# GROUNDWATER GOVERNANCE IN NEWFOUNDLAND:
# USING THE FUNCTIONAL RESONANCE ANALYSIS METHOD TO UNDERSTAND GROUNDWATER RESOURCE MANAGEMENT AT THE MUNICIPAL LEVEL

**By**

**© Julia Fracassi**

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## Abstract

While municipalities in Newfoundland are responsible for managing their water supplies and natural assets, many lack the capacity and resources to do so. Effective groundwater management is becoming increasingly difficult as communities grapple with unpredictable, extreme weather events, flooding, development pressures, population increase and wetland loss. Understanding municipal decision-making processes surrounding groundwater management may shed light on how best to manage this dwindling resource that is integral to communities. The Functional Resonance Analysis Method (FRAM) is a system-mapping tool used for modelling the functionality of a socio-technical system, created by Erik Hollnagel in 2004 (Hollnagel and Slater, 2018). In this thesis, the FRAM is used to analyze the case-study community, Logy Bay-Middle Cove-Outer Cove (LBMCOC), as a socio-technical system, developing a holistic understanding of the Town's decision-making process in regard to groundwater management. While LBMCOC has agreed to participate as a case-study community, they are not a formal partner and the research goals of this thesis may not necessarily reflect the goals of the community itself. Input from community decision makers and other stakeholders inform the model. This model is then used in conjunction with the DynaFRAM, a FRAM-based tool to observe variability in a system, which assist in identifying key factors contributing to strengths and weaknesses in the case-study community's groundwater management approach. These insights may be useful for other municipalities looking to adopt a similar approach. Literature surrounding groundwater governance has increasingly called for the implementation of "holistic water management frameworks" (Famiglietti, 2014). In using the FRAM to understand the community as a system in a holistic manner, this study's methodology expands on the holistic framework approach. It also recognizes the interconnectivity of surface water (wetlands) and

groundwater, a relationship which is oftentimes neglected in water management. The FRAM has yet to be used to analyze a case community context. Therefore, this research may not only be valuable to the community of Logy Bay-Middle Cove-Outer Cove (LBMCOC) but demonstrates a methodological contribution to the environmental management research community as well.

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## List of Abbreviations

| | |
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| CCME | Canadian Council of Ministers of the Environment |
| FMV | FRAM Model Visualizer |
| FRAM | Functional Resonance Analysis Method |
| LBMCOC | Logy Bay-Middle Cove-Outer Cove |
| MNAI | Municipal Natural Asset Inventory |
| WRIM | Water Rights, Investigation & Modelling Section |
| WESP-AC | Wetland Ecosystem Services Protocol for Atlantic Canada |

## List of Appendices

## Definitions of Terms

**Aquifer:** An aquifer is a geologic formation (or group of connected formations) located underground which store potable water (Krešić, 2009). The word aquifer is derived from the latin word “aqua”, meaning “water”, and “affero”, meaning “to bring” or “to give” (Krešić, 2009). Aquifers can be made of rock, gravel, sand or silt and vary in size (Krešić, 2009).

**Green Infrastructure:** Human-made infrastructure created to supplement the services offered by natural assets, such as stormwater ponds or green walls (MNAI, 2017a).

**Groundwater:** Groundwater is water that seeps through the soil, is filtrated, and is then held in the earth’s subsurface in saturated zones throughout rock and soil (Kath and Dyer, 2017).

**Groundwater Recharge:** Groundwater recharge describes the process of water being added to an aquifer via infiltration into the ground (Şen, 2015).

**Natural Asset:** Natural resources, ecosystems, or biological assets that offer a benefit to people (MNAI, 2017a).

**Riparian Area:** The transition zone between the edge of a body of water and dry, upland areas (Government of Canada, 2022). Riparian areas consist of abundant, green vegetation which thrive on moisture (Government of British Columbia, n.d.).

**Surface water:** Surface water refers to bodies of water located above ground, such as rivers, lakes, wetlands, and the ocean (National Geographic, 2022).

**Wetland Delineation:** Referred to in this thesis as a "delineation", a wetland delineation describes the process of identifying and confirming the location and boundaries of a wetland (Government of New Brunswick, 2019). It can only be conducted by an individual trained in wetland identification/delineation, or with education and experience pertaining to soils, wetland hydrology, botany or other relevant fields (Government of New Brunswick, 2019).

**Wetland Development:** Wetland development is defined by the province of Newfoundland and Labrador (n.d.) as the change in use of a wetland which alters its hydrologic characteristics or ability to function due to activities such as infilling, dredging, channelization, removal of vegetation cover or organic matter, or any type of mechanical disturbance to the ground on which the wetland is located.

# Chapter 1: Introduction

Globally, more than 2 billion people depend on groundwater for their everyday water needs (Famiglietti, 2014). In Newfoundland, 21% of the province's population rely on groundwater for their day-to-day use (Government of Newfoundland and Labrador, 2016a). While this resource is vital to billions of people on the planet, there remains much to learn about groundwater systems, how they operate in tandem with other water bodies (i.e. wetlands), and how they will be affected by a quickly changing climate. For some communities in Newfoundland, groundwater is their sole source of water. Protecting a resource that is hidden from plain sight and may respond unpredictably to management efforts is a difficult task. This is further complicated by the knowledge gaps surrounding interactions between groundwater and wetland systems (Rivera, 2005). As populations increase and land becomes a highly sought-after commodity, development pressures are mounting to build on ecologically valuable wetlands. Wetlands provide various ecosystem services which ensure the purification and recharge of groundwater; therefore, the loss of wetlands threatens the future availability of groundwater resources (Bruneau, 2017). As a result, the municipalities who rely on clean groundwater as their primary (and often only) source of water must consider the implications of prioritizing short-term economic gain over long-term sustainability. It is in understanding groundwater/surface water interactions and the effects human activities have on these natural assets that municipalities can make informed decisions regarding their community development and create better policies to ensure a sustainable future.

## 1.1 Problem Statement

Groundwater resource management is shared by the federal, provincial and municipal levels of government (Council of Canadian Academies, 2009). It is the responsibility of local governments to operate, maintain and monitor their water systems (Minnes and Vodden, 2017). Municipalities are also tasked with making decisions that may directly or indirectly affect their groundwater resources. Recent changes in Newfoundland's provincial government structures have now shifted the responsibility of reviewing permits for waterbody alteration to municipalities, many of whom are struggling to make informed decisions surrounding wetland development. Any work being done within the municipality's boundaries that is within or adjacent to a body of water, wetland or floodplain must now first be approved by the municipality, then by the provincial Water Resources Management Division (Government of Newfoundland, n.d.). For the community of Logy Bay-Middle Cove-Outer Cove (LBMCOC), who rely solely on groundwater as their source of drinking water, the decision to allow development on potentially functional wetlands could threaten the health and sustainability of future groundwater supplies for the town. When they were suddenly faced with the responsibility of accepting or denying permits before they were sent to the province to be reviewed, the town felt unequipped to make decisions about their community development without knowing the full implications. Concerned about the future of their groundwater and wetland ecosystems, the town took a number of steps to better equip themselves with the knowledge and resources necessary to make informed decisions about development in the municipality. This study seeks to understand the complexity of the provincial groundwater management policy through the case study of LBMCOC.

The Functional Resonance Analysis Method (FRAM) is a system-mapping tool used to analyze socio-technical systems. Some academics are calling for the holistic management of water resources, where the understanding that groundwater and surface water are interconnected drives policy and decision-making (Famigilietti, 2014; Kath and Dyer, 2017; Rivera, 2005). The holistic nature of the FRAM and its ability to view interconnected functions as a whole will assist in exploring an integrated perspective to groundwater management. The FRAM also serves as a helpful visual tool, as it allows researchers to work with large amounts of data condensed into a manageable model.

This thesis is an interdisciplinary study, as it attempts to bridge engineering and social science methods to understand the policy and decision-making process within a community. The FRAM is a complex tool—it took roughly six months of training to understand and use the method. Therefore, the FRAM models may initially appear overwhelming for readers unfamiliar with the methodology, especially since the method used in this study incorporates both engineering and social science components. All models in this thesis will be accompanied with explanations and visuals to assist the reader in interpreting the models.

## 1.2 Research Questions and Objectives

Municipalities in Newfoundland are currently facing a number of barriers to effective groundwater and wetland management. An objective of this study is to understand the approach taken by LBMCOC with the goal of providing insights and understanding for other municipalities struggling with effective groundwater governance. This will be done using the

FRAM, a tool created to model socio-technical systems. The FRAM will enable us to gain an understanding of the functionality of the system, observe where strengths and weaknesses exist and how they can be either dampened or amplified, and visualize the interconnectedness of the different functions that affect decision-making. To our knowledge, this thesis will be the first instance of the FRAM being used to understand the water management approach of a municipality. Therefore, this work aims to not only shed light on the dynamics of shared provincial and municipal governance of groundwater resources, but also to demonstrate the possibility of this novel use of the FRAM.

This study aims to answer the following questions:

1. How can the FRAM be used to understand the decision-making processes across an entire community in regard to groundwater and wetland management?
2. What are LBMCOC's information and decision processes around groundwater and wetland management?
3. What are the implications of increased municipal responsibilities around groundwater and wetland management in LBMCOC?
4. What factors (drivers and constraints) explain the success of groundwater and wetland management in the community?
5. What best practices can be drawn from this case for potential use by other communities in Newfoundland?

### 1.3 Thesis Structure Overview

This thesis consists of 6 different chapters, including this introductory chapter which discusses the research questions and objectives motivating this work. The second chapter is a literature review which will look at a variety of topics relevant to this study, including groundwater and wetland governance, natural asset management and the FRAM method. Chapter 3 provides a detailed look at the research methods used in this study as well as the case community selection process. Chapter 4 presents the results of the data collection and modelling. Chapter 5 includes discussions of the results from Chapter 4 and recommendations based on these findings. The concluding chapter, Chapter 6, will summarize the document and end with recommendations for future studies.

# Chapter 2: Literature Review

The following section is a literature review which provides background for this study. Materials and research used in this review include peer-reviewed articles, grey literature (such as government documents, reports and white papers) and books. Databases used include Google Scholar, the Memorial University of Newfoundland Library catalogue, Proquest and JSTOR. Literature pertaining to the central themes discussed in this thesis (i.e. groundwater resources, groundwater governance, wetlands, municipal natural asset management and the FRAM method) was collected, reviewed, and summarized in the section below.

## 2.1 Groundwater Resources

Hidden underground in the crevices of rock formations and between particles of soil lies a vital global resource: groundwater (Loë and Kreutzwiser, 2003; Government of Canada, 2013). Groundwater is water that is found in the subsurface of the earth (Kath and Dyer, 2017), which is an important component in the hydrologic cycle (Government of Canada, 2013). As precipitation lands on the ground, the rain seeps down through the soil to meet saturated rock formations (aquifers), becoming what is referred to as "groundwater recharge" (Government of Canada, 2013). Located underground, aquifers are formations of permeable rock where groundwater is stored (either confined or unconfined) and range in size from only a few hectares to thousands of square kilometres (Hiscock et al., 2014, "Water Sources", 2013). Aquifers are both reservoirs and transport channels (Margat and van der Gun, 2013).

It is difficult to accurately estimate the amount of groundwater that can be found on the planet, as data on groundwater is limited (Nowlan, 2005). The U.S. Geological Survey estimates there to be roughly 23,400,000 cubic kilometres of groundwater on Earth, while a literature review completed by Environment and Climate Change Canada revealed other estimates range from 7,000,000 to 330,000,000 cubic kilometres ("Water Sources", 2013). It is estimated that 50% of the planet's potable water comes from groundwater sources (Giordano, 2009). In Canada, 82% of the rural population relies on these groundwater resources (Rivera, 2005), in addition to being used for 43% of agriculture and 14% of industry needs (Nowlan, 2005). This does not include the ecosystem support offered by groundwater supplies across the country (Rivera, 2005).

Groundwater is less susceptible to harmful microorganisms due to its natural filtration as it flows through the aquifer, in addition to the long periods of time it is contained underground ("Water Sources", 2013). However, wells used for drawing groundwater can be vulnerable to contamination from external sources, making the groundwater unsafe for drinking ("Water Sources, 2013).

### 2.1.1 Groundwater Resources and Uses in Newfoundland

As of 2021, there were 510,550 people living within the province of Newfoundland and Labrador, with 110,525 people living in St. John's and the surrounding area ("Census Profile", 2021). In Newfoundland, public water drinking sources consist of surface water as well as groundwater (Eledi et al., 2017). Due to the abundance of fresh water sources in the province (lakes, ponds and rivers), surface water is used by many communities in the province; however, 21% of Newfoundland's population relies on domestic groundwater systems (Eledi et al., 2017; Government of Newfoundland and Labrador 2016a).

Public drinking water is the responsibility of both provincial and municipal government (Minnes and Vodden, 2017). Provincial departments concerned with drinking water in Newfoundland include the Department of Environment and Climate Change (formerly referred to as the Department of Environment and Conservation), Municipal Affairs, Health and Community Services, and Service NL (Minnes and Vodden, 2017; Government of Newfoundland and Labrador, n.d.). Local governments are responsible for operating and maintaining water systems, as well as monitoring water quality (Minnes and Vodden, 2017). Public drinking water systems are governed by the Water Resources Act, the Municipal Affairs Act, and the Municipalities Act, in addition to other guidelines and policies developed by the province (Eledi et al., 2017; Minnes and Vodden, 2017). Due to the small but dispersed population of Newfoundland, there is limited capacity at the provincial level to "meet all requests that are made of them" (Minnes and Vodden, 2015 as cited in Minnes and Vodden, 2017), and budget cuts have further limited these provincial departments to carry out their duties.

### 2.1.2 Global Depletion of Groundwater Resources

Despite our heavy reliance on groundwater for domestic, agricultural and industrial needs, groundwater resources globally are vulnerable to contamination, overuse and degradation (Loë and Kreutzwiser, 2003). In order to maintain sustainable groundwater levels, groundwater extraction cannot exceed groundwater recharge at a large scale for extended periods of time (Gleeson et al., 2010). The use of groundwater at a rate faster than it can recharge itself can lead to the lowering of the water table, land subsidence (soil collapse below ground), deteriorated water quality and seawater intrusion (U.S. Geological Survey, 2018; Famiglietti, 2014). When groundwater levels are lowered, it can also have detrimental effects on streamflow, surrounding ecosystems and the wetlands fed by groundwater sources (Wada et al., 2010).

Despite its importance to drinking supplies—as well as wetlands and other ecosystems—groundwater resources are not well managed in many regions globally (Famiglietti, 2014). According to Famiglietti (2014), in some cases property owners who can afford to do so can retrieve unlimited amounts of groundwater, with no regard for recharge rates—money controls groundwater extraction as opposed to sustainable yield limits backed by scientific data. As a result, "most aquifers in the world's arid and semi-arid zones […] are experiencing rapid rates of groundwater depletion" (Famiglietti, 2014). The issue of overuse is further exasperated by climate change's effects on the water cycle and precipitation patterns, leading to increased extreme weather events such as floods and droughts which alter groundwater recharge rates (Famiglietti, 2014). As wells yield less water and eventually run dry, those in regions relying solely on groundwater have no choice but to dig deeper wells, further depleting groundwater levels and running the risk of contamination (Famiglietti, 2014). While it is imperative that groundwater resources are protected to ensure sustainable yield for future generations, they are often neglected in favour of more visible, obvious surface water sources such as rivers and lakes (Famiglietti, 2014).

### 2.1.3. Holistic Groundwater Management

Located underground, aquifers are not visible in plain sight and therefore do not garner the same attention that surface water bodies such as lakes and wetlands receive (Kath and Dyer, 2017; Jakeman et al., 2016; Rivera, 2005). According to Rivera (2005), this had led to gaps in knowledge regarding how groundwater and surface water affect each other; he urges policy makers to take a more “holistic approach” to policies surrounding water resources. Rivera (2005) suggests that this disconnect is largely due to the fact that water law and policy was developed “more than a century ago” when the interconnectedness of surface water and groundwater were not fully understood. Understanding the relationship between surface water bodies and groundwater resources is increasingly difficult as climate change impacts the water cycle, as mentioned in Section 2.2.5. Like Rivera (2005), Famigilietti (2014) also points to a “holistic water management framework” as the key to understanding and preparing for future declines in renewable water sources. This approach has seen success in Australia (as well as other parts of the world), where groundwater management shifted to an “integrated perspective” in which the recognition of surface water and groundwater’s connectivity drives decision making (Kath and Dyer, 2017). It is also importance to understand their differences. Changes to groundwater take longer to observe (and have longer-lasting impact) than those occurring in surface water (Kath and Dyer, 2017). In some cases, the depletion of groundwater could take more than thousands of years to reverse (Kath and Dyer, 2017). While recognizing these differences, but understanding their connectedness, Kath and Dyer (2017) recommend these two water sources be managed “conjunctively, as ‘one water’”.

## 2.2 Wetlands

Roughly a quarter of the world's remaining wetlands can be found in Canada (Giblett, 2014; Government of Canada, 2016a). There are approximately 1.29 million $km^2$ of wetlands in Canada, many of which are threatened by agriculture and development pressures (Government of Canada, 2016a). The Nature Conservancy of Canada (n.d.) describes wetlands as ecosystems where "terrestrial and aquatic habitats meet", trapping water due to either lack of drainage, periodic flooding or coastal barriers. However, many definitions of wetlands exist. Mitsch and Gosselink (2015) have identified three components present in most wetland definitions: the presence of water (at the surface or within the root zone), soil conditions unique from nearby uplands, and the ability to support plant and animal life adapted to wet environments. Wetlands are either freshwater or saltwater, and in Canada wetland types range from bogs, fens and peatlands to swamps, marshes and shallow waters (Nature Conservancy of Canada, n.d.; Adams et al., 1987 as cited in Bruneau, 2017). Ultimately, any land that retains water long enough for plants and soils to develop can be considered a wetland (Government of Canada, 2016a).

Wetlands provide a number of vital ecosystem services, such as groundwater recharge and water purification, sediment/nutrient retention, storm protection, carbon sequestration and biodiversity maintenance (Bruneau, 2017). Wetlands that have declined past their ability to provide these functions can actually incur more financial costs to the community, as costs related to water treatment, irrigation water shortage, water hauling, flood damage repair and property value would all increase (Bruneau, 2017). There have been efforts to garner support for the protection of wetlands. Signed in 1971, the Ramsar Convention on Wetlands is an international treaty which commits Contracting Parties to protecting and effectively managing their wetlands, designating qualifying wetlands as "Wetlands of International Importance" (also known as the "Ramsar List"), and participating in international efforts to protect transboundary wetlands and shared species (Ramsar, n.d.).

### 2.2.1 Assessing Wetland Functionality

The Wetland Ecosystem Services Protocol for Atlantic Canada (WESP-AC) is the method used in Atlantic Canada to assess the functionality of non-tidal wetlands (Adamus, 2018). WESP-AC has been modified for use in Atlantic Canada, but is an offshoot of the Wetland Evaluation Technique, a peer-reviewed wetland assessment tool used commonly throughout the United States and the first of its kind (Adamus, 2018). Practitioners use the WESP-AC method to quickly assess a wetland by giving scores (from 0 to 10) and ratings (Lower, Moderate, and Higher) to its functions such as: sediment retention and stabilization; water storage; stream flow support; nitrate removal; carbon sequestration; fish, amphibian, reptile, pollinator and bird habitat; public use; ecological condition and sensitivity (Adamus, 2018). These scores/ratings are generated to help inform decisions surrounding wetland development, preservation or avoidance (Adamus, 2018). The WESP-AC is also used to assess and monitor wetlands when carrying out restoration projects (Adamus, 2018). The assessment is first conducted as a desktop study through the use of previously existing data, online information and aerial imagery, followed by a site visit for the field work portion (Adamus, 2018). Wetlands with enough low scores/ratings that do not meet the threshold for a functional wetland are considered non-functional. It is important to note that high-functioning wetlands are not necessarily healthy, nor are healthy wetlands always high-functioning (Adamus, 2018). This is due to the fact that there is no scientific consensus as to what constitutes a healthy wetland, as well as the fact that no solitary wetland can provide all functions at a high level (Adamus, 2018). Instead, to understand the overall functionality of a wetland, one must look at the various functions, how they are weighted and their interactions with each other (Adamus, 2018).

### 2.2.2 Wetlands and Groundwater Connection

Section 2.1.3 highlights the need for holistic groundwater management as made evident in groundwater policy literature. This integrated perspective recognizes the connectivity of surface water and groundwater and how they are both affected by change (Kath and Dyer, 2017). In most places, surface-water bodies are not only connected to groundwater but are also integral to their flow systems (Winter, 1999). The two may not even be physically connected, but even waterbodies that are separated from groundwater sources via an unsaturated zone will still recharge groundwater levels in that area (Winter, 1999). While these two systems may appear to be separate, a change that occurs to one will greatly affect the other (Winter, 1999).

