but unfortunately determined to have insufficient data. However, the monitoring provided an in-depth look at the domestic wastewater system. Figure 6 shows household wastewater generation.

Grenada's Water Sector: Conceptual Model

Legend

Blue arrows: potable water flows
 Orange arrows: wastewater flows
 Red arrows: risk flows
 Green arrows: safely treated wastewater flows
 Pink arrows: climate change flows
 Purple arrows: potential water reuse flows

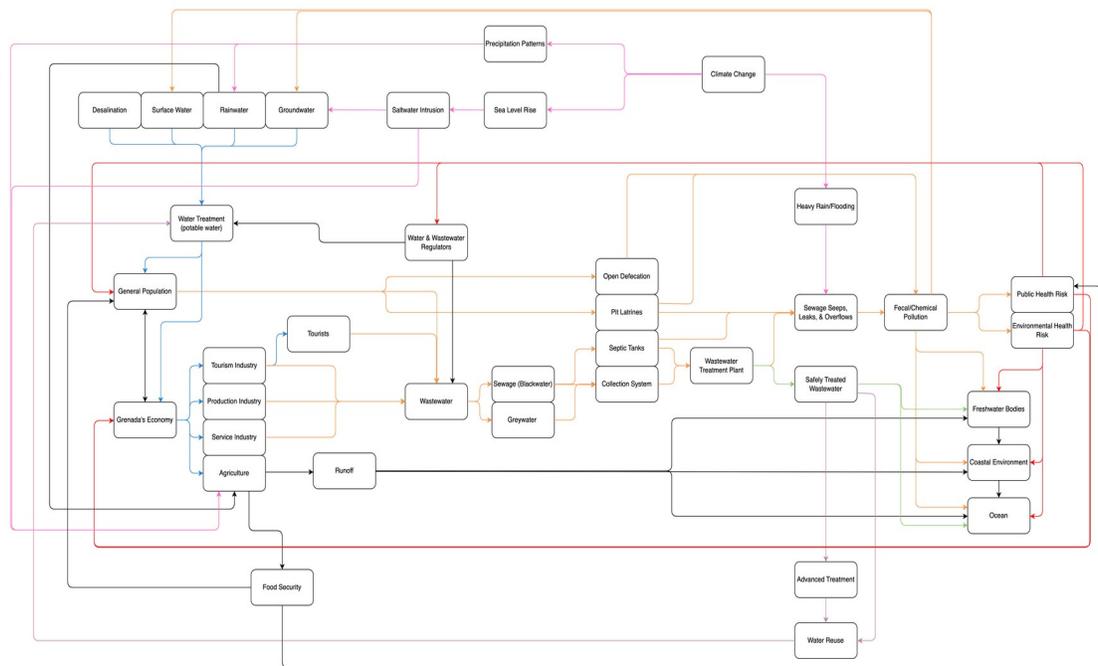


Figure 5: The conceptual model representing the water sector system in Grenada. Blue arrows represent potable water flows, orange arrows represent wastewater flows, red arrows represent risk flows, green arrows represent safely treated wastewater flows, pink arrows represent climate change flows, and purple arrows represent potential water reuse flows.

In the Country Estimate, wastewater was considered collected if it reached a wastewater treatment facility which could either be a wastewater treatment plant receiving sewage from piped collection systems and delivered sludge from septic tanks or on-site treatment from functional septic tanks with a leach field (WHO, 2021). Wastewater flows from septic tanks can either be transferred off-site and delivered to a wastewater treatment plant or remain on site in the tank unemptied or emptied and buried on site (WHO, 2021). Flows collected at treatment plants are considered safely treated if they are treated with secondary treatment with biological removal technology or if their effluent meets discharge standards (WHO, 2021). Flows from septic tanks can be considered safely treated if fecal sludge remains on site (WHO, 2021). However, household flows without connection to piped sewers or septic tanks (open defecation or pit latrines) cannot be classified as collected nor safely treated (WHO, 2021). Wastewater within the collection system might not be collected at the treatment plants and instead discharged directly into receiving waters (WHO, 2021). This may also be the case if the treatment plants are not operational (WHO, 2021). Wastewater flows collected at the treatment plants may not be safely treated when flows bypass treatment processes, the system is over capacity, effluent does not meet standards, or only primary treatment is being used (WHO, 2021). Wastewater from septic tanks may not be contained if tanks are incorrectly installed, not well functioning, or not maintained (WHO, 2021). Although Figure 6 is only looking at domestic wastewater, it clearly shows that wastewater treatment is not reliable within the current system and most wastewater ends up discharged into the environment.