Groundwater plays multiple roles in maintaining health and stability in wetland ecosystems (Wu et al., 2020). Surface water and groundwater interact “by infiltration into or exfiltration from the saturated zones” (Sophocleous, 2002, as cited in Wu et al., 2020). The interactions between surface water and groundwater affects the levels of nutrients, heavy metals and ions in the water (Wu et al., 2020). In arid or semi-arid areas where surface water sources are non-existent, groundwater levels directly impact the formation, health, and functionality of wetlands (Crosbie et al., 2009, as cited in Wu et al., 2020). The rather stable temperature of groundwater can help regulate wetland temperatures, making them a more suitable environment for plants and wildlife inhabiting the wetland (House et al., 2015, as cited in Wu et al., 2020). According to Wu et al., 2020, while research surrounding groundwater's contributions to wetland functionality is gaining more traction, this cannot be said of research pertaining to surface water and groundwater interactions taking place within wetland itself, due to the complexity and variability in wetland conditions. They assert that research has yet to fully explore how wetlands rely on groundwater systems for stability, how human activity affects these interactions, and how restoration/management efforts can manage surface water/groundwater interactions to promote ecosystem sustainability. As the effects of climate change worsen, it is increasingly important that we understand these interactions in order to better protect wetland ecosystems moving forward.

### 2.2.3. Risks Affecting Wetland Ecosystems

There are numerous risks threatening the health, functionality, and existence of wetland ecosystems:

- Land conversion is a major threat to wetlands. Previously, wetlands were not valued as productive land and were often drained, filled, and converted into farmland (Government of Canada, 2016a). For example, in Ontario 68% of wetlands have been converted for alternate uses and no longer offer vital biodiversity support and ecosystem services (Government of Canada, 2016a).

- Economic growth and increasing human population density are two factors placing unprecedented pressures on Canada’s wetlands (Ministry of Natural Resources and Forestry, 2015).

- Changing water flow can negatively affect wetland functionality. For example, the alteration of water levels of lakes and rivers caused by dam and weir construction can alter water flow to the point that wetland function is altered or stops altogether (Ministry of Natural Resources and Forestry, 2015).

- The introduction of invasive species to a wetland can throw off the balance of the ecosystem as the invasive species competes with native species, diminishing the diversity and habitat quality of the wetland (Ministry of Natural Resources and Forestry, 2015). Healthy, well-functioning wetlands are less susceptible to invasive species (Ministry of Natural Resources and Forestry, 2015).

- Wetlands are also greatly affected by pollution. Despite having the natural ability to filter pollutants, when faced with excessive pollution from domestic sewage, heavy metals, pesticides, sediments and fertilizers, wetland function as well as fish and wildlife health can degrade significantly (Ministry of Natural Resources and Forestry, 2015).

- The increasingly unpredictable weather patterns events such as floods, heat waves, storms and droughts that are occurring due to climate change place stress on wetland ecosystems (Ministry of Natural Resources and Forestry, 2015). These changes to the hydrological cycle could result in the reduction of wetland size, diversity loss, wetland type alteration or the conversion of wetlands into dry land (Ministry of Natural Resources and Forestry, 2015).

This is not an exhaustive list of all the threats affecting wetland health, especially since wetlands sometimes face multiply threats at once, which may present unique challenges due to the cumulative effects (Ministry of Natural Resources and Forestry, 2015).

### 2.3 Groundwater Governance

Governance can be defined as "the exercise of political authority and the use of institutional resources to manage society's problems and affairs" (World Bank, 1991). The Groundwater Governance Project—supported by the Food and Agriculture Organization of the United Nations (FAO), UNESCO, the World Bank and the International Association of Hydrogeologists (IAH)—was one of the first initiatives to try to create a global inventory of the state of groundwater governance, as well as provide a framework for such projects (Karar, 2017). One outcome of this project was the Global Groundwater Diagnostic, a report contributing to the existing body of knowledge on groundwater governance (Karar, 2017). This report states that there are four main components to groundwater governance: actors, legal frameworks, policies, and information and knowledge (Groundwater Governance Project, 2016). In addition to these four components, there are a number of innovative instruments that can be used in the management process. Technical instruments include surveying, quality/quantity monitoring, modelling, and other types of diagnostic analysis tools (Karar, 2019). There are managerial and planning instruments such as land use/spatial planning, environmental impact assessments and groundwater protection zoning (Karar, 2017). Regulatory instruments include groundwater property rights, well licensing/registration, drilling accreditation, water legislation and groundwater caps (Karar, 2017). Examples of economic instruments include the strategic pricing of groundwater and environmental taxes (Karar, 2017). Behaviour-changing instruments are examples of "soft" policy tools which rely on voluntarism, like information sharing, awareness-raising and various forms of training (Karar, 2017). According to Moench et al. (2003), an intimate knowledge of the groundwater system (both its "social and physical dimensions") and adequate organizational capacity are necessary for these instruments to be utilized effectively. Groundwater is a common pool resource, which makes it difficult to govern (Weekes, Krantzberg and Vizeu Pinheiro, 2019). While many definitions exist, Ostrom (2008) defines common pool resources as resources whose size—amongst other characteristics—make it difficult to control users' access to the resource. Additionally, a person's use of the resource subtracts from the abilities of other people to use said resource. Karar (2017) asserts that groundwater management is a "wicked problem", as there are multiple stakeholders with goals that do not always align, as well as various uncertainties due to changing social, economic and ecological conditions surrounding a complex system hidden from plain view deep below the ground. It is this complexity and difficulty to identify solutions that qualifies groundwater as a wicked problem. Rittel and Webber (1973) identified a number of defining characteristics of wicked problems, such as:

- Wicked problems are difficult to formulate and define

- There is no way to test the solution to a wicked problem, and every solution is a "one-shot operation", as "every implemented solution…leaves traces that cannot be undone"
- All wicked problems are unique
- Planners are liable for the consequences of any efforts to address the wicked problem

As both a common pool resource and a wicked problem, effective groundwater governance can prove challenging to governments and communities with limited capacity, who may not be able to implement the technical, regulatory, economic and managerial instruments that can be mobilized to tackle groundwater issues. Another obstacle to effective groundwater governance is the complex relationship between groundwater recharge, surface water and groundwater watersheds, as they are not always aligned with each other, nor do they coincide with political boundaries (Winter et al., 2003). A watershed (also referred to as a catchment or drainage basin) is the delineation of an area of land that receives and channels rainfall and snowmelt into a waterbody (National Oceanic and Atmospheric Administration [NOAA], n.d.). Watersheds can be as small as an inland lake or they can be large enough to encompass rivers, lakes and reservoirs (NOAA, n.d.). While ground water hydrologists are typically concerned with aquifer systems, groundwater systems have watersheds as well, but they often do not align with surface watersheds (Winter et al., 2003). While watershed-based source water protection and policy approaches are gaining in popularity, Winter et al. (2003) argue that groundwater watersheds should receive equal consideration in management practices by "integrating groundwater into this 'systems' approach" but acknowledge the difficulty of doing so when surface water and groundwater watersheds do not necessarily align. Evidently, governing bodies concerned with protecting both groundwater and surface water face the challenge of managing resources which are interconnected functionally, separated physically, and which may extend beyond their borders and jurisdiction.

### 2.3.1 Groundwater Governance at the Federal Level

At the federal level, Environment Canada is the lead department responsible for groundwater, while Natural Resources Canada's responsibilities focus on developing a further understanding of groundwater systems, quantity and quality (Council of Ministers of the Environment [CCME], 2010). Other federal departments involved in groundwater issues include Health Canada, Public Services and Procurement Canada (formerly Public Works), Indigenous Services Canada (formerly the Department of Indian and Northern Affairs) for groundwater issues on First Nations land, Transport Canada and the Department of Fisheries and Oceans (CCME, 2010). Ocean conservation efforts, resource management, and international relations (managing transboundary waters) all lie within federal jurisdiction, in addition to the management of water located within federal parks, facilities, First Nation reserves, as well as in Nunavut and the Northwest Territories (Government of Canada, 2016b).

There are certain areas of groundwater governance where shared jurisdiction exists. The *Canada Water Act* establishes the need for collaboration between federal and provincial governments in water resource management efforts (Government of Canada, 2016b). These efforts include water regulation, monitoring and surveys, as well as the organization of sustainable water resource programs (Government of Canada, 2016b). Cost-sharing is typically used to fund these programs, with the federal and provincial governments each covering half the cost of the project (Government of Canada, 2016b). Another federal water law that pertains to groundwater is the *Fisheries Act,* which may be relevant when seeking to protect groundwater resources relied on by fish habitat, as well as the *Canadian Environmental Protection Act* which is concerned with toxic substances and pollution affecting water resources (Council of Canadian Academies, 2009).

### 2.3.2 Groundwater Governance at the Provincial Level

Canadian provincial and territorial governments (apart from Nunavut and the Northwest Territories) have primary jurisdiction over the majority of water management and protection responsibilities (Government of Canada, 2016b). According to the Government of Canada (2016b), the majority of water use permits and licenses are under the jurisdiction of provincial water management authorities.

Provinces are not only responsible for the regulation of groundwater supply and protection, but are also expected to direct the groundwater governance strategy for the province (Canadian Council, 2010). This includes enacting laws and regulations that support the effective management of groundwater, as well as coordinating funding, public education initiatives and technical studies (CCME, 2010). There is often collaboration with municipalities, conservation districts, and watershed and aquifer management boards to tackle various groundwater-related issues (CCME, 2010). Other collaborators may include groundwater associations, academic institutions, First Nations and industry (CCME, 2010). Responsibilities such as drinking water treatment/distribution or wastewater management are often delegated to municipalities (Government of Canada, 2016).

### 2.3.3 Groundwater Governance at the Municipal Level

In Newfoundland, municipal and provincial governments share responsibility for ensuring drinking water is safe and accessible, but the level of involvement municipalities have in groundwater management is constrained by their capacity (Eledi et al., 2017). Larger municipalities who have access to funding and are able to hire consultants can engage in more robust management efforts, whereas municipalities with a lack of resources and no access to technical experts or consultants will have difficulty making informed decisions surrounding management efforts (CCME, 2010). Under the Water Resources Act 2022, in order to protect their water supply areas as designated protected public water supply areas (PPWSA), municipalities must apply for designation to the Water Resources Management Division (WRMD) of the Department of Municipal Affairs and Environment (Eledi et al., 2017). For water supplies derived from groundwater, they are referred to as “wellhead protected water supply areas” (Eledi et al., 2017). Other municipal responsibilities include:

- Maintaining the operation of public water supply systems and testing for quality (Vodden et al., 2014)
- Enacting by-laws and regulations to protect water supply systems and areas (Vodden et al., 2014)

- Maintaining and posting signage around their PPSWAs and wellhead PPSWAs (Eledi et al., 2017)
- Regularly surveying the area and monitoring development activity within the PPWSA (Eledi et al., 2017)
- Informing the provincial government of any violations of the Water Resources Act (such as development activity without permits/authorization from the Minister) (Eledi et al., 2017)

In 2010, the Canadian Council of Ministers of the Environment (CCME) surveyed Canadian groundwater regulators, researchers, consultants, users and other stakeholders about "knowledge and knowledge gaps" of various groundwater concerns (such as groundwater governance, surface water and groundwater connections, etc.) (CCME, 2010). When asked about Canadian groundwater governance at the municipal level, some respondents felt that policy and leadership should be the primary responsibility of the province, with municipalities and conservation authorities overseeing the control and monitoring of groundwater resources since they are already involved with local land use planning, management and protection (CCME, 2010). In contrast to this view, other survey respondents felt that shifting this responsibility to municipalities "represents a downloading of provincial responsibilities" (p. 10) to local governments lacking the authority, funding or capacity to engage with these issues effectively (CCME, 2010). As an alternative, some respondents suggested groundwater management should be primarily a federal and provincial responsibility but with a municipal presence to advocate for the needs of local governments (CCME, 2010). The Council of Canadian Academies (2009) argues that the delegation of groundwater management from province to municipality is most likely to succeed if provinces ensure local governments have the funds and human resources to support these efforts, and the commitment to monitor and report their progress. Table 1 is a summary of federal, provincial and municipal groundwater responsibilities described in Section 2.3.1, 2.3.2, and 2.3.3**.**

Table 1: Groundwater Governance Responsibilities of Different Levels of Government (Source: Author's Construct)

| **Level of Government** | **Responsibilities Related to Groundwater Governance** |
|---|---|
| Federal | • Primarily responsible for groundwater<br>• responsibilities: ocean conservation efforts; resource management; the management of transboundary waters; management of water located within federal parks, facilities, First Nation Reserves and Nunavut and Northwest Territories<br>• relevant federal departments: Natural Resources Canada: (groundwater systems, quantity and quality monitoring), Health Canada, Public Services and Procurement Canada, Indigenous Services Canada (groundwater issues on First Nations Land), Transport Canada, Department of Fisheries and Oceans |
| Provincial | • primary jurisdiction over majority of water management and protection responsibilities within province<br>• responsible for regulation of groundwater supply and protection as well as groundwater management strategies for the province<br>o including enacting laws and regulations to support groundwater management<br>o collaborate with municipalities, conservation districts, groundwater associations, academic institutions, First Nations and industry |
| Municipal | • drinking water treatment/distribution and wastewater management often delegated by province<br>• role in management efforts varies based on municipal capacity |

Source: Adapted from Government of Canada (2016b); Canadian Council (2010); CCME (2010)

### 2.3.4 Barriers to Effective Groundwater Governance

In the survey conducted by CCME (2010) referenced in the previous section, respondents identified a number of difficulties faced by Canadian government departments tasked with groundwater management. A primary constraint to effective management is securing adequate funding to carry out their work (CCME, 2010). As funding for groundwater studies is procured on a case-by-case basis, there is a lack of funding available for the long-term programs needed to effectively manage and monitor groundwater over a sustained period of time (CCME, 2010). Another obstacle was a lack of resources and staff to carry out current management efforts (CCME, 2010).

As groundwater resources are managed by the federal, provincial and municipal government, complications arise when these three governing bodies have conflicting approaches and/or poor coordination (Council of Canadian Academies, 2009). For example, it may be the case that groundwater managed by the provincial government does not meet health guidelines for safe drinking water that a municipality relies on for drinking supply, due to poor coordination amongst provincial and municipal governments (Council of Canadian Academies, 2009). Additionally, it is increasingly difficult to manage groundwater when international transboundary issues come into play; laws, culture, policy approaches and socio-political conditions can differ significantly (Blomquist and Ingram, 2003).

Changes to surface water can be observed more easily than those occurring to groundwater. As aquifer sizes vary considerably, changes to groundwater conditions can occur from as quickly as a few seconds to as long as millions of years (Sophocleous, 2012, as cited in Kath and Dyer, 2017). This can make it difficult to monitor and assess management approaches, as managers may be discouraged when changes are not observed in groundwater systems (Kath and Dyer, 2017). Conversely, it may appear that groundwater systems are well-functioning, but only because there is a delayed response to negative impacts that have yet to manifest (Kath and Dyer, 2017). These false impressions can negatively affect policy and governance approaches if managers are unaware of these characteristics of groundwater (Kath and Dyer, 2017). A poor understanding of groundwater systems is a significant barrier to effective groundwater governance. As noted in Section 2.2.3, the understanding of the connection between groundwater and surface-water is "universally poor" (Evans, 2007, as cited in Kath and Dyer, 2017), as well as knowledge of water flows, quality, and the condition, size and permeability of aquifers (Kath and Dyer, 2017). It is difficult to make precise, strategic policy when there is a lack of data on the groundwater system.

### 2.4 Managing Municipal Natural Assets

Aquifers, wetlands, forests, streams, and riparian areas are all considered municipal natural assets as they provide valuable service functions to the municipality (Asset Management BC, 2019). These functions vary from waste treatment, water treatment and rainwater management to flood protection, recreation and habitat (Asset Management BC, 2019). They can also be referred to as "natural capital" (Municipal Natural Assets Inventory [MNAI], 2017a). The terms "natural asset" and "green infrastructure" are sometimes used interchangeably; however, the term "green infrastructure" encompasses a larger meaning than solely natural assets

(MNAI, 2017a). While "natural asset" refers specifically to natural resources and ecosystems that offer benefits to people, "green infrastructure" refers to human-made infrastructure engineered to mimic the services provided by natural assets, such as rain gardens, stormwater ponds, green walls and rain barrels (MNAI, 2017a).

Traditionally, asset management at the municipal level focused solely on human-made, engineered infrastructure (Asset Management BC, 2019). The word "asset" traditionally referred to infrastructures such as roads, bridges, water treatment facilities and piped infrastructure (MNAI, 2017a). Increasingly, awareness is growing around the importance of managing natural assets, as the services they provide work in conjunction with engineered infrastructure to serve community needs (Asset Management BC, 2019). For example, wetlands, forests and streams store rainwater and minimize flood damage, which relieves pressure from aging infrastructure that is overburdened by severe weather (Asset Management BC, 2019). According to the Municipal Natural Assets Initiative (MNAI), natural assets can provide equivalent services to those offered by engineered assets, and municipalities can save capital, operating costs and reduce risk by identifying and managing their natural assets (MNAI, 2017b).

According to MNAI (2017a), the process of managing natural assets can begin through either direct asset management, shared natural asset management, or indirectly via policies, bylaws, plans and guidelines that support the management of natural assets. The incentive to pay attention to these natural assets is growing due to a number of influencing factors, such as changing provincial legislative requirements, new criteria for federal Gas Tax grants, and new public sector accounting guidelines which have all led to municipalities needing to initiate natural asset management plans to follow these new standards (MNAI, 2017a). The goal is that local governments will be well-positioned to provide services to the community through the "proactive management of healthy natural assets" (Asset Management BC, 2019).

**2.5 Functional Resonance Analysis Method (FRAM) Overview**

The Functional Resonance Analysis Method (FRAM) is a method of modelling the functionality of a socio-technical system, developed by Erik Hollnagel in 2004 (Hollnagel and Slater, 2018). It models the technical, organizational and human elements of a system by focusing on functionality to understand the system's complexity and adaptability (Smith et al., 2020).

In a FRAM model, each function in a system is represented by a hexagon. Each hexagon has six "aspects" by which they can be connected to each other. The six aspects are: time, control, input, output, precondition and resource (Hollnagel and Slater, 2018). Figure 1 shows a FRAM hexagon labelled with the six aspects.

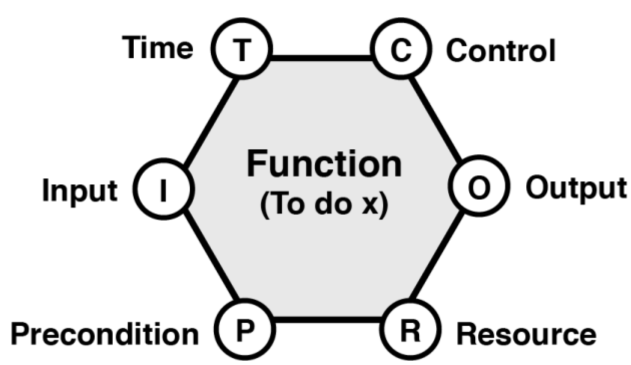



Figure 1: FRAM Hexagon Diagram (Source: Author's Construct)

To demonstrate how hexagons can be connected in a FRAM model, Figure 2 shows one portion of a FRAM model describing the process of brewing a cup of coffee. The output of Function C is that a filter is inserted into the coffee maker, which is the input for Function B, to fill filter with ground coffee—Function B can only occur after Function C has been carried out. However, Function B also needs a resource to be active—in this case, that resource is ground coffee. Therefore, in order for Function B (to fill filter with ground coffee) to occur, it needs an input from Function C and the resource supplied by Function A. To summarize, an input is something which activates a function, whereas a resource is something that is consumed by the function while active (Hollnagel and Slater, 2018). This is a simplified example of how functions in a FRAM model can be connected. More detail on how a FRAM model works can be found in Section 3.6.

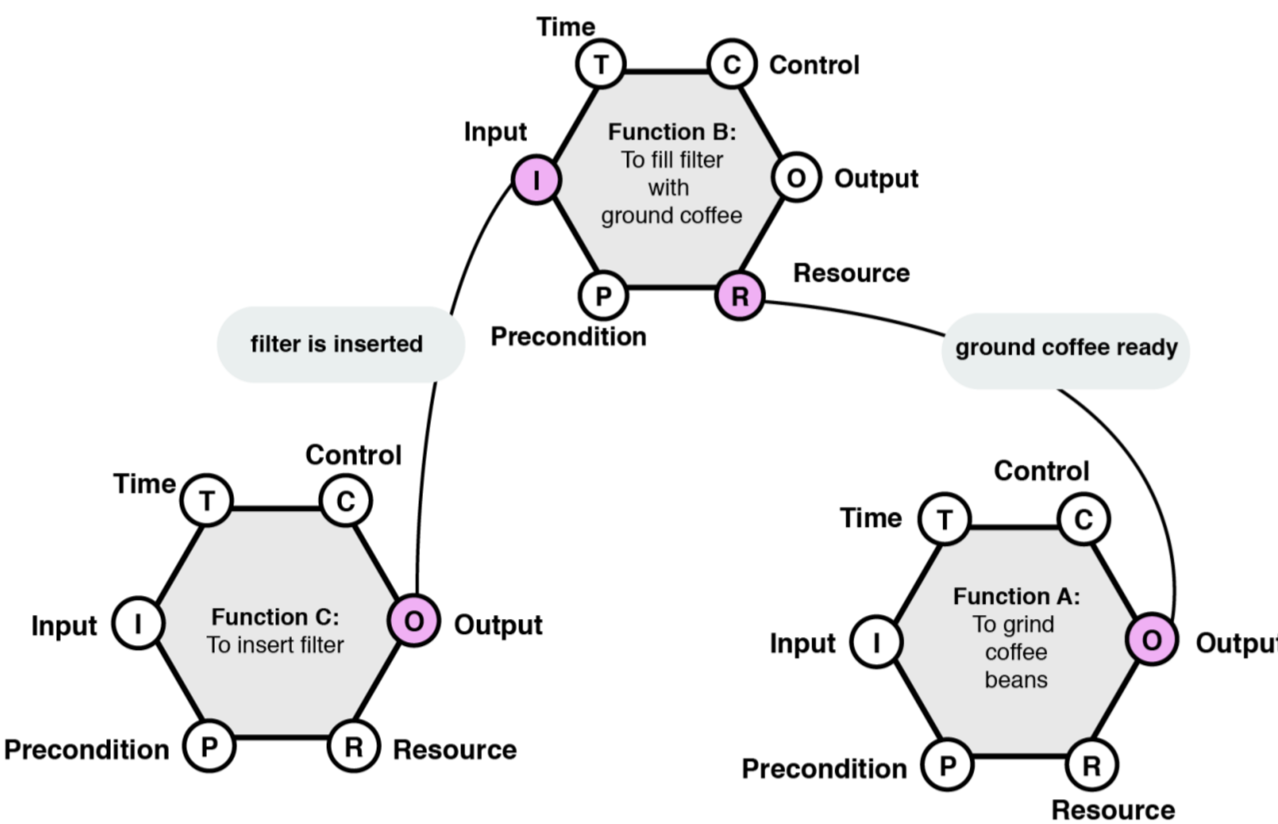



Figure 2: FRAM Model Coffee Example (Source: Author's Construct)

A major strength of the FRAM is that it provides a holistic view of a socio-technical system and its components, rather than reducing a system to its separate parts and functions (Hollnagel and Slater, 2018). One weakness of the method is the significant amount of time needed to develop a model due to the extensive qualitative data required (Hollnagel and Slater, 2018). It is through modelling a system's functionality and variability with the FRAM that a researcher can observe the functional relationships and patterns that might emerge from the model, which may shed light on the complexities associated with explaining system outcomes (Smith et al., 2020).

### *Functional Variability in FRAM Models*

FRAM models are used to observe the functional system structure as well as the variability related to the many ways it can function (Smith et al., 2020). The functions in a model map the possible ways work can be carried out in a system and the pathways connecting them, and functional variability can be observed in the outputs/pathways that actually occur (Smith et al., 2020). For instance, changing the output of one function could create an entirely new path in the model; after continually changing the output of that function to see new outcomes, a pattern might eventually be observed that could reveal something about how the system works. It is not necessarily desirable to eliminate all functional variability from a system; the variability of human components of a system sometimes allow them to adapt to changes in a system, making it more resilient (Smith et al., 2020).

Once a system's functions and their connections (their "aspects", described in deeper detail in Section 3.6) have been added to a FRAM model, a researcher can then begin to look at functional variability within the model. Functional variability can be observed:

- in the different outputs resulting from the work done by a function (Smith et al., 2020)
- in multiple functions, by observing how functions affect those that come after them in the model ("upstream" vs. "downstream" functions) (Smith et al., 2020)
- between functional signatures (described in the following section) (Smith et al., 2020)

A FRAM researcher can identify methods of monitoring and controlling the variability in a system once they have identified where it exists in the model (Smith et al., 2020). The process of identifying functional variability within a FRAM model is often iterative, as more data is collected and the model is refined (Smith et al., 2020). As Smith et al. (2020) put it succinctly, "…building the FRAM model provides an understanding of the potential ways that an operation could succeed", and functional variability can shed light on which pathways lead to which outcomes.

***Functional Signatures***

Functional Signatures are created from a FRAM model when a functional variation is observed after an event occurs, an output is identified, and this unique "signature" is recorded in a database. In this study, "functional signature" and "scenario" will be used interchangeably. These functional signatures are then grouped and organized based on their level of performance.

For example, a FRAM researcher is able to observe high-performance vs. low-performance groups to get a better understanding of how functional variability occurs within the system. Using the example of brewing a coffee, there may be a group of functional signatures where the coffee turns out perfectly, and a group of functional signatures where the coffee is always burnt. A researcher analyzing the model then notices that all the functional signatures where the coffee was brewed perfectly had a function where a kitchen timer was used, yet that function was not active in all the functional signatures where the coffee was burnt. Grouping outcomes in a systematic manner allowed the researcher to isolate a function that significantly affects the system's performance and outcomes. It is through this categorization that researchers can identify which functional signatures led to a desired outcome, so that it can be replicated in the future to repeat successful outcomes. The use of functional signatures in FRAM analyses has also been enhanced with the development of the DynaFRAM tool.

### *DynaFRAM Software*

While the FRAM is primarily a qualitative method, a tool called the DynaFRAM has been developed to be used in conjunction with the FRAM Model Visualiser (FMV) to help researchers observe and understand both qualitative and quantitative aspects of functional variability in the system (Salehi et al., 2021). While the FMV is used to create and visualize the FRAM model itself, the DynaFRAM allows a quantitative analysis through the ability to collect, record, and compare various functional signatures (Smith, n.d.). It also helps researchers observe the relationship between temporal variations, functions and the resulting outcomes (Salehi et al., 2021). The visual component of the program enables researchers to capture screenshots/videos of various possible scenarios/combinations of functions, and how they interact with each other in relation to time (Salehi et al., 2021).

#### *FRAM Applications*

A wide literature review aiming to look at all published FRAM research (in the English language) reviewed more than 1700 documents (Patriarca et al., 2020). The literature review showed that the majority of FRAM research pertained to aviation, healthcare, industrial operations and transportation domains such as maritime and railway (Patriarca et al., 2020). Only 3 studies applying the FRAM to urban planning have been published, but they were all concerned with transportation infrastructure. The FRAM is not typically used to look at the decision-making process taking place within a municipality, nor to map a political process.

### 2.6 Summary

This chapter has provided an overview of a number of topics central to the thesis of this study, including groundwater resource management and governance, wetland ecosystems, holistic groundwater and wetland management approaches, natural asset management and the FRAM method. This literature review was conducted to provide an understanding of these topics and how they are interconnected as a foundation for this study. It has also shed light on areas which have not received significant attention in academia but will be a focus of this research.

This thesis seeks to understand how the FRAM can be used to look at LBMCOC's decision making process surrounding wetland/groundwater issues. Since the FRAM not only looks at a system itself, but external influences on that system, it was the goal of the literature review to collect as much information as possible to provide context and understand not just the municipality, but the government structures it exists in, the state of wetlands and groundwater in the province, and the current approaches being taken to manage these resources. LBMCOC does not exist in a vacuum—in order to assess the success of their management approach, it is beneficial to understand the systems they are operating within.

Initially, the intent for this thesis was to use the FRAM to understand groundwater-related issues in a community. However, preliminary engagement revealed that the community of LBMCOC was managing their groundwater and wetland resources in tandem—solely focusing on groundwater in this study would not reflect the current approach taken by the municipality. The decision to consider wetland management alongside groundwater management was reinforced by findings from this literature review, which showed a number of academics and studies calling for a more integrated groundwater/wetland management approach. This includes the holistic framework approach, which promotes the management of groundwater and wetlands with recognition of their interconnectivity. The knowledge gap which this thesis seeks to address is the capability of the FRAM to describe policy and resource management-related decision making within a municipality, and it is the aim of this study to contribute to the body of knowledge on applications of the FRAM methodology. The FRAM itself can be considered a holistic tool, as it promotes viewing a socio-technical system in its entirely, including external factors and influences. Therefore, focusing on the holistic management of groundwater and wetland management is not only a contribution to literature on that approach, but is also aligned with the FRAM methodology.

# Chapter 3: Research Design and Methods

## 3.1 Methodology

An integral component of this research is to observe how the FRAM can be used to understand the decision-making processes of a municipality; therefore, the FRAM method influenced the methodological approach to this study.

This thesis will rely on qualitative data collected from a single case-study community. As a case study is an in-depth study with an emphasis on description and understanding (Davis, Lachlan and Westerfelhaus, 2017), it is an appropriate choice to be used in conjunction with the FRAM. Both the FRAM method and case studies rely on purposive or "selective" sampling, a process where a researcher relies on their judgment to select the appropriate case-study community and participants for the study (Davis, Lachlan and Westerfelhaus, 2017). Another similarity of the two methods is the process of the researcher immersing themselves in the case until they "have reached saturation—until no new insights, understandings, or descriptions occur" (Baxter and Jack, 2008 as cited in Davis, Lachlan and Westerfelhaus, 2017). While using the FRAM, it is important to analyze the data and work with the program until the researcher feels they have gained all possible insights the model has to offer.

An inductive approach—also referred to as grounded theory—will be taken, which begins with the researcher gathering data, observing it for patterns, and then developing theories based on what was observed (Davis, Lachlan, and Westerfelhaus, 2017). Starting with open research questions allows us to gather as much information as possible during the interview stage—information that may not immediately appear relevant to the study may later be useful when constructing the FRAM model. A thematic analysis will be conducted using data from the transcribed interviews to extract key points to be used in the FRAM model. The FRAM is based on the breadth-first principle, meaning it is more effective to describe all the functions before adding in detail (Hollnagel and Slater, 2018). Therefore, gathering a wide breadth of data, developing a hypothesis and then further refining the research approach is conducive to the FRAM method. A field work component was added to this study since—similar to ethnography—the time researchers spend in the field adds to their ability to understand and describe the case (Davis, Lachlan and Westerfelhaus, 2017).

Due to the extensive qualitative data necessary to populate a FRAM model, the time constraint of the master's thesis only permitted for one case study to be completed. If this project spanned a longer time period, it is likely that more insights would emerge from being able to compare and contrast the FRAM models of multiple case study communities, which could yield results relevant to municipalities other than LBMCOC. For this study, working with one case study community proved to fit well within the timeline of a master's thesis—participants with knowledge or experiences relevant to the scope of the study were contacted, and those who agreed to participate were interviewed to the point of data saturation.

### 3.2 Case Study Selection Process

The community of LBMCOC was chosen for the case study as it fit the criteria necessary for conducting the study. The primary criterion was that the case had to be a community in

Newfoundland currently facing a challenge in groundwater management that was within the scope of a master's thesis. It was important that the issue of groundwater governance was a present concern for the community with the hopes that the final research produced would be of some value to said community. Another requirement was that that the town show enthusiasm and willingness to collaborate with researchers. It takes significant effort and capacity to be able to take the time to work with researchers, and it is critical that community case-study work is not done at the expense of the community itself. Therefore, the ideal municipality would be one that has staff with the capacity and interest to participate, in order to avoid overburdening a smaller community with possibly overstretched volunteer staff. With these criteria in mind, a list was compiled of communities to contact and inquire about participation in the study. A town staff member from Logy Bay-Middle Cove-Outer Cove was enthusiastic about the research and agreed to participate in this study.

### 3.3 Overview of Case Study Municipality

#### *Town Background and History*

The town of Logy Bay-Middle Cove-Outer Cove (LBMCOC) is located on the northeastern coast of the Avalon Peninsula, just a 10-minute drive away from the city of St. John's (Bently and MacDonald, 2020). According to Statistics Canada (2016), as of 2016 LBMCOC had a population of 2,221 but that number is quickly growing.

The town was officially incorporated in 1986; however, its history dates further back in time (Pitt and Smallwood, 1997). The name "Logy Bay" was first seen on a map in 1675; it is believed that fishermen frequented the area in the seventeenth and eighteenth centuries, with permanent settlement beginning sometime around the early 1800s (Pitt and Smallwood, 1997). The word "logy" signifies feeling lethargic and sluggish, and it is believed this name was given to the town due to the heavy presence of cod in the area that would feel "logy" from eating large amounts of capelin (Pitt and Smallwood, 1997). Logy Bay's abundance of good farmland, as well as ease of access to fishing grounds from Torbay Point to Flat Rock Point attracted Irish immigrants whose culture and dialect have left a mark on the town to this day (Pitt and Smallwood, 1997). The community was relatively self-contained until 1827, when a road was developed linking the town to St. John's (Pitt and Smallwood, 1997). The two became increasingly connected in the early 1900s as roads and infrastructure expanded (Pitt and Smallwood, 1997). Logy Bay's fishing industry declined when fishermen were lost to American bases in World War II; however, a few commercial dairy farms remained (Pitt and Smallwood, 1997). It is now a popular destination for locals and visitors alike who are drawn by the annual capelin roll, the arrival of capelin that swim to shore every summer to spawn, signaling the beginning of summer weather (Newfoundland and Labrador, n.d.). Today, LBMCOC is a town that prides itself on its rural living located conveniently close to the city but is grappling with an increasing population and development pressures.

### ***LBMCOC Today***

Bishop and Blanchard (2009) note that the town's agricultural history can still be felt—a great deal of residents partake in hobby farming—however, many of the farms that once populated the town have now been converted into large, un-serviced residential lots. No significant commercial development has taken place in the town, as residents are able to access resources and amenities from neighbouring municipalities, specifically St. John's (Bishop and Blanchard, 2009). When faced with the decision of installing piped infrastructure and a sewage system, the town declined, choosing to remain an un-serviced community (Bishop and Blanchard, 2009). This decision was made to constrain growth in the community in order to maintain the low-density, rural lifestyle highly valued by the community members of LBMCOC (Bishop and Blanchard, 2009). This decision would also save the town from significant infrastructure costs associated with the maintenance of piped services.

While LBMCOC has made efforts to stay rural, the town still faces pressures from a growing population and expanding development, placing stress on its natural infrastructure. It has been observed that the conversion of natural landscape into rural residential lots has led to an increase in impervious surfaces which can contribute to increased storm water run-off, higher water levels and flood risks (Bently and MacDonald, 2020). In an effort to prevent the further degradation of natural assets in the town, the Municipal Plan and Development regulations were amended with conservation and asset management in mind (Bentley and MacDonald, 2020). These assets include floodplains located near areas such as Kennedys Brook, Soldier's Brook and Drukens River, and wetlands that are integral for flood control, groundwater recharge, and biodiversity support amongst many other functions (Bentley and MacDonald, 2020). The inventory, management and protection of these assets was completed by the town who recognized their importance in ensuring the sustainability of their groundwater supply (Bentley and MacDonald, 2020). As mentioned earlier, LBMCOC refused piped infrastructure and sewer systems with the intent to rely on solely groundwater as the water source for the community. There are no surface water sources located within the municipal boundaries, therefore it is paramount that they ensure groundwater resources are not used beyond their yield. Managing and protecting wetlands in the community plays a key role in groundwater conservation, as explained in detail in Section 2.4.2 of the literature review.

### 3.4 Data Collection

Before beginning the data collection phase, approval by the Grenfell Campus Research Ethics Board (GC-REB) was received for GC-REB File Number 20222792. The research materials and protocols described in this section were approved by the ethics board before being used in this study.

The data collection process began with preliminary engagement with LBMCOC to identify their most pressing issues and develop a strategy for our collaboration. This preliminary engagement consisted of informal conversations to direct the scope of the research and was not considered formal data collection, although it was helpful in identifying key informants who held knowledge relevant to the study. This included identifying the key problem to focus on in our research and the appropriate scope of the project, which was the issue of wetland development in the community. Key informants identified challenges related to the shift in responsibility from the provincial government onto municipalities, now tasked with approving or denying development permits to alter a body of water. For example, large-scale lot developments such as subdivisions that are to be built on or adjacent to a body of water (this includes wetlands) require a Section 48 permit issued by the Water Resources Management Division before construction can begin (Government of Newfoundland, n.d.). Throughout the formal data collection phase, multiple interviewees shared that in the past, the responsibility of issuing permits belonged primarily to the provincial government, after which municipalities could approve or decline. Due to reorganization at the provincial level, the onus was now on municipalities to make decisions about large-scale developments in their boundaries. As a result, LBMCOC—along with every other municipality in the province—found themselves at the helm of a process they lacked the expertise, knowledge, or capacity to effectively participate in. Since protecting wetlands from development is integral to groundwater protection, a valuable resource for LBMCOC, they took a number of measures to equip themselves with the tools and data to make better-informed decisions about development in the municipality.

It is one of the aims of this study to understand the implications surrounding the downloading of responsibilities from the provincial to the municipal level. Now that the primary focus of the thesis had been identified through preliminary engagement with the community, the next step was to proceed with the research design, proposal, and ethics review process before engaging in formal data collection consisting of interviews. The purpose of these interviews was to collect data that could be used to build a FRAM model. This requires speaking to interviewees who are knowledgeable and work within the system we are describing—in this case, that would be those involved with the decision-making processes that affect the community, and community members themselves. Participants that were likely to yield valuable data for the model included municipal town staff, LBMCOC residents involved in the community, developers who had experience dealing with the municipality, provincial employees involved in decisions affecting the town, and external groups which had influence on the town's decision processes, such as the federal government or environmental advocacy organizations. The goal of the interviews was to collect as much detailed data as possible regarding the work done by different people within the system, to be able to develop an approximate model reflecting how decisions are made and how processes such as decision making, approvals, assessments and policy creation are carried out by different groups within LBMCOC. Figure 3 shows the steps taken for the data collection process, beginning with the preliminary research phase up to the data analysis phase.

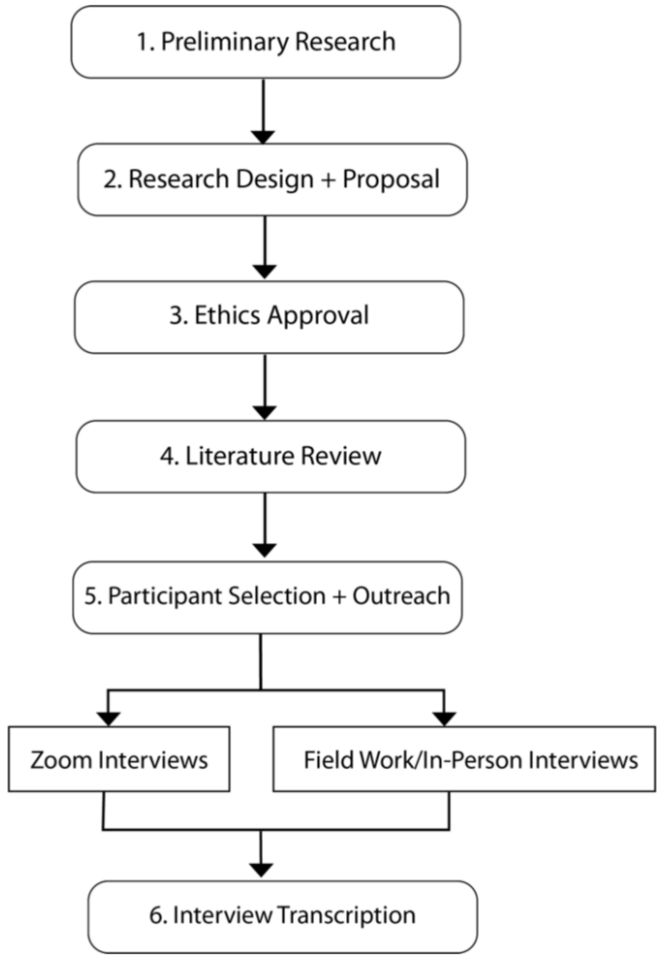



Figure 3: Research Steps Flow Chart (Source: Author's Construct)

***Participant Selection***

After identifying the focus of the study, academic literature, online municipal information, government reports and policy documents were gathered and read to learn more about LBMCOC, their community history, policy challenges and staff structure in preparation for the research proposal phase. Once the ethics approval was received and a literature review was conducted to familiarize myself with the themes of the study, the participant selection and outreach phase began. The process of selecting participants was directly informed by the FRAM methodology, which, as mentioned in Section 3.1, employs “selective” sampling. This is due to the nature of the method which requires researchers to select participants who carry out specific functions in the system and understand it well. Recruiting participants who do not have expertise or any participation in the socio-technical system being described would yield data outside the scope of the model. Snowball sampling was employed as a secondary sampling method once interviews began, as numerous participants offered to put me in touch with other contacts they felt would be an asset to the study.