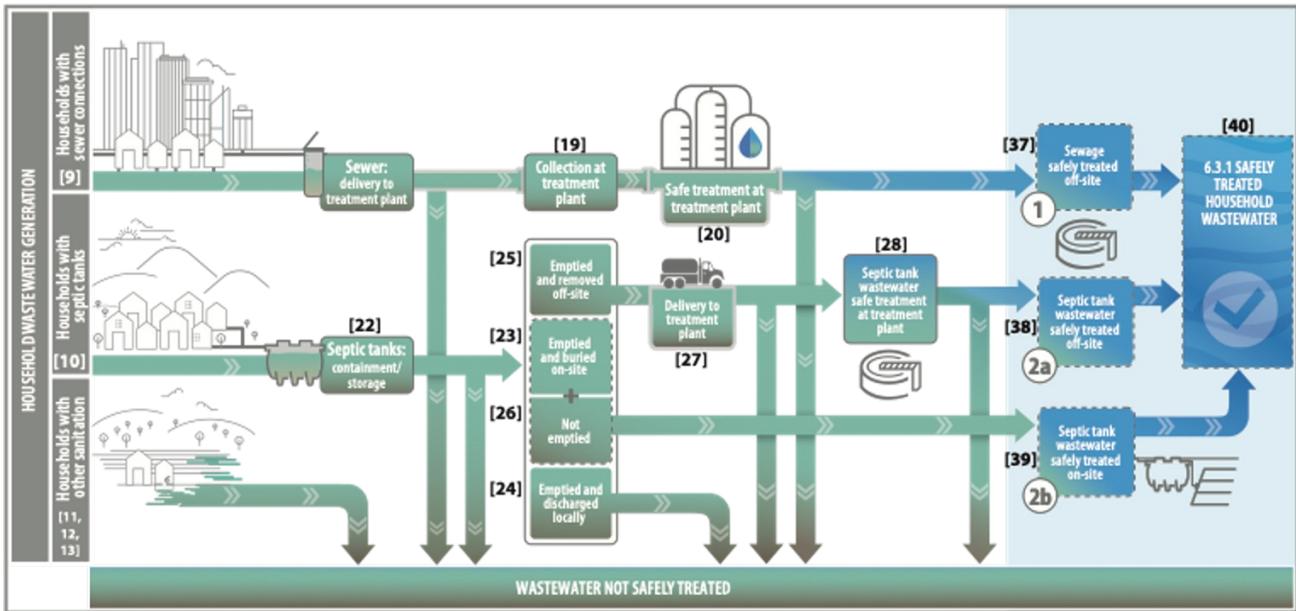


Figure 6: Household wastewater generation in Grenada (WHO, 2021).

4 System Fragilities

This section describes the fragilities relevant to Grenada’s water sector. Fragilities are parts of a system that are capable of being harmed; they are inherent to the system and exist independently of time or outside forces. If time were to stop, risk would be diminished, and any hazards would disappear.

There are many fragilities within Grenada’s economic and social system including a fragmented approach to water resource management; lack of knowledge and understanding of the available water resources; increasing impacts from environmental degradation, pollution, and inappropriate land use; lack of enforcement of regulations and needed improvement to current legislation pertaining to water services and water resources; inadequate infrastructure which affects the ability to ensure water quality and meet demands which impacts the potential and attractiveness of the hotel and tourist industry; lack of an adequate municipal sewage disposal system; lack of financial resources; and inadequate plans for the impacts of natural disasters and climate change adaptation (Government of Grenada, 2020). The main fragilities are listed below in more detail.

Fragmented government organization

Figure 3 shows that Regulatory Quality and Government Effectiveness are two governance indicators that have deteriorated in recent years and many institutional problems have occurred from the current fragmented and uncoordinated approach (Government of Grenada, 2020).

Economic instability

Much of the economy is dependent on water and does not have the resources to respond to natural disasters or global stressors (Government of Grenada, 2019).

Table 2: Fragilities related to their relevant hazards and consequences.

Fragilities	Hazards	Consequence
Fragmented Government Organization	Decision making	Poor regulations and monitoring
Economic instability	Economic disruption	Economic collapse
Sensitive ecosystems	Climate change	Ecosystem collapse
Fecal/chemical pollution	Inadequate wastewater treatment	Communicable disease (epidemics), decreased public health, decreased environmental health, contaminated water sources
Coastal Settlement and Infrastructure	Extreme weather events	Infrastructure damage, loss of life and livelihood, environmental damage
Dependence on water	Overconsumption of water	Decreased social, economic, environmental, and public health
Economic dependence on agriculture industry		
Economic dependence of tourism industry		

Sensitive ecosystems

Unique indigenous biodiversity need specific environmental conditions to sustain a healthy ecosystem and the resulting benefits (UNEP, 2019).

Fecal/chemical pollution

Wastewater flows are often unsafely treated and discharged into the environment (WHO, 2021).

Coastal settlement and infrastructure

Science has predicted that Grenada will experience increasing damage in the future due to hydro-meteorological events and climate change (Government of Grenada, 2019). The majority of buildings are located in the coastal regions of the island which puts them at risk of sea-level rise and hurricanes (Government of Grenada, 2019).

Dependence on water

In recent years, Grenada’s water consumption has increased due to increased population, standard of living, and growing tourism (CREST, 2023).

Economic dependence on the agriculture industry

The agriculture industry is expected to have increased water demand as population and economic expansion increase (Government of Grenada, 2019).

Economic dependence on the tourism industry

The growth of the tourism industry is requiring increased water usage (Government of Grenada, 2019).

5 Hazards and Threats

A hazard is an event or entity that can act upon a system's fragilities and disrupt or degrade the system. There are two types of hazards, exogenic and endogenic. Exogenic hazards originate outside of a system and act upon it. Endogenic hazards originate within a system, usually from an exogenic hazard acting upon a fragility and creating another hazard. Table 2 shows the hazards and the fragilities they can exploit.

5.1 Exogenic Hazards

The following hazards occur from outside the system.

5.1.1 Climate change

Current climate change projections suggest increases in annual temperature average, reduction in annual rainfall, increased intensity of hurricanes, tropical storms, droughts, severe floods, and increases in sea surface temperatures (Government of Grenada, 2019).

5.1.2 Extreme weather events

Science has predicted that the frequency of natural disasters will increase, and tropical hurricanes will be stronger and more intense – causing economic, social, and environmental costs to rise exponentially (Government of Grenada, 2019). Also, most, if not all, infrastructure requires climate-resilient improvements (Government of Grenada, 2020).

5.1.3 Economic disruption

Natural disasters and other global stressors cause expensive damage. Grenada's economy could not handle the social and infrastructure damage in its current state (Government of Grenada, 2020).

5.2 Endogenic Hazards

The following hazards occur from within the system.

5.2.1 Decision making

With the fragmented approach of Grenada's government, water treatment and distribution has undergone improvements, but wastewater treatment and general environmental monitoring have yet to be addressed (Government of Grenada, 2020).

5.2.2 Inadequate wastewater treatment

Wastewater pollution can contaminate freshwater sources, spread disease, and decrease overall public and environmental health (USGS, 2018).

5.2.3 Overconsumption of water

As population increases and economic expansion is prioritized water usage will continue to increase (Government of Grenada, 2019). The current annual water supply is not enough to meet current demand, let alone increased demand (Government of Grenada, 2019).

6 Foresight and Possible Futures

Each hazard comes with a spectrum of possible futures. Possible futures can range anywhere from plausible to implausible and desirable to undesirable. The four archetypal futures are used to explore each hazard. These four futures are collapse, continue, discipline, and transformation.

Each future for the endogenic hazards will need to consider the effects of the exogenic hazards. For this case study, the possible futures of the exogenic hazards will not be explicitly discussed.

The following outlined possible futures provide realistic foresight for each hazard.

6.1 Decision making

Collapse: The government's fragmented approach to the water system is completely ineffective. There is no consistent water quality monitoring or water quality data to aid in determining the health of the ecosystems. Critical decisions cannot be made and small issues become unsolvable problems. Climate change effects are unmanaged. Economic disruptions and extreme weather events cause economic collapse and irreversible damage.

Continue: The current fragmented approach is recognized by the government. There is some monitoring but no historical water quality data. Critical decisions can be made and planning improvements are prioritized. Climate change effects are being considered. Economic disruptions and extreme weather events could cause economic stress bordering on collapse and expensive damage.

Discipline: The government restructures its approach to water management. Formal water quality monitoring is implemented. Critical decisions are already planned for and easily made. Climate change effects are managed. Economic disruptions and extreme weather events have emergency plans for managing economic stress and damage.

Transformation: The government takes a coordinated, participatory approach to manage the water sector. Water quality standards are set and expected to be met under a monitoring program. Decision-making is focused on innovation and improvements. Climate change effects are offset. Economic disruptions and extreme weather events have emergency funding for managing damage. The economy is stable.