Participants deemed relevant to the scope of the study were contacted via email using a pre-written recruitment text approved by the Grenfell Campus Research Ethics Board, informing them of the details of the study, the format of the interview, and contact information for the supervisors of the study, ethics board, and principal investigator (myself). The recruitment text can be found in Appendix I. When participants responded confirming they would like to participate, they were sent a consent form approved by the Grenfell Campus Research Ethics Board that was to be signed before the commencement of the interview. This consent form can be found in Appendix II. If the forms were not signed, then verbal confirmation was recorded before beginning the interview.

All the participants were to be either from Logy Bay-Middle Cove-Outer Cove (the case study community) or working with the town in some capacity. A list was created of potential participants who might have knowledge relevant to the scope of the study. These included town council members, residents of the community, developers, Provincial and Federal government employees. The semi-structured interview questions varied based on the expertise of the participant. For example, interviews with town council members and employees in other levels of government focused on how issues make it to the agenda, what difficulties they face in decision-making and collaborating with various levels of government, and how they are approaching solutions to present and future groundwater-related issues. Community members were asked about their perception of how issues are handled within the community, their concerns regarding groundwater and wetland management and whether they feel these issues are being adequately addressed. Data collected from participants was used to develop the FRAM model, using the FRAM methodology. As we are building a holistic map of how the community operates, it was necessary to engage in targeted recruitment, contacting the specific people who carry out specific functions in the system. For example, town council members provide a valuable yet different perspective than Provincial employees, but all of this data helps us develop a well-informed FRAM model. As these individuals are directly involved in the community, they are considered experts in the socio-technical system we are analyzing.

***Interview process***

At the time of conducting this study, COVID restrictions in different parts of Canada were beginning to be lifted, but the possibility of restrictions returning was looming. To accommodate for this uncertainty, participants were offered the option to conduct interviews virtually through a video call application or in-person (should restrictions allow). Interviews conducted online were recorded through the software (the application ZOOM was used) following verbal consent from the interviewee. In-person interviews were recorded using a handheld recording device if the interviewee agreed to being recorded. Before every interview, the participant was asked to confirm that they had read through and agreed to the consent form approved by the Ethics Board. They were also reminded of the anonymity and confidentiality of the interview, as well as the protection of the data recorded from the interview.

Once the interview began, participants were asked questions from the Ethics Board-approved interview guide which was in a semi-structured interview format. This format helped keep all interviews consistent by following a similar structure, but the semi-structured nature gave room for more open conversations should participants feel inclined to share information outside the scope of the question. This often led to unanticipated insights that would later prove to be valuable in the data analysis phase. Even data that was not eventually used in the study still offered important context for someone like me who resides outside of the case study community but aims to understand how it operates. The interview length was determined by the availability of the participants, which ranged from thirty minutes to a total of an hour and a half. A total of six participants were interviewed for this study. Due to this small number of participants, it is possible that there may be missing opinions and perspectives not represented in this research. However, interviews were conducted until everyone available—who was relevant to the study at the scope determined for this thesis—had been interviewed. Additionally, the data from the interviews was supplemented by other methods to provide information for the model, including a site visit to the community. The semi-structured interview guide can be found in Appendix III.

### *Field Work Component*

It was imperative that the community be visited in person to experience it and gather more context for the research. The duration of the field work in LBMCOC was one week in May 2022. The accommodation used for the trip was reflective of the community: a quaint house on a large lot with a bee farm, chicken coop and vegetable garden. Hobby farming was visibly present on many residential lots, as mentioned in Section 3.3. The drive from St. John's was indeed brief, and the shift from urban city to rural was quick yet visible. Conducting interviews in person added a new dynamic to interviews, allowing meaningful connections to take place with community members. Having to work remotely due to COVID, it has been evident how physical distance can leave one feeling removed from the work. By being physically present in the town, there were more opportunities for casual conversations with locals that eventually led to leads for possible interviewees, as well as information that would not have been available online.

## 3.5 Data Analysis

One of the research questions driving this study is: "How can the FRAM be used to understand the decision-making processes made across an entire community in regard to groundwater and wetland management?" This question will be answered through the process of the study itself. The data analysis phase involves looking at the data collected from the interviews, extracting information relevant to the themes of the study and using it to develop a FRAM model of the town's groundwater and wetland management processes. It is in working with this data, looking at the model and seeing what insights emerge that we can understand whether the FRAM is a tool that can be effective in understanding the decision-making process of a municipality.

### *Qualitative Analysis*

The first step in the data analysis process was a thematic analysis. Once the audio recordings from all the interviews were transcribed, it was easier to read through the documents to quickly gain an understanding of what was discussed, as well as refer to specific details mentioned by interviewees that would be used for developing the FRAM model. After an initial reading, each interview transcript was scanned repeatedly for any information that could be used in the FRAM model, which was then highlighted. Quotes that conveyed participant's attitudes and feelings towards certain issues were highlighted in yellow to be used throughout the report. Any information given by interviewees that described work being done (that could be converted into a function in the FRAM) within the scope of groundwater/wetland management and policy were highlighted blue. After reading and highlighting key information in the transcripts, a number of themes emerged; these include low capacity, community support, rural lifestyle, external support, science-based evidence, development pressures and funding (any transcript text aligned with a theme was highlighted a specific color for easier identification). For example, there were a number of instances were interviewees mentioned that many LBMCOC staff and residents had the desire to protect groundwater sources in order to sustain a low-density, rural lifestyle.

One LBMCOC resident said:

> The opening statement [of the waterbody study] says we are a rural community by choice. And that says it all to me. The people who have stepped forward to leadership positions on the town council since the town was incorporated, all had a desire to see the town maintain its rural character going forward. So that was really never a question.

A town staff participant stated:

> We really emphasize that rural living community feel and there's nobody that I've ever encountered in my time here that wants to turn this community into like a piped service, more city-type style. Yeah, they really want to maintain everybody's private large, one-acre pieces with your own well, your own septic, and in order to maintain that feeling in this community, we have to know that we have the natural assets and natural resources to sustain that.

These quotes are two of many describing similar sentiments. It quickly became clear that maintaining a rural community was motivation for the town's diligent groundwater and wetland management. This became the starting point for the FRAM model, as it led to questions about the type of work that was done in order for these decisions to be made (FRAM functions can only describe work being done in a system). Information gathered from interviews revealed that LBMCOC had refused piped infrastructure, a multi-level groundwater study was conducted to ensure groundwater was a viable source of water for the community, and so the town chose to rely on groundwater (as no headwaters are located within their community boundary). This information was then converted into the functions: "To assess headwaters in community boundary", "To conduct multi-level groundwater study" and "To adopt well and septic policy". This process of identifying themes, collected and highlighting evidence of those themes in interview transcripts and interpreting them into the FRAM model was repeated until it appeared all relevant themes had been extracted from the data and the structure of a rudimentary FRAM model was established. The FRAM model construction process is described in detail in the next section.

The next step was to look at the FRAM model and develop questions based on what was not explained by the current model. Then for the next round of participants (three participants were interviewed each round), questions addressing the knowledge gaps identified would be asked to collect data to further complete the model. The FRAM process is iterative, and it is often necessary to oscillate between interviews and the model to continually tweak and refine it. When the FRAM appeared robust enough to be used for analysis—while still within the scope of the study—the DynaFRAM program (a complementary tool to the FMV) was used. The DynaFRAM allows researchers to observe functional variability in the system, by playing out different scenarios and outcomes in the model based on Excel sheet data inputted by the researcher. For example, on the spreadsheet one can experiment with temporal variations in the functions to observe how different paths occur as a result. Similarly, altering when functions begin or how long they occur for can shed light on the relationships of various functions and how they affect each other. The results of the DynaFRAM scenario experiments will be described in detail in the Results and Discussions section. The results were used to answer research question 3 (the implications of increased municipal responsibilities around groundwater/wetland management) and research question 4 (what factors explain the success of LBMCOC's approach). This entire data analysis process has been summarized in Figure 4.

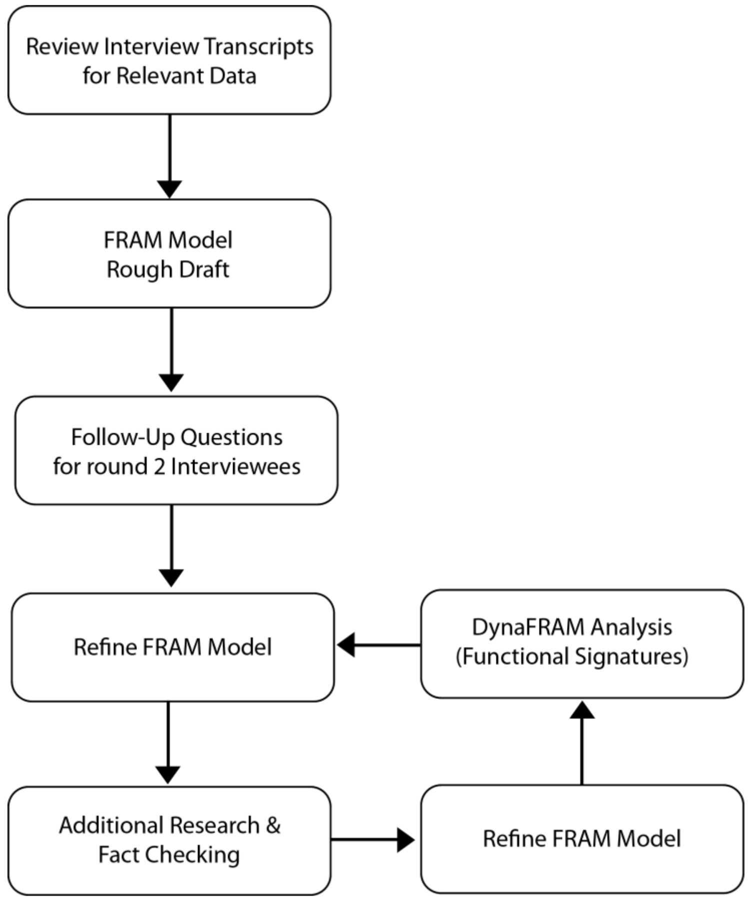



Figure 4: Data Analysis Flow Chart (Author's Construct)

Once the "Refine FRAM Model" phase was entered, the cycle repeated until the model included all relevant data from the interviews, was a close approximation of the system, and contained enough detail to support a DynaFRAM analysis to assist in answering the research questions.

## 3.6 Building a FRAM Model

To create a FRAM model, the researcher must first collect qualitative data from those in the system with an expertise in how it operates in order to identify the system's functions (Hollnagel and Slater, 2018). While visually the model appears similar to a cause-and-effect flow chart, it is important to keep in mind that its functionality differs greatly, and that FRAM models are not linear (Hollnagel and Slater, 2018). Each FRAM function is represented by a hexagon, and all the hexagons are connected by lines indicating their relationship to each other (Hollnagel and Slater, 2018).

### *How to Build a FRAM Model*

The first step in creating a FRAM model is to identify the functions necessary for the system to perform (Hollnagel and Slater, 2018). It must be noted that the method operates on the "breadth-first principle", where emphasis is placed on identifying all the functions first before describing them in detail (Hollnagel and Slater, 2018). Then the aspects of each function are to be identified (however, it is not necessary—nor possible—to identify every aspect). Figure 5) depicts these six aspects around a hexagon, which represents a single "function" in a FRAM model.

There are six aspects:

1. Input (I). Input refers to something that is used by the function in order to produce the output (Hollnagel and Slater, 2018).

2. Output (O). Output is the result of the work done by the function (Hollnagel and Slater, 2018).

3. Precondition (P). A condition necessary for another function to be executed (Hollnagel and Slater, 2018).

4. Resource (R). Something needed to be consumed by the function in order to do work (Hollnagel and Slater, 2018).

5. Control (C). A control function is anything that regulates or monitors another function resulting in a specific output (Hollnagel and Slater, 2018).

6. Time (T). The time aspect shows the affect temporal variation (the start time, end time or duration of a function) has on a function (Hollnagel and Slater, 2018).

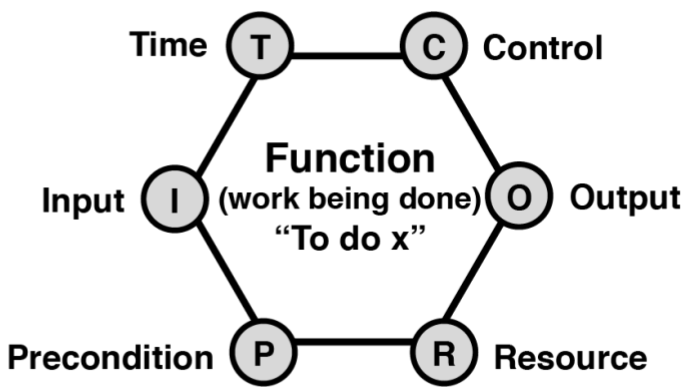



Figure 5: FRAM Function and Aspect Diagram
(Source: Author's Construct)

Figure 6 shows one example of how different functions in a model can be connected. In this example, Function A's output is a precondition to Function B, meaning Function B cannot do work until Function A's output occurs. Afterwards, Function B is able to do work to produce an output needed for Function C to occur.

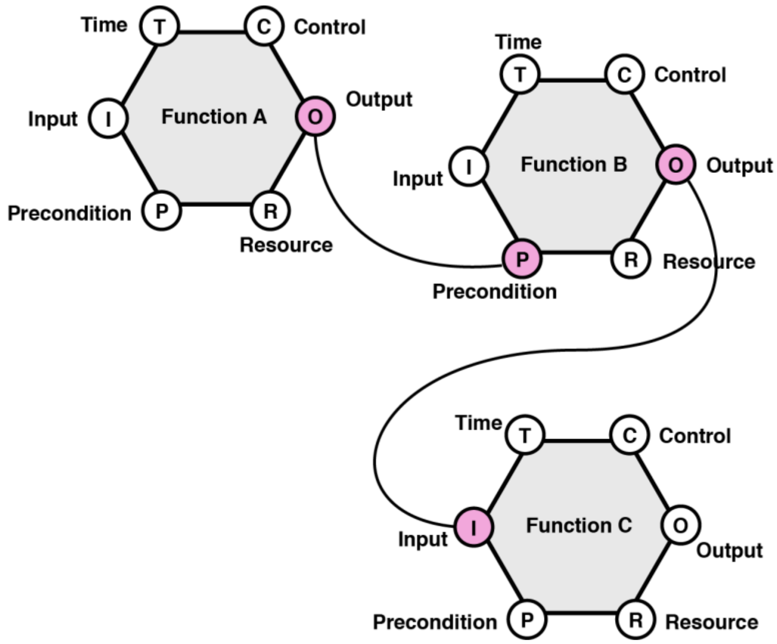



Figure 6: Example of FRAM Function Connections
(Source: Author's Construct)

The relationships between functions, their aspects, and how they are interconnected may become clearer as the map is increasingly populated by hexagons connected to each other in various ways. FRAM researchers can solely use the FRAM Model Visualiser (FMV) to conduct an analysis; however, the DynaFRAM tool offers a unique way to look at functional variability in the model. Running through various scenarios (used interchangeably with "functional signatures"), observing the differences in outcomes, playing with the orientation of functions and asking questions about the model are some of the ways researchers can begin to gain insight into the system. Figure 7 shows a screenshot of the DynaFRAM software program. The white hexagon functions show the base FRAM model, and the orange hexagons and newly created orange pathways show the new functional signature that has occurred within the model. The

DynaFRAM allows user to visualize new pathways and different outcomes within the model, as well as track and record functional signatures to better understand variability in the system.

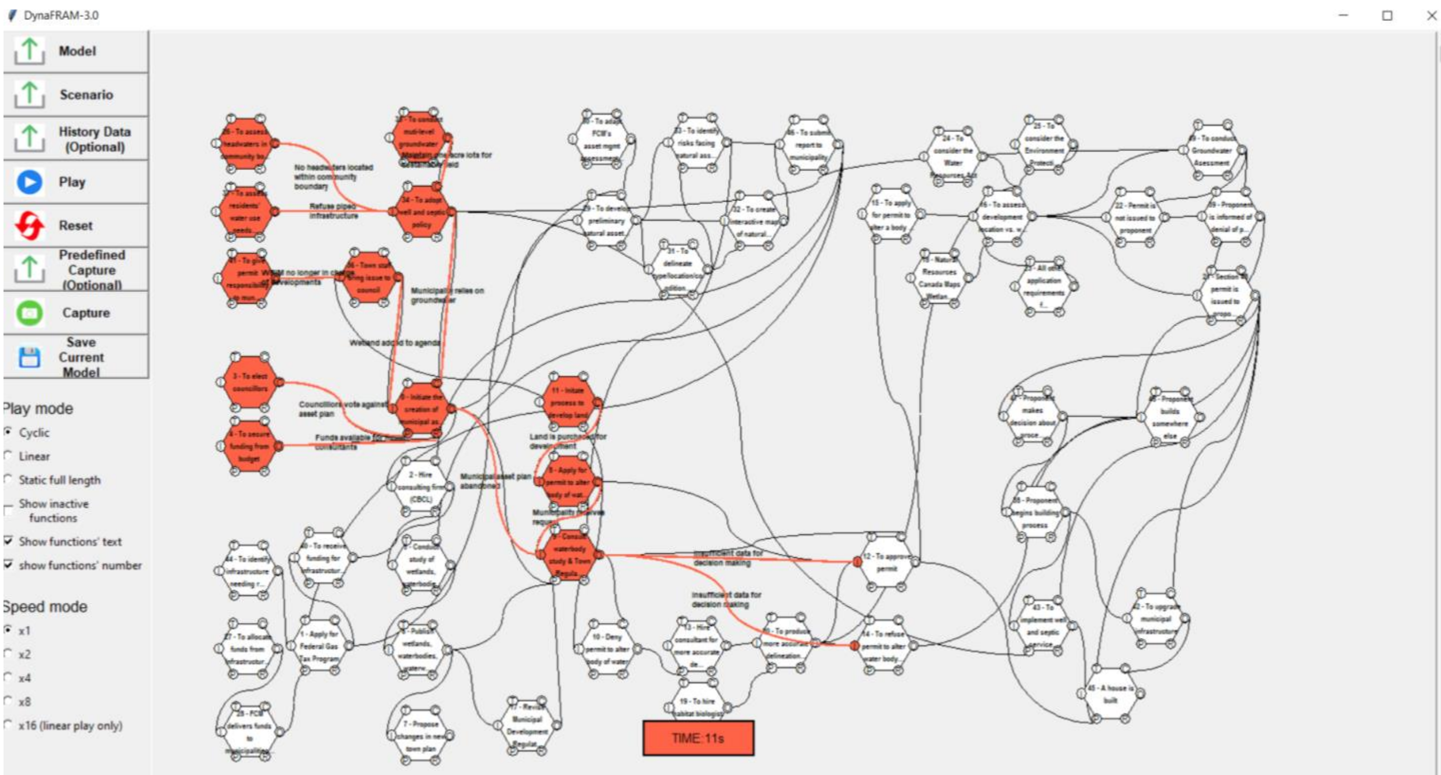



Figure 7: DynaFRAM Software Screenshot (Source: Author's Construct)

There may be some instances where variability results in what we might consider positive or negative outcomes, which can be either “dampened” or “amplified” to lead to a desired outcome (Hollnagel and Slater, 2018). Looking at these factors helps researchers understand the resiliency of a system, and its ability (or inability) to adapt to variability (Hollnagel and Slater, 2018). A FRAM model is never truly complete, as it is only an approximation of the real socio-technical system; however, its true value lies in the ability of a researcher to interpret and discover insights in a system using the model as a visualization. It is at the discretion of the researcher to define the breadth, scope and detail of the model (Hollnagel and Slater, 2018).

The FRAM's methodological contribution is threefold:

- it informs the structure and methodological approach of this study
- it serves as a visual guide, condensing complex information into an easy-to-read map that helps researchers digest large amounts of data quickly
- the functional signature analysis completed using the DynaFRAM program can reveal nuances in a system's operations that may otherwise have gone unnoticed

Decision-making processes are rarely linear and straightforward; the FRAM will first allow us to make sense of what the system looks like and how it works, before we can attempt to answer the research questions. Table 2 summarizes the research questions driving this study and how the FRAM methodology will assist in answering them.