6.2 Inadequate wastewater treatment

Collapse: Wastewater treatment is not significantly improved. As populations and water usage increase, wastewater contamination severely impacts public and environmental health. Drinking water sources are dangerously impacted and the cost to treat the water to drinking standards has increased

significantly. Infrastructure is extremely poor and climate change effects and extreme weather events exacerbate the many existing weaknesses within the system. The economy suffers from the loss of tourism, fisheries, and agriculture due to unsafe water.

Continue: Wastewater treatment is recognized as an area of concern but little changes have been made. Poor infrastructure and collection create environmental and public health concerns. Current freshwater sources are likely impacted but easy to treat to drinking water standards. Climate change and extreme weather events could have many negative impacts on the current system. The economy is focused on expansion although it is recognized that the current wastewater system is a threat to socioeconomic development.

Discipline: Wastewater treatment and infrastructure is improved so that public and environmental health can be maintained. Freshwater sources are hardly impacted by wastewater contamination. Climate change and extreme weather events pose small threats to the system and infrastructure. The economy is stable as water-based economic drivers are significantly contributing to socioeconomic development.

Transformation: Wastewater treatment and infrastructure is innovative, and the system is secure. Public and environmental health is thriving. Water reuse is implemented and supplements the freshwater supply as well as decreases effluent discharges into the environment. Climate change and extreme weather events are easily managed. The water sector supports socioeconomic success.

6.3 Overconsumption of water

Collapse: The consumption of water increases with increased demand, but supply cannot maintain the levels of usage. Climate change impacts on water supply are severe and unmanageable. Water becomes scarce and quality decreases. Public and environmental health diminishes.

Continue: Water supply is barely able to keep up with water usage and increased demand is supplemented with desalination. Climate change impacts are manageable. Public and environmental health is maintained.

Discipline: Water supply is closely monitored and distributed with both socioeconomic and ecosystem health in mind. Climate change impacts are manageable. Public and environmental health is stable.

Transformation: Water reuse is implemented and the natural water supply is abundant. Water and water usage are well regulated and monitored. Climate change impacts are offset. Public and environmental health is thriving.

A collapsed future would be the worst-case scenario because Grenada's socioeconomic, public, and environmental health would likely diminish beyond repair. Fresh water would be contaminated and scarce, wastewater would be severely untreated, and there would be no economic stability in the face of climate change, economic disruption, or extreme weather events. A transformative future would be the most desirable future and would guide Grenada toward the goal statement. The transformative future would consider the purpose of Grenada's coastal ecosystems while meeting the water needs of the growing population and economy while properly managing the water and wastewater. While a disciplined future would aim for the goal statement, it would still have major flaws. Working towards a transformative future would be the most beneficial to Grenada.

7 Interventions

Grenada needs major improvements to its water and wastewater management with growing population, economic development, and increasing climate change effects. Water is crucial to the country's environmental and socioeconomic success and therefore needs to be prioritized. The following interventions aim to evaluate reasonable options for the betterment and improvement of water sector management while meeting water needs and protecting the purpose of Grenada's coastal environment. Table 3 summarizes the interventions and their main pros and cons.

public and private organizations and civil society, and prioritized transparency (Government of Grenada, 2020).

Grenada's government could restructure to have one entity that focuses on water and water quality. This entity would consider all water needs – agriculture, fisheries, tourism, and general population demand as well as provide a top-down structure around water and wastewater management. This entity would form water quality standards and pressure direct operation managers, like NAWASA, to meet those standards. The government entity would also create a formal and consistent monitoring program. This program would ensure that there is data and understanding of overall water quality and encourage discharges to meet water quality standards by pressuring for improvements of infrastructure. An entity like described would remove current barriers to proper water management and improvements by allowing the relevant organizations to work together.

Pros:

- Creates a coordinated, participatory approach
- Increases water quality standards and monitoring
- Increases infrastructure improvement
- Removes barriers to management

Cons:

- requires funding
- requires specialized personnel
- large-scale shift within government organization

7.1 Cross-sector coordination

To address the current fragmented approach, there needs to be the establishment of water resources management institutions, good governance, maintenance of effective coordination between relevant 7.2 Increase wastewater treatment

Wastewater treatment appears to be a lower priority in the many current planning and annual reports, but wastewater treatment is essential to public and environmental health.

7.2.1 Increase wastewater treatment plants

Grenada could build additional treatment plants and install the necessary infrastructure to expand wastewater collection.

Table 3: Interventions addressing the hazards and possible future scenarios and their main pros and cons.