Table 2: FRAM Methodology for Answering Research Questions (Source: Author's Construct)

<table>
<tr><th>Research Questions</th><th>Analysis Method</th></tr>
<tr><td>1. How can the FRAM be used to understand the decision-making processes made across an entire community in regard to groundwater and wetland management?</td><td><ul><li>the thesis itself is an exploration of whether the FRAM can be used in a community context<ul><li>explored in the methods, data analysis, results and discussions sections of this study</li><li>the thesis will conclude with reflection on effectiveness of FRAM in study context</li></ul></li><li>qualitative analysis used to interpret interview data and extract functions to be used in the FRAM model<ul><li>thematic analysis: themes identified in the transcripts used to shape scope of FRAM model and reveal what work was being done</li></ul></li></ul></td></tr>
<tr><td>2. What are LBMCOC's information and decision processes around groundwater and wetland management?</td><td><ul><li>transcripts are reviewed to see where participants mention sources of information/data used for decision-making processes<ul><li>i.e. information such as community feedback, data from consulting firms/municipal planner, municipal documents, etc.</li></ul></li><li>this information is added to FRAM model</li><li>helps to understand reasoning behind LBMCOC's actions/decisions</li></ul></td></tr>
<tr><td>3. What are the implications of increased municipal responsibilities around groundwater and wetland management in Logy Bay-Middle Cove-Outer Cove?</td><td rowspan="2"><ul><li>these research questions will be answered using the DynaFRAM program<ul><li>looking at different scenarios (functional signatures) to see which functions affect what outcomes (i.e. observing how provincial functions affect the municipal permit approval process)</li></ul></li></ul></td></tr>
<tr><td>4. What factors (drivers and constraints) explain the success of groundwater and wetland management in the community?</td></tr>
</table>

| | |
|---|---|
| | ◦ enables us to understand strengths/weaknesses in the system<br>◦ observe varying importance of functions<br><br>• the DynaFRAM analysis is driven by questions about the model which could shed light on the research questions<br><br>◦ i.e. "What happens if the municipality rejects a permit?", "If LBMCOC didn't have their own wetland delineations, what would the model look like?", "Do the provincial maps and delineations affect municipal decisions?"<br><br>• these exploratory questions assist with looking at the system critically and finding areas of uncertainty in the model that require more analysis<br><br>• DynaFRAM analysis is carried out until new information about the model is realized which helps in answering research question 3 and 4 |
| 5. What best practices can be drawn from this case for potential use by other communities in Newfoundland? | • Results from research question 4 are extrapolated to apply to other municipalities<br><br>◦ recommendations for other municipalities can be made once we can demonstrate—using the FRAM—which functions in the model contributed to LBMCOC's successful management efforts |

# Chapter 4: Results

This section will explore the results and findings from the FRAM analysis conducted on the community of LBMCOC. First, an overview will be provided of the complete FRAM model to show the entirety of the system and observe the scope/boundaries of the model. Subsequent sections will be organized based on the research questions outlined in Section 1.3, meanwhile this entire analysis endeavours to implicitly answer the first research question, “How can the FRAM be used to understand the decision-making processes made across an entire community in regard to groundwater and wetland management?”.

The FRAM is a novel tool that has emerged from the discipline of engineering, yet in this study it is being used to model social functions. While every effort has been taken to present these materials in an understandable way, the methods used in this thesis are likely to be unfamiliar to most audiences. It is not expected that the reader understands each step of the model at first glance, nor be able to immediately look at and successfully interpret an entire FRAM model. Rather, it is recommended that readers instead rely primarily on the accompanying explanations to assist in understanding the results. Readers may prefer to read the discussion in Chapter 5 to gain a better understanding of the content described in the FRAM before returning to the results section.

### 4.1 Research Question 1: How can the FRAM be used to understand the decision-making processes made across an entire community?

This chapter presents the FRAM model generated using data from the semi-structured interviews conducted with LBMCOC residents, developers, town staff and provincial government employees. The audio recordings from these semi-structured interviews were transcribed for ease of analysis. Then the transcriptions were scanned for data that appeared relevant to the research questions and helpful to include in the model. Throughout the analysis phase, the FRAM model was continually refined, and the transcripts were revisited often to ensure all relevant data was included in the model.

Figure 8 is a simplified flow chart version of the FRAM model that can be used to get a general understanding of the model before viewing it in higher detail. The colours and orientations of the boxes correlate to the colour-coded functions used in the FRAM model. Since the FRAM model (Figure 9) itself is quite large, it has been divided into colour-coded sections to assist with readability. Below the model is a legend to identify the meaning of the various colours. The purple section contains functions carried out by the municipality, the pink section is functions carried out by the Municipal Natural Assets Initiative (MNAI), the yellow section is federal government functions, green is provincial and the blue section shows functions that would be carried out by a developer looking to build a subdivision. The functions themselves are colour-coded to correspond to these categories. As work is sometimes done by various groups, it is not uncommon to find a function of one colour in a different coloured section. A text version of the FRAM model which has been exported directly from the FRAM Model Visualiser (FMV) program can be found in Appendix IV. Some readers may find it helpful to quickly review the text version if the visual model is difficult to interpret.

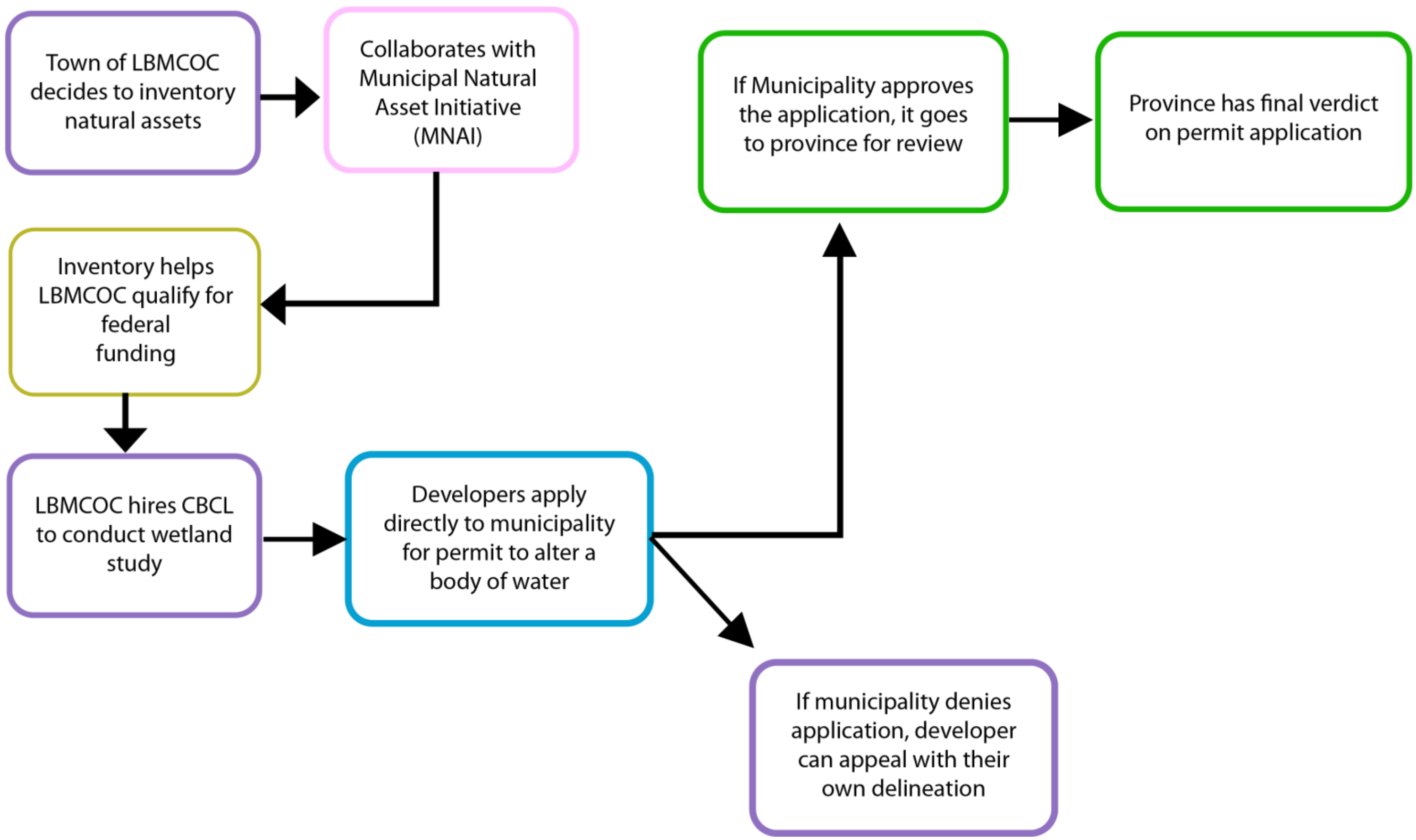
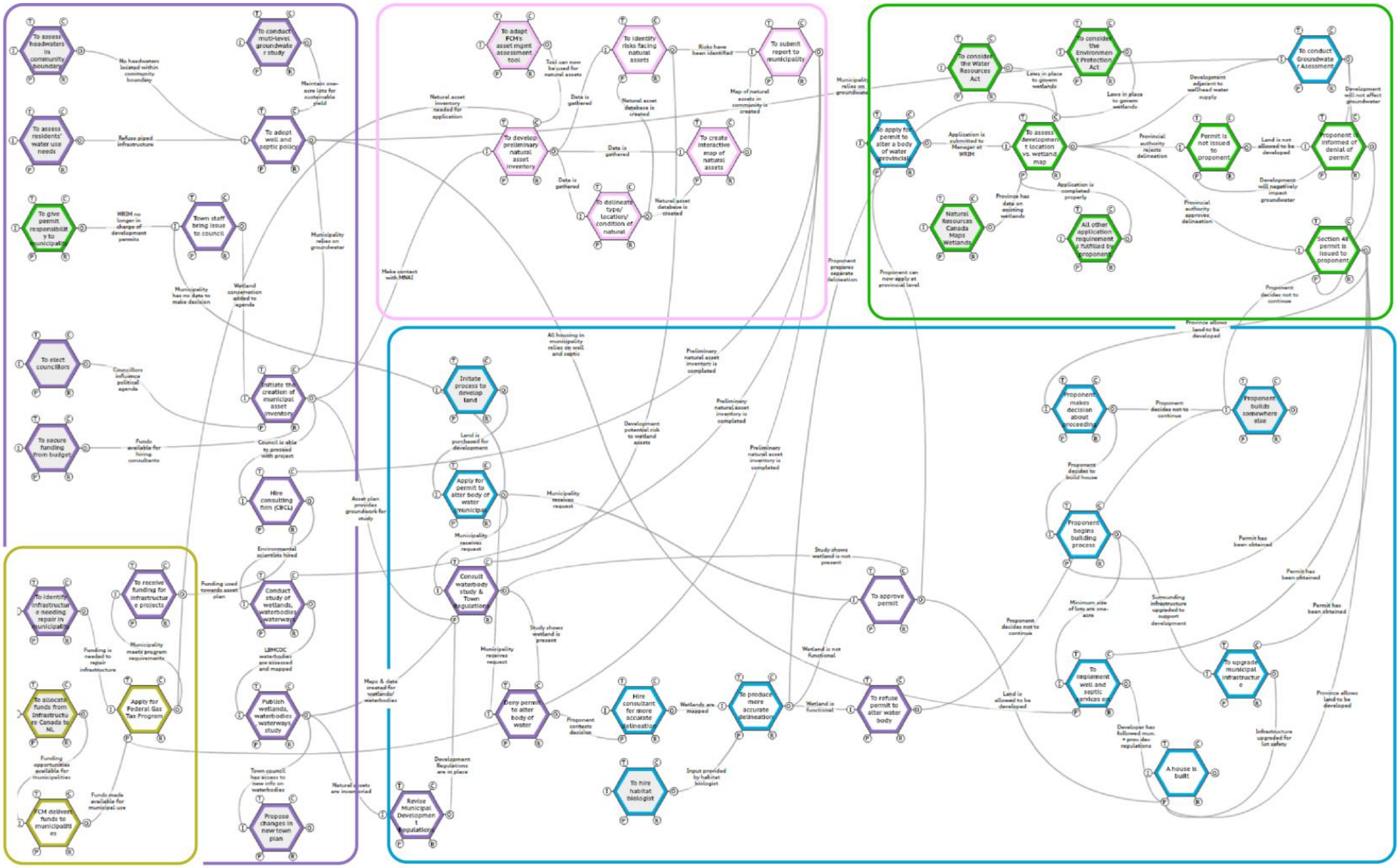



Figure 8: Flow Chart Guide to FRAM Model (Source: Author's Construct)



**Colour Legend:**

- Municipal Functions
- Provincial Functions
- Federal Functions
- MNAI Functions
- Developer (Proponent) Functions

Figure 9: FRAM Model Overview (Source: Author's Construct)

In the preliminary engagement with the community, when asked about the biggest challenge in groundwater governance, participants shared that a current obstacle they were facing was the downloading of responsibility onto the municipality to screen development permits affecting wetlands within municipal boundaries. As made evident in the literature review, groundwater and wetland health are interconnected. The loss of wetlands would lead to diminished groundwater recharge rates, a lack of water purification, sediment retention and storm protection, amongst many other factors that affect groundwater quality and availability as described in depth in Section 2.4.2 (Bruneau, 2017). Therefore, in protecting wetland health, they are also protecting valuable groundwater resources, and so the issue of wetland management falls within the scope of this thesis.

The FRAM model contains a number of processes carried out by various stakeholders which all influence wetland management. The functions at the top-left corner of the model describe the various conditions that eventually led to LBMCOC developing their own municipal natural asset plan. This includes reaching out to MNAI, a not-for-profit that empowers municipalities with “scientific, economic and municipal expertise” to assist them with the identification and management of natural assets (MNAI, n.d.). The yellow section at the bottom-left corner of the model shows how federal grant programs incentivize the inventory of natural assets (in addition to municipal infrastructure assets), which contributed to LBMCOC’s decision to take on the natural asset inventory project. The blue section shows the process of a developer applying for a permit to alter a body of water, first at the municipal level, and then—if approved by the municipality—in the top-right corner at the provincial level. Whether the permit is approved or not by the province determines which functions are active at the bottom-right corner in the blue section. For example, if the permit is approved, the function “proponent begins building process” is active, but if the province denies the application, the function “proponent builds somewhere else” will become active instead.

The following sections will look at multiple scenarios (created with the DynaFRAM program) that could take place within the model, where various combinations of functions lead to different outcomes. Observing these relationships and how these paths are affected by time, duration, or the activity of different functions will help us in understanding how the system operates as a whole and answer the research questions driving this study.

***FRAM Scenario Demonstration***

Figures 10 through 12 are snapshots showing the progression of a hypothetical scenario outputted by the DynaFRAM program. In this thesis, FRAM model images are shown using either the FRAM Model Visualiser program which uses a variety of colours to identify different functions, or the orange and grey DynaFRAM snapshots which show functional signatures. Both types of visuals will be used depending on what is being shown/demonstrated in the figure. This scenario will be dissected to demonstrate how to interpret a FRAM model, therefore the FMV will be used to help identify the individual functions. It will also illustrate one potential outcome of the model.

When a function is “active”, it is doing work and will be highlighted purple to make that visible for the user. The DynaFRAM displays scenarios as a video, therefore the scenarios can only be shown in this thesis through screenshots taken periodically throughout its duration. Rather than take a new screenshot when each new function becomes active, three “snapshots” were taken throughout the scenario to show the passage of time in a more efficient manner. To assist readers, red boxes will be used to highlight new functions that have become active in each screenshot.

In this scenario, a developer (also referred to as the proponent) has decided to apply for a permit to alter a body of water in order to proceed with the development of a large subdivision in LBMCOC.

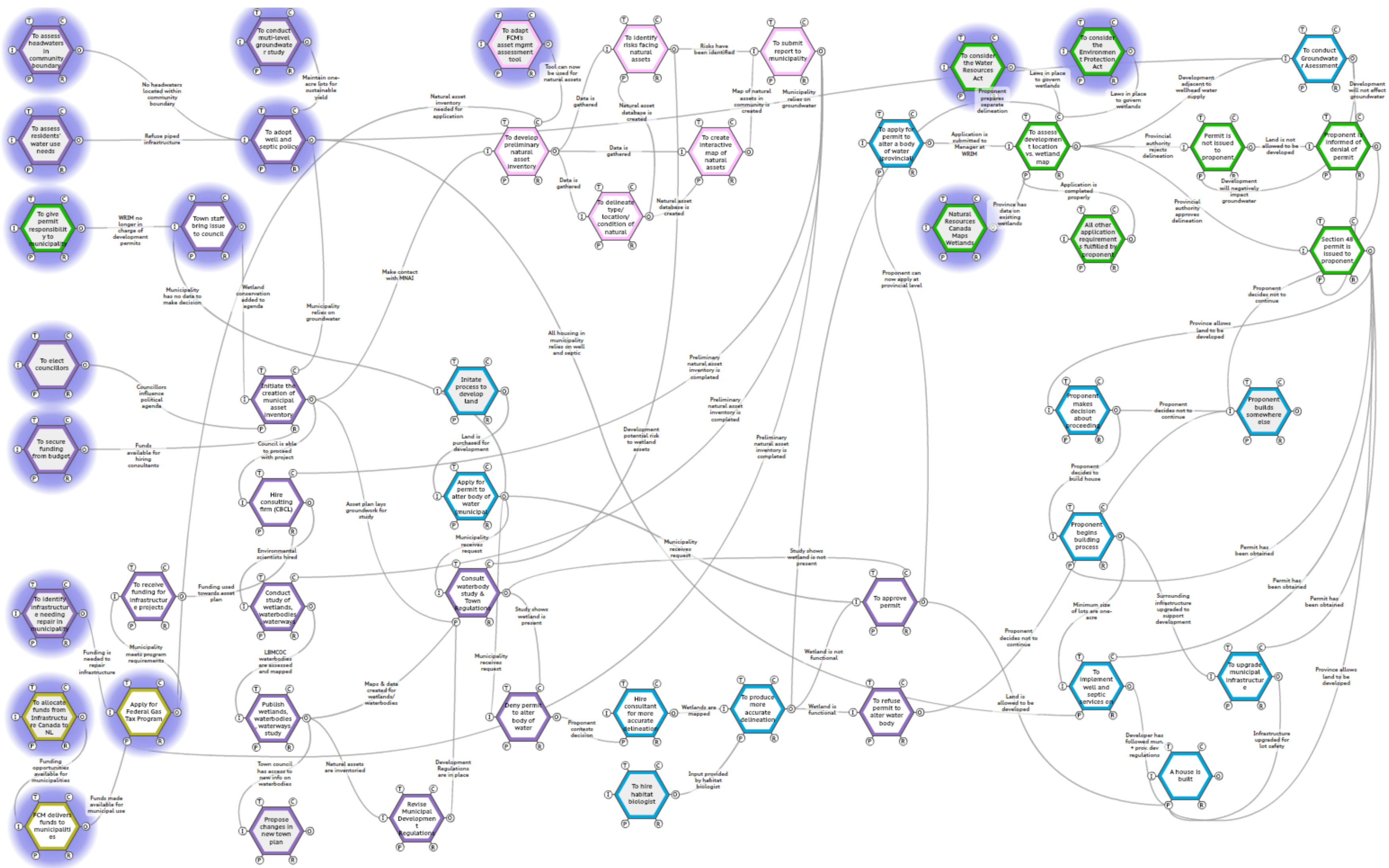



Figure 10: FRAM Scenario Snapshot Taken Before Scenario Begins (Source: Author's Construct)

Figure 10 depicts the model before the scenario begins, with purple highlight showing which functions are already active. The background functions are immediately active as they depict work that has already been done before the scenario begins. In this scenario, the FRAM begins with the function "to assess headwaters in the community boundary", which has the output that no headwaters are located within LBMCOC's boundaries. Another function, "to conduct a multi-level groundwater study" has the output that the community must maintain one-acre lots to ensure a sustainable groundwater yield. To the left, the function "to assess residents' water use needs" resulted in the decision to refuse piped infrastructure as LBMCOC decided it did not suit a community of its size. The outputs of these three functions all contribute to the function "To adopt well and septic policy" as a result. Another function that is active before the scenario begins is "To give permit responsibility to the municipality", a green function (indicating it is a provincial function) whose output is that the province is no longer primarily responsible for issuing development permits.

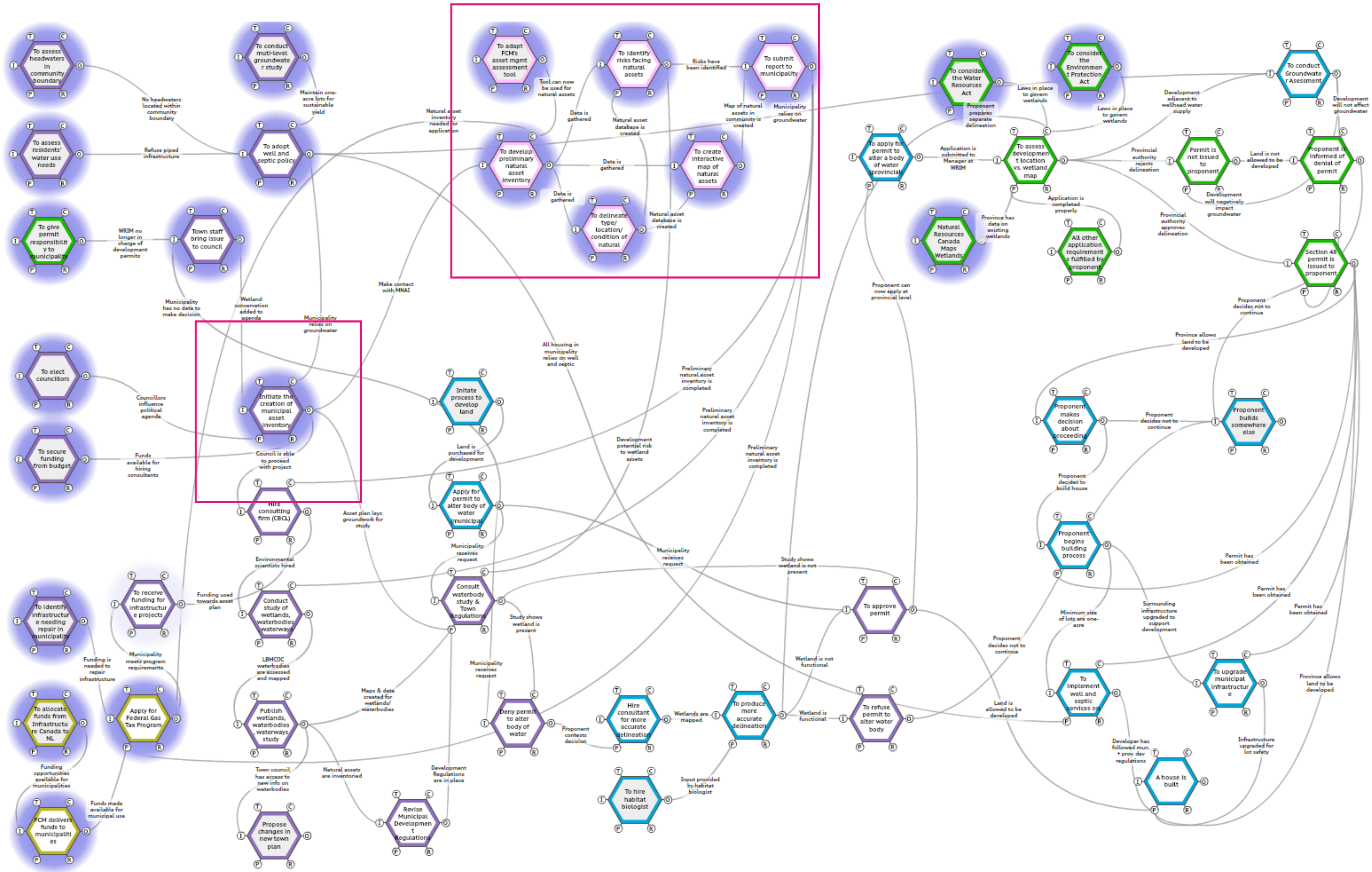


Figure 11: FRAM Scenario Snapshot Taken After Preliminary Natural Asset Inventory is Created (Source: Author's Construct)

Once the scenario begins, the first function becomes active when the town staff bring their concern regarding this newfound responsibility to council, as can be seen in Figure 11. LBMCOC is now tasked with making decisions about the future development of the municipality with no expertise or experience to do so. In this functional signature (also referred to as "scenario"), the municipality reaches out to MNAI to initiate the natural asset inventory project. The pink functions show the organization's successful efforts to develop an inventory, delineate the type/location/condition of natural assets, identify risks and threats to the natural assets, create a digital database and submit a summary report to the municipality. Now that the natural asset inventory is completed, at the bottom-left corner of the FRAM map we can see the function "To receive funding for infrastructure projects" is now active because the completion of the asset inventory has qualified the municipality for the Federal Gas Tax grant (now referred to as the Canada Community-Building Fund) (Government of Canada, 2022). As a result, when the community decides to proceed with their natural asset management initiative and hire a consulting firm to map their wetlands, they have the funding available.

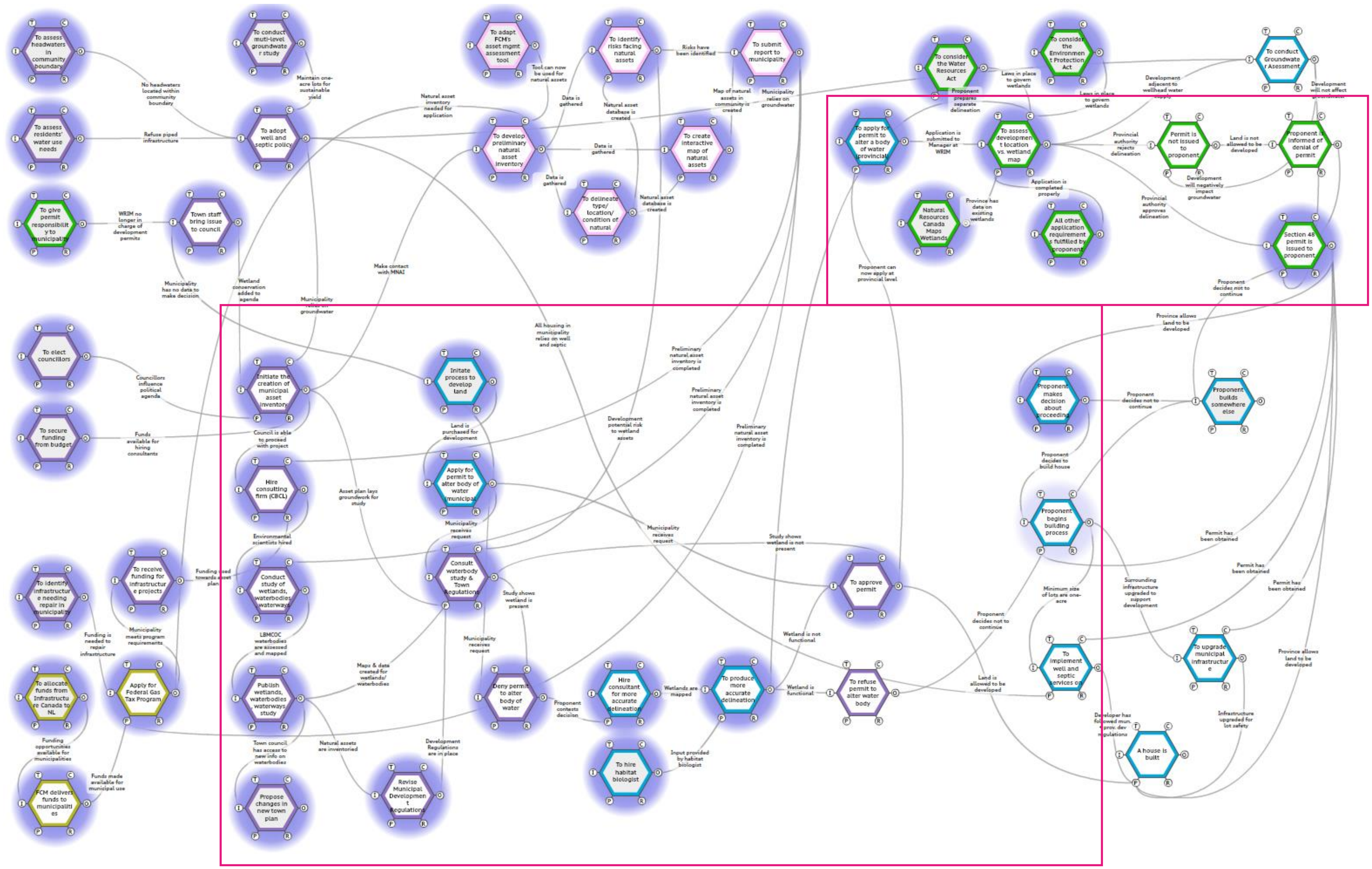


Figure 12: FRAM Scenario Snapshot Taken After Proponent Receives Permit (Source: Author's Construct

As shown in Figure 12, LBMCOC then hires CBCL Engineering and Environmental Design Services (CBCL Limited) whose environmental scientists conduct a study of the wetlands, waterbodies and waterways in the municipality. With this information, changes are proposed in the new town plan. Another output of the function “To publish wetlands, waterbodies, waterways study” is that natural assets are now inventoried, and the municipal development regulations can be revised to reflect the town’s new knowledge pertaining to the protection of their natural assets. Next, the functions in the blue section are now starting to become active as the proponent initiates the process to develop land. When they apply to the municipality for a permit to alter a body of water, the municipality can consult the waterbody study and town regulations now in place after commissioning CBCL. In this scenario, their wetlands database shows that a wetland is present, so they deny the permit. The proponent decides to contest the decision, hence the function “Hire consultant for more accurate delineation”, which results in a more accurate wetland assessment that the municipality will review and compare to their existing database. In this case, the wetland is proven to not be functional and is therefore approved by the municipality, who then indicates their approval to the province via email or letter (as shown in Figure 12).

The proponent must now apply at the provincial level. If their application requirements are fulfilled and the maps used by the province (i.e., Natural Resources Canada 1:50,000 scale National Topographic System maps/ArcGIS maps) do not indicate the presence of a wetland, their permit will likely be approved. Figure 12 shows that the proponent is now permitted to continue the building process, as seen in the bottom-right corner of the model.

This shows the outcome of just one functional signature. Throughout the data analysis process, many functional signatures were generated to envision different outcomes and variables in the model to understand how the system operates. For example, we considered hypothetical scenarios ("functional signatures") where there was no funding to support the natural asset inventory project, where council did not support the decision to take on the project, where MNAI was not able to assist the municipality and guide them through the process, etc. The results and observations which emerged from the DynaFRAM analyses will be explored in the subsequent section.

### 4.2 Research Question 2: What are LBMCOC's information and decision processes around groundwater and wetland management?

Before attempting to answer the more in-depth questions pertaining to drivers or constraints in the system, it was first important to describe the system itself and understand the community's information and decision processes surrounding groundwater and wetland management. The interview transcripts were analyzed to determine the institutions/stakeholders that influence the decision-making process of LBMCOC; this information informed which groups were included in the FRAM model.

### *Town Staff*

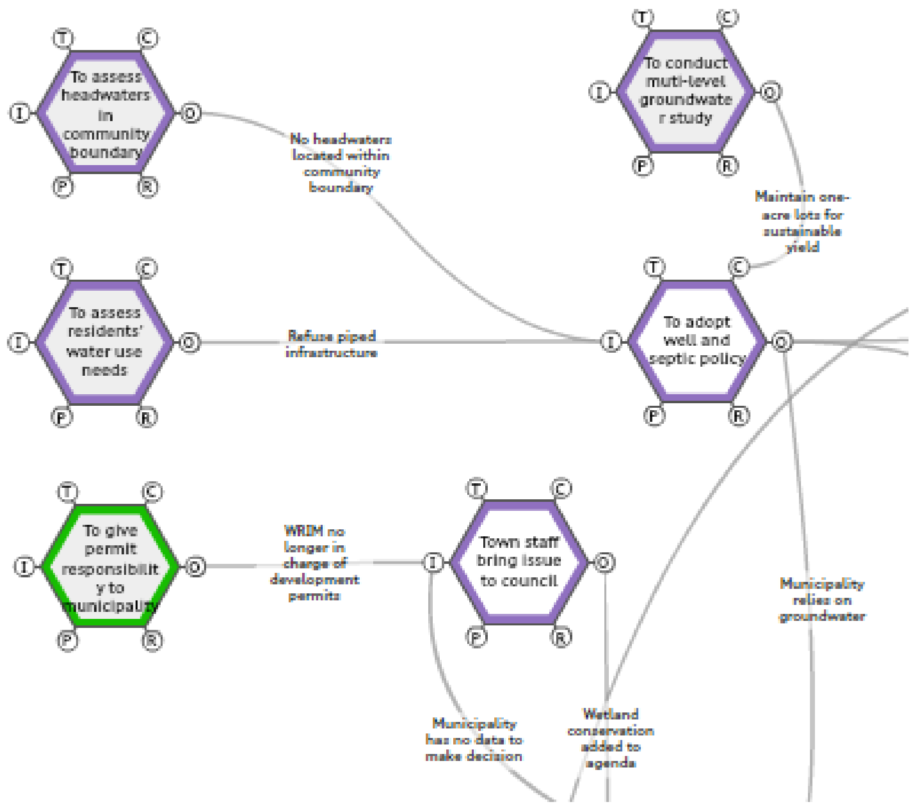



Figure 13: Town Staff Functions in FRAM Model (Source: Author's Construct)

Figure 13 is a screenshot of the top-left corner of the model, containing the function "Town staff bring issue to council". During interviews, participants indicated that one of the roles of town staff was to liaise with the community residents to learn about issues concerning the town that may need to be addressed by town council. This model demonstrates this dynamic by showing the instance of when the province downloaded the responsibility of permit applications to the town, and how that issue would have been brought to the council by town staff, who play a significant role in influencing the town's political agenda.

*Municipal Asset Inventory Initiative (MNAI)*

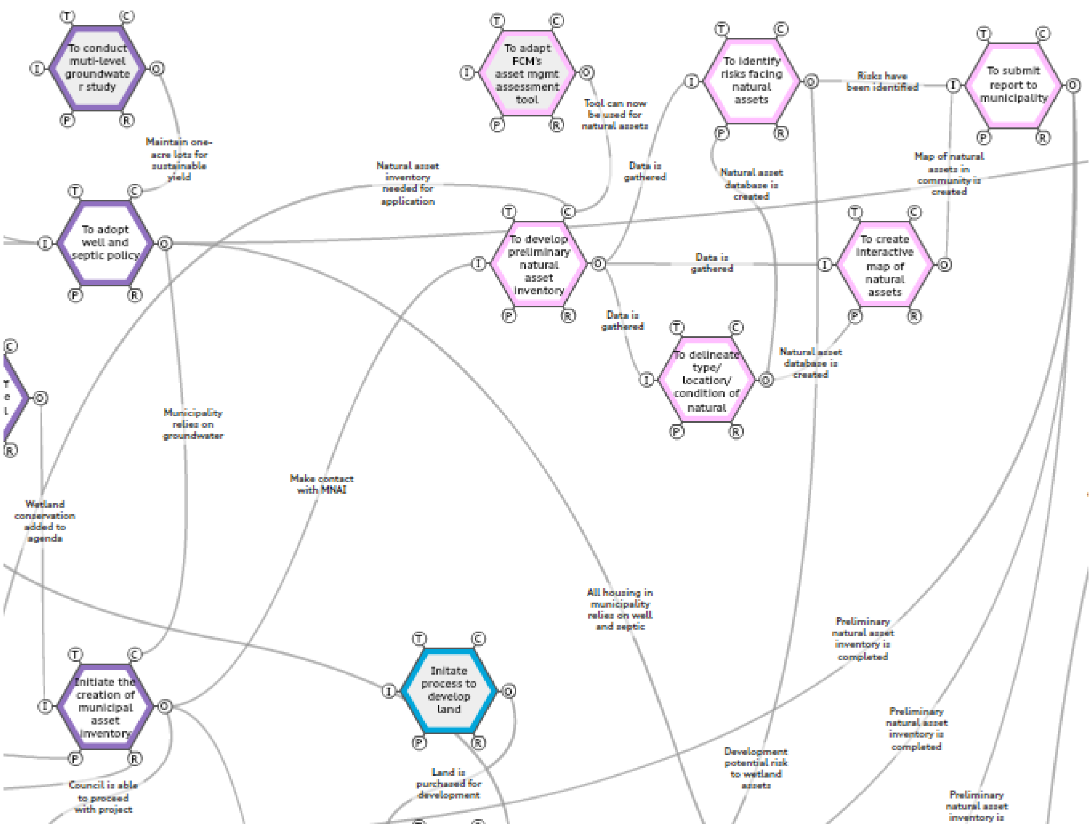



Figure 14: MNAI Functions in FRAM Model (Source: Author's Construct)

MNAI was instrumental in initiating LBMCOC's natural asset management efforts, as demonstrated in Figure 14. The municipality reached out to the organization who then assisted them with gathering data to develop an asset registry and online database. Some of the functions carried out by MNAI to achieve this include: "To identify risks facing natural assets", "To create interactive map of natural assets" and "To delineate type/location/condition of natural assets". They provided the town staff with risk identification tools to help pinpoint current threats to wetlands in the municipality. MNAI also published a report for the town, complete with recommended next steps LBMCOC could take should they decide to further pursue natural asset management projects. Later on, LBMCOC would go on to hire the consulting firm CBCL Limited, when they felt it was in their best interest to publish a study on their wetlands, waterbodies and waterways.

### *Consulting Firm: CBCL Limited*

In February 2020, an environmental scientist and fisheries and wildlife biologist produced a report on behalf of CBCL for the town of LBMCOC, which became an important source of information for the municipality. The environmental services were carried out to gather more in-depth information on the town's natural assets (building on the preliminary work carried out by MNAI) to be used to finalize updates to LBMCOC's Municipal Plan and Development Regulations (Bentley and MacDonald, 2020). Services provided by CBCL included:

> The identification and mapping of all wetlands, waterbodies and waterways located within the Town's municipal boundary, including those requiring flood zone provisions; a review of proposed flood zones; and recommendations of appropriate buffers and conservation measures for protecting the Town's natural assets while still allowing for rural development within the Town boundary. (Bentley and MacDonald, 2020)

The wetland study became a valuable tool for the municipality, which now had research and data to support their permit review process. The role of the wetland study in LBMCOC's policy process can be observed in Figure 15, with an arrow indicating the function where CBCL was initially hired by town council.