Intervention	Pros	Cons
Cross sector coordination	coordinated approach, water quality standards and monitoring, infrastructure improvements, barriers to management are removed	requires funding, needs specialized personnel, large scale shift within government organization
Increase wastewater treatment plants	centralizes and increase wastewater treatment, decreases current poorly designed infrastructure, decreases wastewater contamination	very expensive, requires major installation around the country
Improve current treatment plants and wastewater infrastructure	decreases wastewater contamination and poorly designed infrastructure, increases wastewater treatment, uses current infrastructure	expensive
Wastewater to drinking water	supplements water supply, decreases wastewater effluent discharges and wastewater contamination	expensive, needs innovative technology and treatment, needs comprehensive water reuse education
Non potable water reuse	supplements water supply, reduces cost of drinking water treatment, decreases effluent discharges, decreases wastewater contamination	expensive, needs water reuse education

Pros:

- centralizes and increases wastewater treatment
- decreases current poorly designed and constructed septic tanks and pit latrines
- decreases wastewater contamination

Cons:

- very expensive
- requires major installation of piping throughout the country

7.2.2 Improve current treatment plants and wastewater infrastructure

Grenada could improve the capacity, treatment, and reliability of the current treatment plants it has and expand the range of wastewater collection. In other areas, Grenada could improve the infrastructure and

reliability of septic tanks and pit latrines.

Pros:

- decreases wastewater contamination
- decreases current poorly designed and constructed septic tanks and pit latrines
- increases wastewater treatment
- uses current infrastructure

Cons:

- expensive

7.3 Water reuse

Water reuse is growing in popularity as a mitigation option for water scarcity (Government of Grenada, 2020). Wastewater reuse needs a positive public perception which requires advanced treatment with high quality standards for hygiene and public education (Government of Grenada, 2020). Many water utilities recycle wastewater to help combat water scarcity, reduce pollutant loading, and reduce flooding risk (Macler et al., 2021). There are many non potable water uses for wastewater, with only addition disinfection, to be safely utilized (Macler et al., 2021). Industrial, commercial, and municipal water users can be well served by reclaimed wastewater at a lower cost than the high cost of developing high quality potable water (Macler et al., 2021).

7.3.1 Wastewater to drinking water

Grenada could build an advanced treatment facility to treat wastewater to drinking water standards.

Pros:

- supplements water supply
- decreases wastewater effluent discharges
- decreases wastewater contamination

Cons:

- expensive
- needs innovative technology and treatment processes
- needs comprehensive water reuse education for positive public perception

7.3.2 Non potable water reuse

Grenada could add additional treatment and disinfection to current treatment plants to treat wastewater for safe non-potable water uses.

Pros:

- supplements water supply by reducing the usage of treated water for drinking

- reduces the cost of treating drinking water
- decreases effluent discharges
- decreases wastewater contamination

Cons:

- expensive
- needs water reuse education for positive public perception

8 Discussion and Conclusions

Hydrological, ecological, and social cycles link water resources in all its forms (Government of Grenada, 2020). For Grenada, water joins terrestrial and marine systems, the economy, and society where the effect of impacts on land and marine systems are often quickly felt (Government of Grenada, 2020). It is imperative that water and wastewater management be integrated into the management of terrestrial and marine systems (Government of Grenada, 2020). Reaching the goal statement requires all the stakeholders to come together and prioritize water needs as well as public health and the purpose of Grenada's coastal environment. While drinking water is an imperative part of the water sector, wastewater has been overlooked for too long and needs to be addressed for proper water sector management. With climate change and other external hazards, Grenada needs the water sector for socioeconomic stability, public health, and protection of its coastal environment.

9 Recommendations

After mapping the decision space, defining the wicked problem, determining the fragilities and hazards, expanding on possible futures, and developing interventions, recommendations are made as a means to reach a desirable future. The goal of the recommendations is to implement the most effective, feasible, and ethically sound interventions. The goal statement for this case study is "A future where water needs are met, water and wastewater are well managed, and the purpose of Grenada's ecosystems are protected." These recommendations are made to provide Grenada with a pathway towards reaching this goal.

Recognizing that:

- Climate change is changing water resources
- Grenada's government has a fragmented approach to managing the water sector
- Water supply is not meeting water demand
- Wastewater is not adequately treated or managed

Acknowledging that:

- There are many stakeholders with interest in the water sector
- Addressing water and wastewater management will not be easy to accomplish
- Grenada is aware of many of its current water sector issues

The following interventions are recommended to Grenada's government for implementation:

- Improving cross-sector coordination to better manage the water sector
- Improve current treatment plants and wastewater infrastructure
- Implementing non potable water reuse to supplement the water supply

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