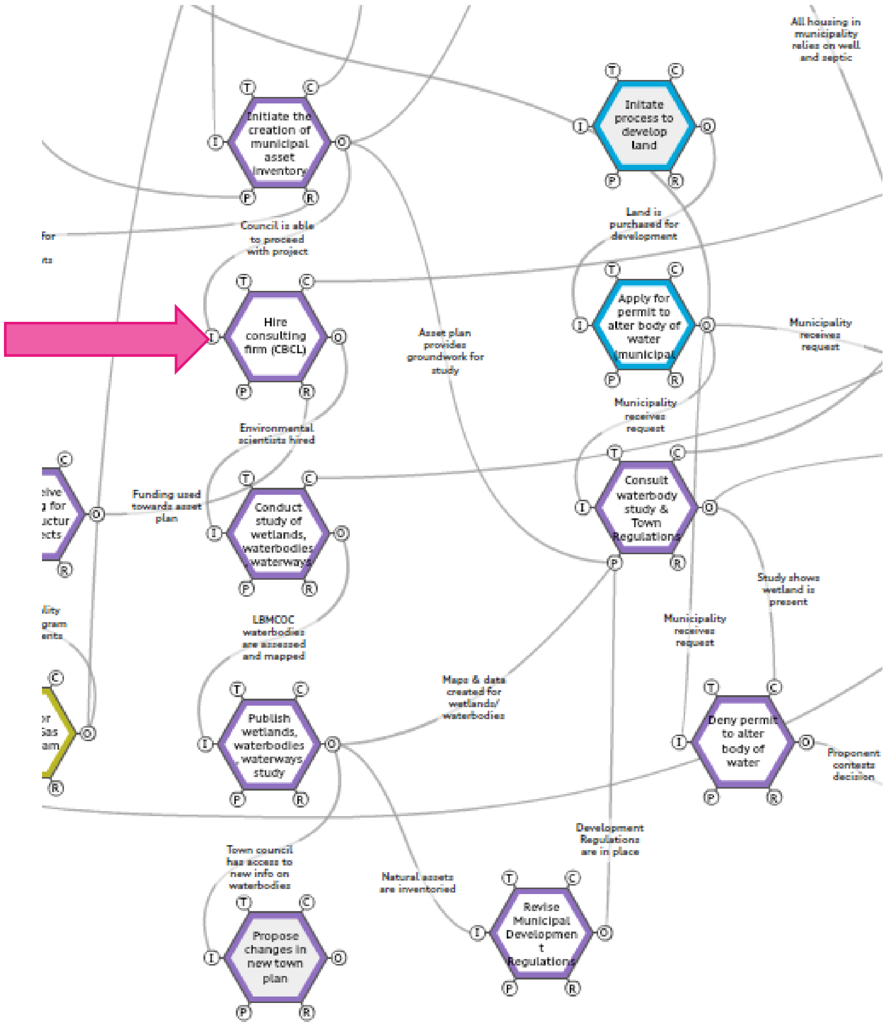



Figure 15: CBCL Functions in FRAM Model (Source: Author's Construct)

***Development Regulations***

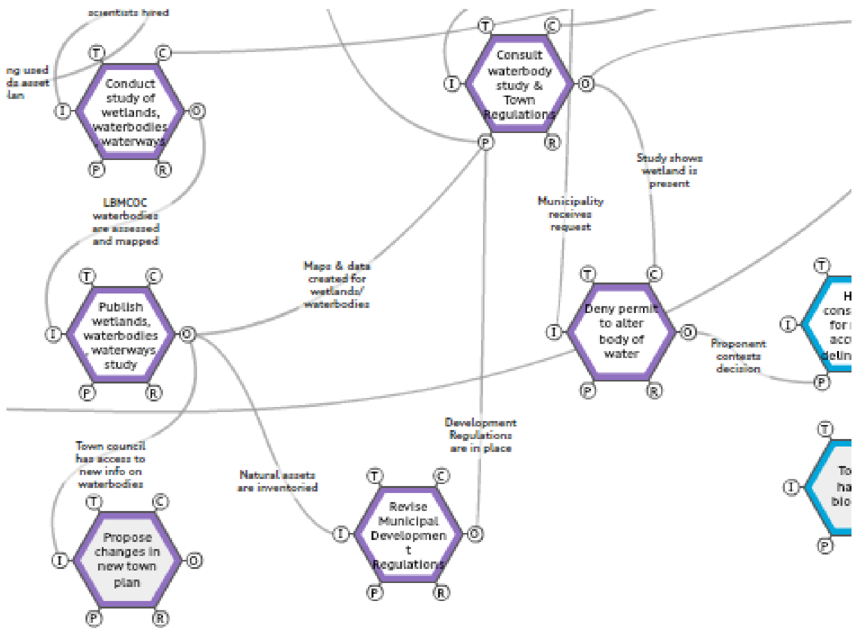



Figure 16: Development Regulations Functions in FRAM
(Source: Author's Construct)

In order to ensure that the results from the wetlands, waterbodies and waterways study had a lasting impact on the municipality regardless of changes in council and staff, it was imperative that the data was integrated into the town's Development Regulations so that guidelines and policy would be in place long-term. The connection of the Development Regulations to the permit approval process can be seen in  Figure 16. While the 2005-2015 Development Regulations make no mention of groundwater nor wetlands, the proposed 2021 Municipal Plan and Development Regulations (adopted as of July 25, 2022) highlights the importance of sustainable groundwater use and wetland management (Town of Logy Bay-Middle Cove-Outer Cove [LBMCOC], 2021). For example, one of the goals mentioned in the report is to "protect the hydrologic functions of waterways and wetlands as a critical component of the Town's ecology and its groundwater supply…" (Town of LBMCOC, 2021). The document then outlines a number of objectives to achieve this, such as restricting (or prohibiting) development in sensitive areas such as wetlands, waterways and waterbodies (Town of LBMCOC, 2021). Another objective is to enter into a Municipal Habitat Stewardship Agreement with the Department of Fisheries and Land Resources in a conservation effort to protect lands that are both wetlands and coastal areas (Town of Logy Bay-Middle Cove-Outer Cove, 2021). When a Municipal Plan is approved in accordance with the Urban and Rural Planning Act, 2000, it becomes a legally-binding document (Town of LBMCOC, 2021). As stated in the proposed Municipal Plan and Development Regulations (2021):

> As a legal document, the Municipal Plan is binding upon Council and any person or group using or proposing to use land anywhere within the Planning Area. From the date the new Municipal Plan becomes legally effective, all new development must be in conformance with the Municipal Plan.

Figure 17 shows a scenario run through the DynaFRAM where the CBCL wetlands study is completed, but the results are not integrated into the municipal Development Regulations. As a result, when the proponent applies for a permit to alter a body of water, the town has no legal document to support their justification in rejecting the proposal. This demonstrates the importance of mobilizing knowledge gained from these studies. It is not enough to have these reports published—they must be effectively integrated into town planning tools to ensure their proper use and longevity as town staff and council change.

The following list summarizes all the sources of information used by LBMCOC in their decision-making processes, as identified through the data analysis phase:

- town staff, who connect concerned community members to town council

- MNAI, who provided guidance on the natural asset management strategy
- CBCL Limited, the environmental consulting company responsible for the wetlands study
- LBMCOC's Municipal Plan and Development Regulations, a policy document guiding the management and development of LBMCOC

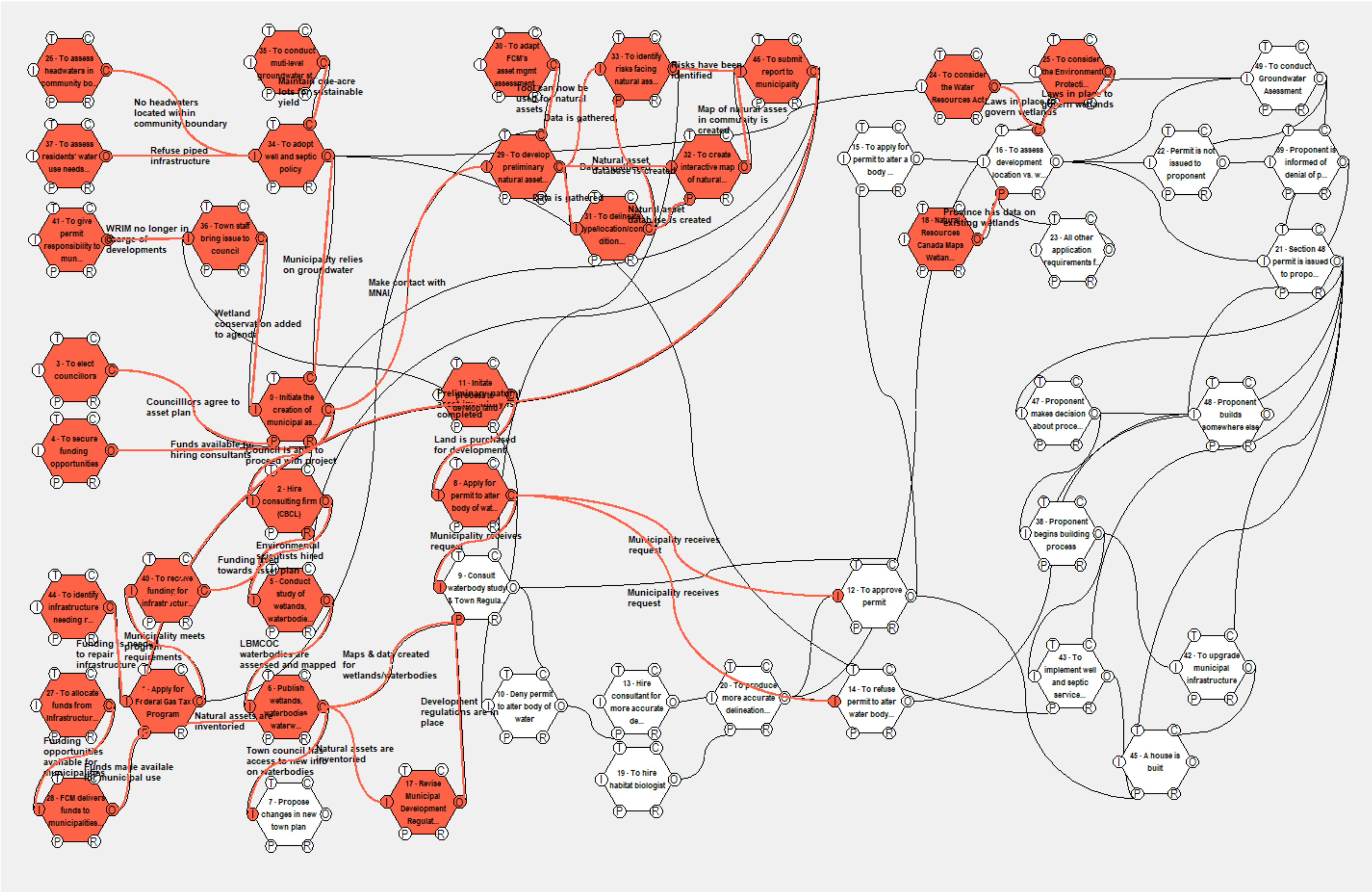


Figure 17: FRAM Scenario Without Development Regulations (Source: Author's Construct)

### 4.3 Research Question 3: What are the implications of increased municipal responsibilities around groundwater/wetland management?

This section will look at the present state of provincial-municipal responsibilities and whether it is beneficial to groundwater and wetland management at the municipal level in Newfoundland. Figure 18 is a DynaFRAM screenshot from a sample scenario where a proponent successfully receives a permit from the province to alter a body of water. Here it can be observed that the proponent first must apply at the municipal level, and then at the provincial level. Once the municipality approves the permit, there is no further collaboration with the province aside from the municipality sending them an email or letter indicating their decision; rather, the proponent must submit another application to the Water Rights, Investigation & Modelling Section (WRIM) of the Water Resources Management Division. It was in mapping out the system in the FRAM that I could visualize the process and see where work was being done and what resources were being utilized. While observing Figure 18, it was evident that there are many functions in this model showing the creation of a map, which prompted a closer look at what wetland maps were produced by which stakeholders in this system.

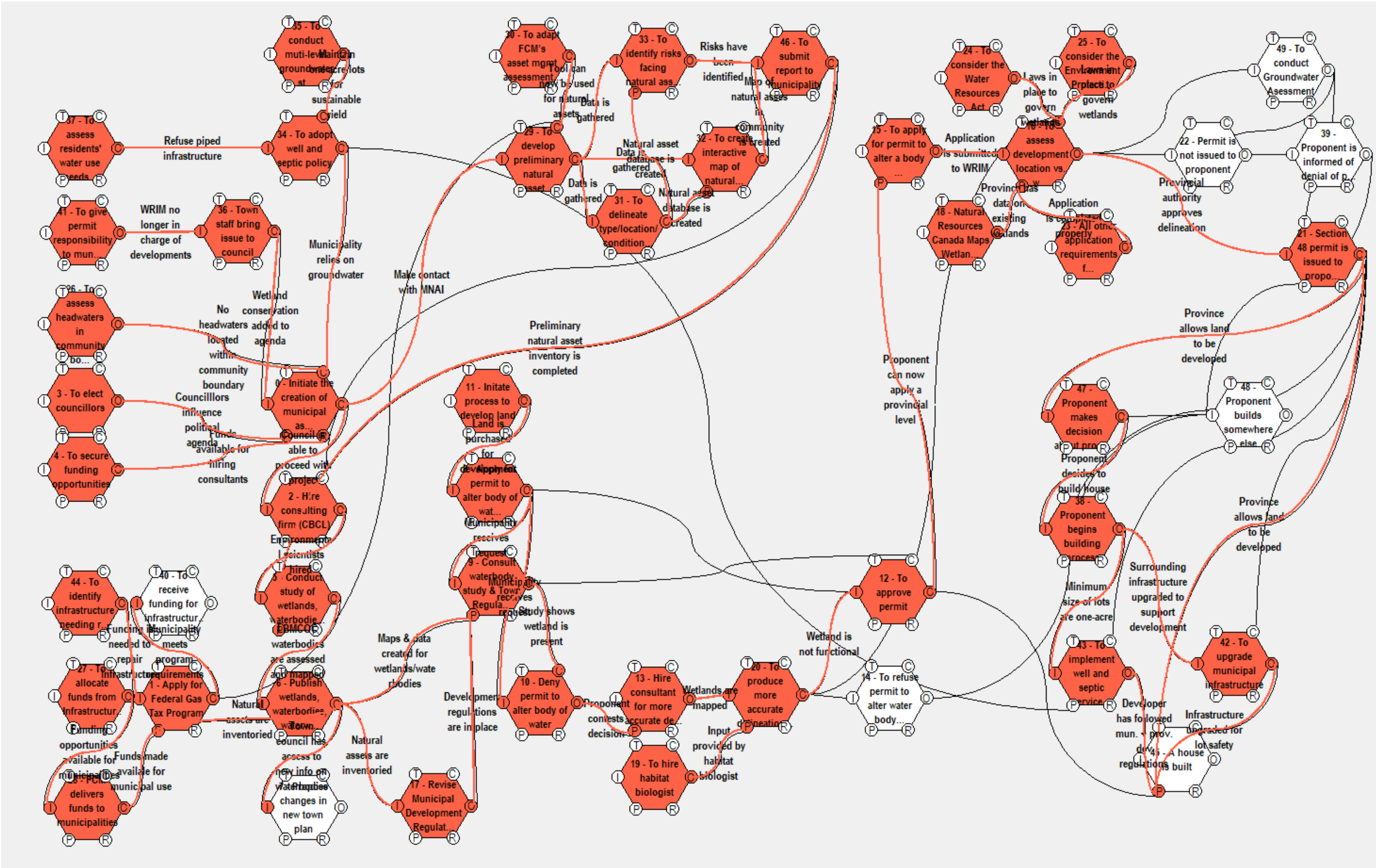



Figure 18: FRAM Model Showing Permit Approval Process (Source: Author's Construct)

The municipality has their database of wetlands built from work with both MNAI and CBCL. Their work consisted of tabletop studies and field work that delineated wetland boundaries, but due to time and cost constraints, it was unfeasible to assess the functionality of every wetland in the municipality. Additionally, wetland functionality and boundaries may change with time and vary from when the study was first conducted. As a result, if the municipality denies a permit, the proponent has the option of hiring a qualified firm to conduct their own delineation of the wetland and conduct a functionality assessment, which may provide a more accurate delineation than the municipality's database (this delineation process is demonstrated in Figure 18. At the provincial level, Natural Resources Canada 1:50,000 scale National Topographic System Maps and the ArcGIS map service (provided by NL GIS and Mapping Division of the Department of Fisheries, Forestry and Agriculture) are used to identify the location of wetlands and waterbodies. In sum, 4 different maps are being used to assess wetland presence, which could lead to some inefficiency in the process. In terms of the accuracy of the maps being produced, the National Topographic Data Base (1944-2005) is a legacy product that is no longer updated (Government of Canada, n.d.) and the CanVec topographic data series is irregularly updated and may not show changes to wetland boundaries, which is why the province will review revised mapping if submitted by the proponent. While these maps may show wetland boundaries, they cannot indicate the functionality of a wetland. In order to do so, the WESP-AC method for assessing wetland functionality described in Section 2.4.1 of the literature review would need to be carried out. This assessment is comprehensive, as it not only includes a tabletop study and aerial imagery analysis, but also a site visit (Adamus, 2018). Therefore, decisions at the provincial level may be excluding the functionality of wetlands as criteria for accepting or denying permits, since they are only relying on the aforementioned maps. Furthermore, Edinger and Hermanutz (2015) note that, at the 1:50,000 scale, only large wetlands are identified, despite the presence of many small-sized wetlands. They assert that wetland assessments should not only rely on mapping using visible wavelength and infrared aerial photography, but also field assessments (Edinger and Hermanutz, 2015). While this would likely improve the accuracy of wetland assessments, capacity to carry out field work for a vast number of wetlands is limited at both the municipal and provincial level. For other municipalities in Newfoundland without the resources or capacity to hire consultants to generate a wetland database or carry out field work, the only data being used to assess permit applications are the 1:50,000 scale maps used by the province.

In the FRAM model, the only connection between the municipal and provincial process that can be observed is that the municipal function "To approve permit" has the output: "Proponent can now apply at provincial level". This means that the municipality must approve the permit in order for the province to be able to proceed with their assessment of the application. As previously mentioned, the province only requires an email or letter from the municipality indicating their decision on the permit, without justification for said decision. While the town of LBMCOC has delineated their own wetland maps to justify their approval or denial of a permit, these maps are not visible to the province, nor is there an opportunity for this information to be shared. These maps have been an effort on the part of LBMCOC but are not a requirement of municipalities. The WRIM encourages municipalities to do their due diligence in assessing zoning, easements and Proof of Ownership, however wetlands are not mentioned as a criterion to review during the decision-making phase (Government of Newfoundland and Labrador, n.d.). Towns in Newfoundland have been given primary jurisdiction over this process; however, many of them require funding, supportive staff, community buy-in and significant capacity to engage in wetlands mapping. For the communities lacking in these categories, their wetlands are left vulnerable. Interviewees indicated that they believed these issues are better handled from a bottom-up approach as any development would directly affect these towns, but numerous participants cited a desire for more open communication and collaboration across different levels of government to compensate for the lack of technical expertise and resources at the municipal level. One town staff interviewee stated:

> I really think it has to be like a collaborative effort. I mean, if I had to pick one, I would probably go bottom up because [we] know this town better than someone in government who has to deal with 100 municipalities, right? However, we internally do not have the expertise of hydrologists and you know, those that are qualified to really understand and study groundwater. So, in the same sense, I feel like we do rely on them for their expertise on things that are very specific or very technical, because we don't have that knowledge. So that's why I think it should be a collaborative effort whereby we provide the information that we have the justification, the reasoning, and then they look at it from the technical side and kind of work together on the piece of how to proceed given all sides of it.

To summarize, the FRAM model shows a clear division between municipal and provincial processes that prevents collaboration and the sharing of information and resources. Municipalities in Newfoundland vary in their capacity to manage their natural assets; for those without the knowledge or expertise on groundwater and wetland management, they may struggle in making an informed decision on who should receive a permit to alter a body of water. While the consensus amongst those interviewed was that a bottom-up approach to wetland management was preferred, interviewees indicated a desire for more collaboration between different levels of government.

### 4.4 Research Question 4: What factors explain the success of groundwater/wetland management in LBMCOC?

This section will explore which factors contributed to or hindered the success of groundwater and wetland management in LBMCOC. The DynaFRAM was used to test variables in different scenarios to see what influence different functions had on various outcomes. Socio-technical thinking argues that a system is resilient if it resists failure, returning to its basic functionality after enduring some form of surprise, stressor or negative event (Smith et al., 2017). In my analysis, I changed certain factors to see whether that prevented the municipality from being able to continue with their natural asset management work. For example, what if there were no funds available in the town budget to hire a consultant? Is that a constraint in the system, or would that funding be found elsewhere? Or what if the Gas Tax Fund did not require a natural asset inventory from municipalities? Would there still be an incentive for municipalities to start such projects? The results of the analysis are described in the following paragraphs.

### *Reliance on Groundwater*

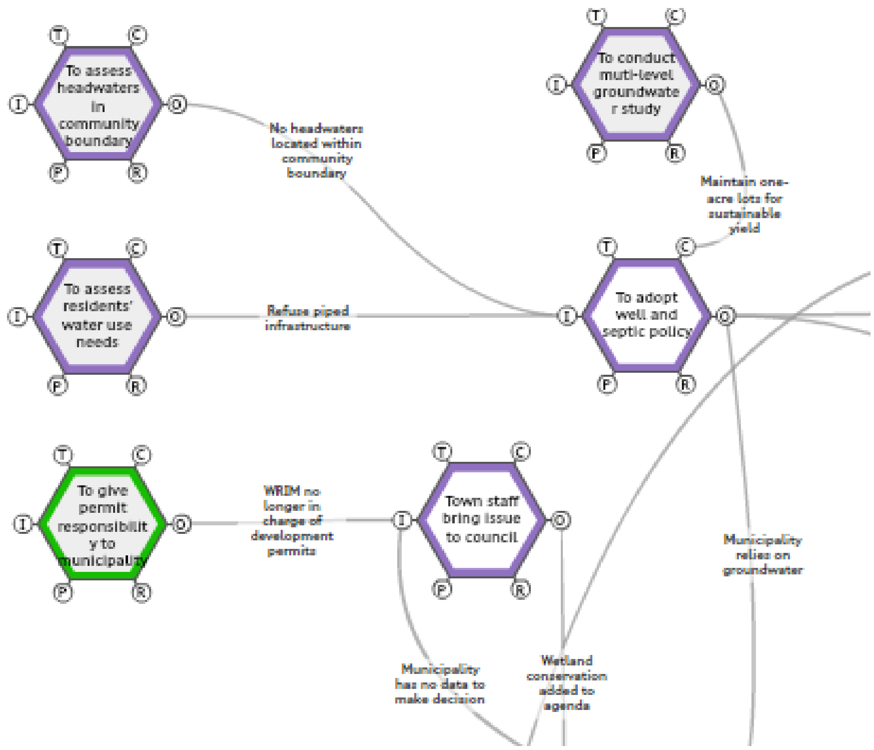



Figure 19: FRAM Model Segment Showing LBMCOC's Groundwater Policy (Source: Author's Construct)

There are a number of pre-existing conditions that positioned LBMCOC to be better prepared for the wetland management process, highlighted in Figure 19. Section 3.3 provides an overview of the history of LBMCOC and describes the town's efforts to maintain its rural feel and lifestyle despite its close proximity to St. John's. This decision to keep the community population low and resident lot size large influenced their decision to refuse piped infrastructure for the town and rely solely on groundwater for daily water use needs. The installation of water and wastewater infrastructure would not only have saddled the community with significant operating and maintenance costs, but would have also enabled smaller residential lot sizes and higher density living that would alter the rural community feel and threaten the tradition of hobby farming in the town.

As shown in Figure 19, another contributing factor for their decision to rely on well and septic was their assessment that no headwaters were located within the community boundary. Since LBMCOC decided to forego piped infrastructure, this left them with the decision to rely on groundwater instead. The town conducted a multi-level groundwater study which showed that maintaining lots at a minimum of one acre would prevent wells from being overdrawn by high demand. While this proved groundwater use to be a viable, long-term infrastructure decision for the town, it also meant that protecting groundwater quantity and quality would become a major priority for the community. Consequently, making informed decisions about which developments can occur in LBMCOC is not only integral to maintaining the rural lifestyle they value, but also protecting the wetlands responsible for filtering and recharging the town's groundwater.

***Securing Funding***

The town of LBMCOC was able to proceed with the preliminary natural asset inventory because they had funding available in the budget. As Figure 20 shows, the "To secure funding from budget" function is a resource for the "Initiate creation of municipal asset plan function", which means that without funding, the latter function cannot do work. This results in the town not reaching out to MNAI, not qualifying for the Gas Tax Fund, not publishing the wetlands, waterbodies and waterways study and therefore not having any guidelines in the development regulations related to wetland conservation when receiving an application to alter a wetland. Interviewees indicated that the next step in the natural asset management process would be to assess the functionality of the wetlands in the town, but that required funding that the municipality does not currently have available. Evidently, securing funding can be a constraint to municipalities struggling with other expenses.

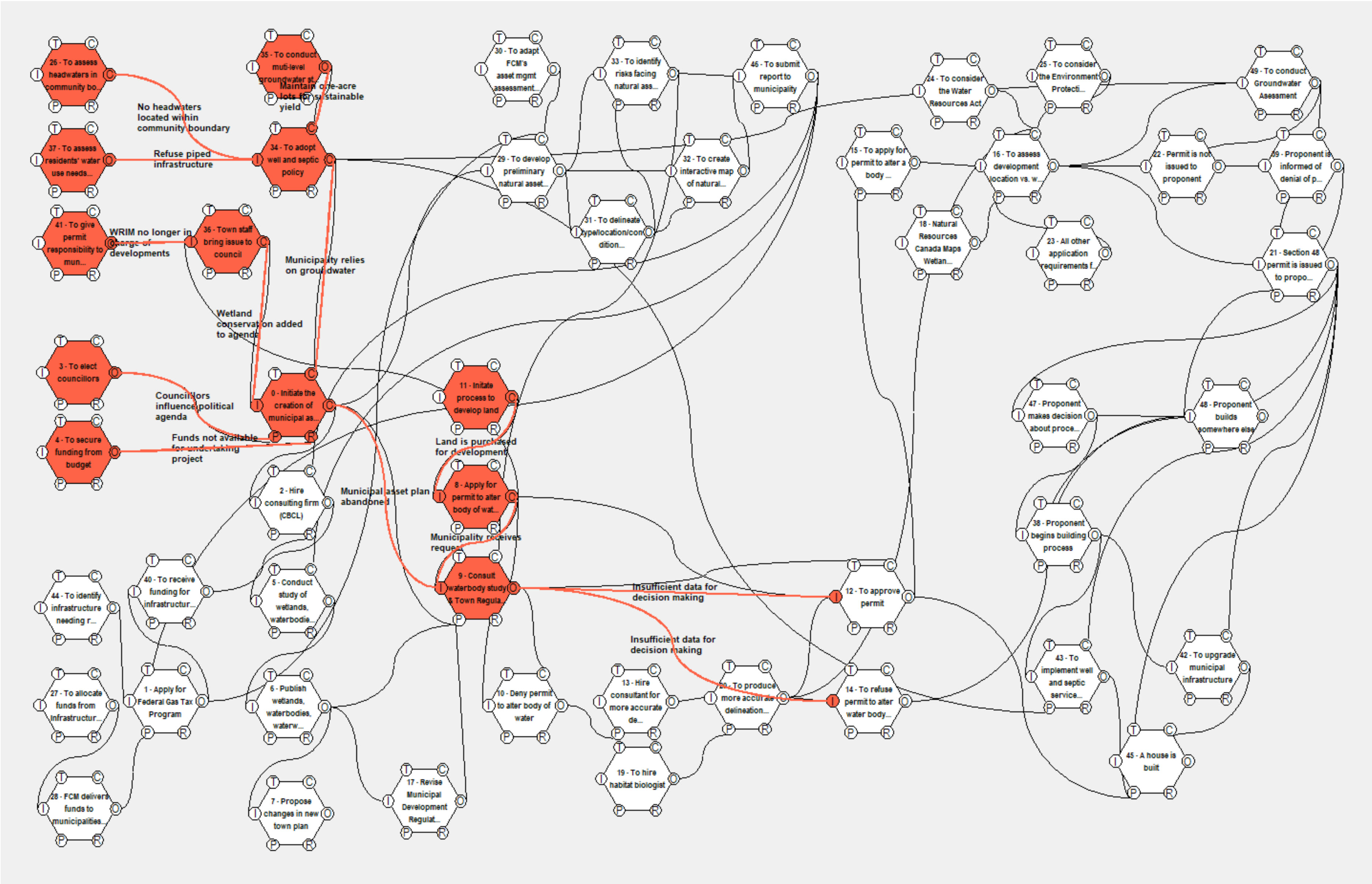


Figure 20: FRAM Model Showing Scenario without Funding (Source: Author's Construct)

### ***The Gas Tax Fund***

The Gas Tax Fund was one of many incentives for LBMCOC to take on natural asset management. According to MNAI (2017a), changes to the eligibility criteria for Federal Gas Tax grants were made to promote natural asset management strategies at the municipal level, and the case of LBMCOC is a prime example of its effectiveness. In this FRAM model (shown in Figure 21) it can be observed that if the town did not meet the criteria for the Gas Tax program, they would not have had the additional funding to hire consulting services from CBCL Limited to produce the wetlands study. The Gas Tax program not only incentivizes natural asset management, but assists municipalities in carrying them out. As noted in the previous section, funding is a vital resource in these efforts.

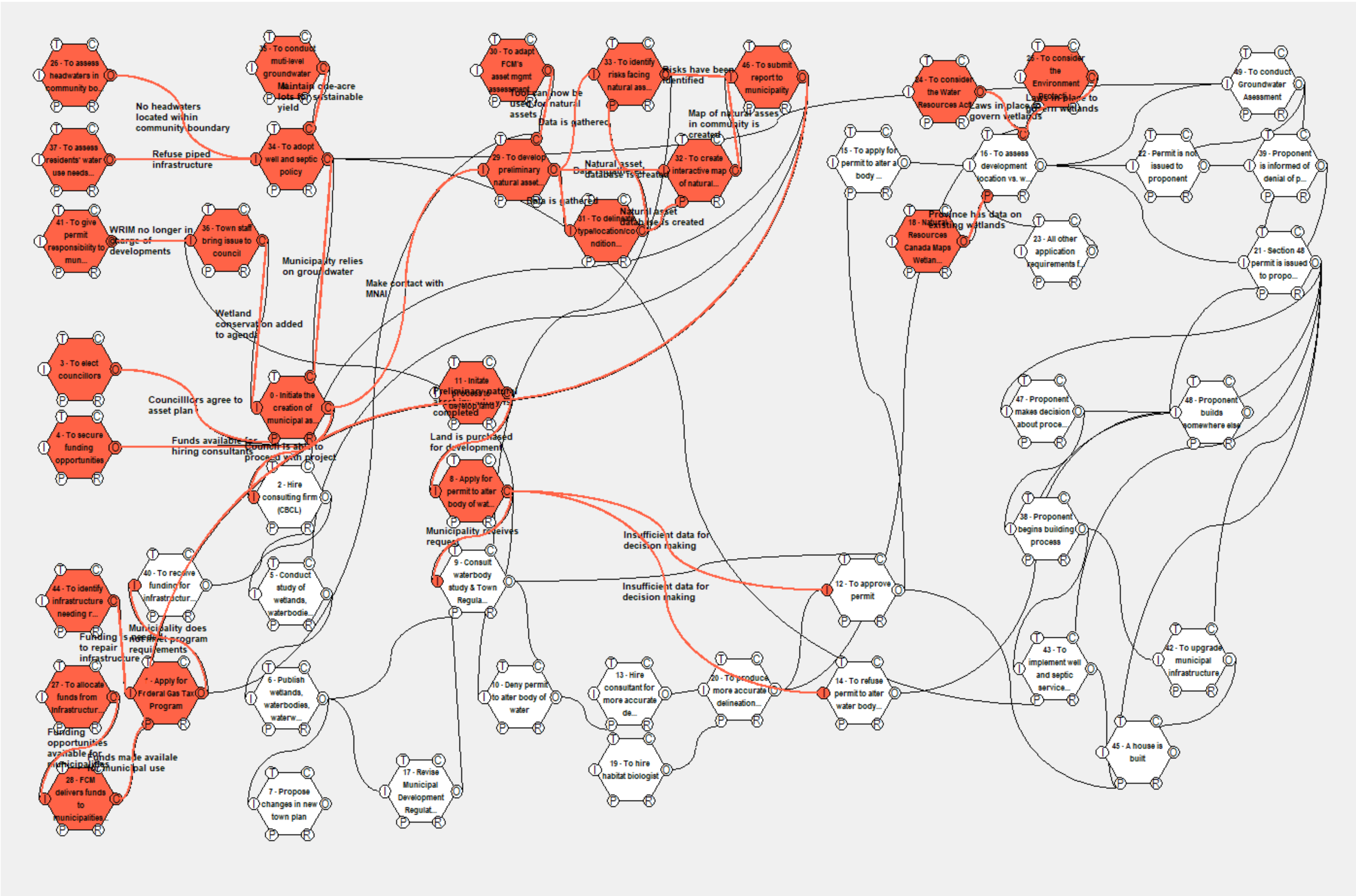


Figure 21: FRAM Model Showing Absence of Gas Tax Fund (Source: Author's Construct)

***Support from MNAI***

Towns in Newfoundland may feel overwhelmed when certain responsibilities are downloaded to the municipal level; however, third-party organizations such as MNAI can offer valuable tools and support, discussed in further detail in Section 4.3. MNAI provided LBMCOC with a framework for their asset inventory, worked with them to develop a report on their natural assets which assisted with the procurement of federal gas tax funding, and outlined next steps for the municipality to follow should they decide to proceed with their management strategy.
If MNAI was unable to collaborate with the town for any reason, LBMCOC would have been aware of their need for a natural asset plan but would not have had the knowledge or tools to take the first step towards management, as is demonstrated in Figure 22. Furthermore, as discussed in the *Gas Tax Fund* section, their inability to develop a preliminary natural asset inventory with MNAI may have prevented them from securing a Gas Tax grant, resulting in a lack of funding to hire consultants for the wetland study. The process of mapping the relationships of these stakeholders in the system using the FRAM allowed me to observe the effects these connections have on outcomes in the community.

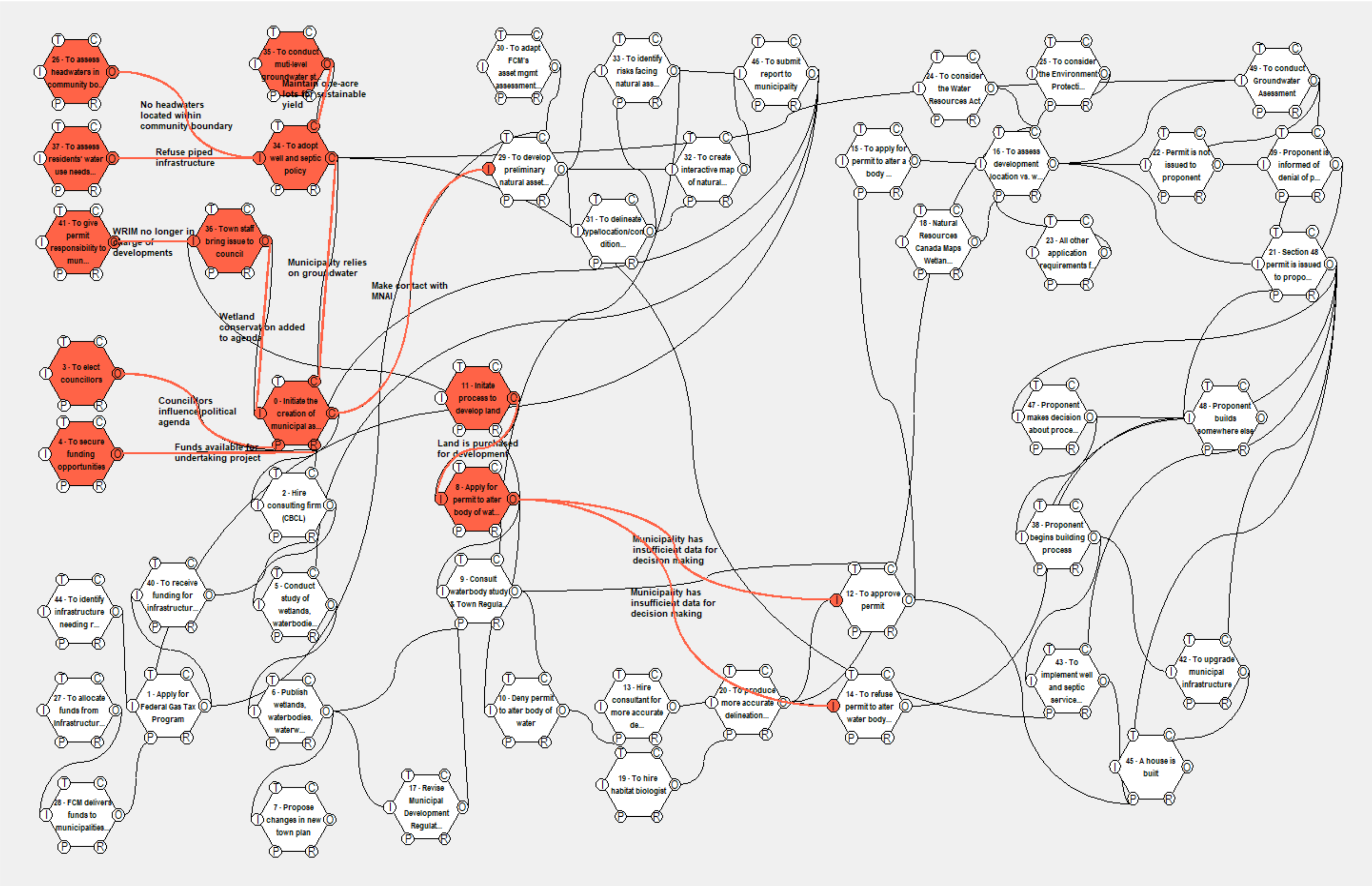



Figure 22: FRAM Model Showing Scenario without MNAI Support (Source: Author's Construct)

### *Council and Community Support*

Figure 23 depicts a scenario where the town staff brings their concern regarding wetland management to the council, but the council does not see it as a priority that justifies expenditure and therefore vote against the initiative. Subsequently, the MNAI functions and federal functions are not active because the preliminary natural asset inventory was not conducted and as a result, the town did not qualify for a Gas Tax grant. This FRAM model shows the outcome of not having council support.

According to MNAI (2021), in their risk assessment of LBMCOC, "political risk" was one of the threats identified as a risk to wetlands in the community. This encompasses changes in council, policy and/or political pressures resulting in less support for management strategies. Future council changes could present a constraint if the conservation of wetlands is not seen as a priority, as demonstrated above. When asked about how the town responds to pressure to development wetlands, one town staff interviewee stated:

> So honestly it really depends on the mindset of council, because these higher decisions come from council. So if you have a council that's really, really cognizant of groundwater and natural assets, then you'll see that there's probably more red tape and more hesitancy to work with developers and allow things to proceed

Presently, LBMCOC's town council does see wetland conservation as a priority, as it was a councillor who initially reached out to MNAI regarding the asset inventory. Interviewees stated that groundwater protection was a popular campaign platform, and that currently, residents are aware of the importance of protecting groundwater supplies. Council and community buy-in promote these initiatives when they support town staff efforts and budget to be allocated towards management strategies.

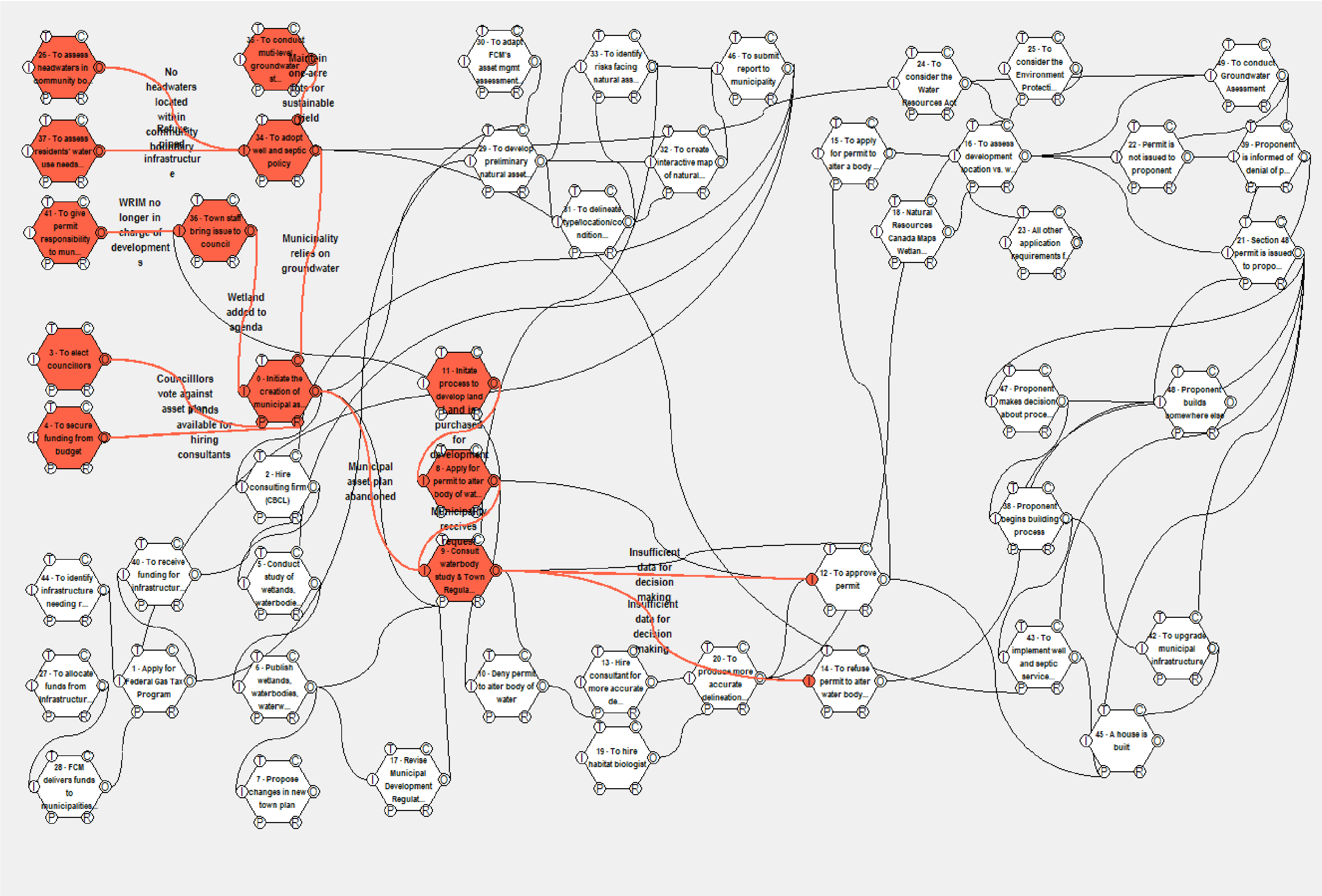


Figure 23: FRAM Model Showing Absence of Town Council Support (Source: Author's Construct)

***Knowledge Mobilization***

Another strength found in LBMCOC's approach was the town's quick efforts to mobilize the data collected through their work with MNAI and CBCL Limited. The Wetlands, Waterbodies and Waterways study was published in 2020, and by 2021 was already integrated into a proposed revision of the Municipal Plan and Development Regulations, which was adopted in July of 2022 (Town of LBMCOC, 2021). It was imperative that the management strategies were integrated into a legally-binding document as quickly as possible to prevent any developments from slipping through the cracks and being approved without regard for wetland management, as described in depth in Section 4.3. Figure 24 shows the perils of being slow to mobilize data. In this scenario, despite efforts on behalf of MNAI and CBCL Limited, if the function "Revise Municipal Development Regulations" is too long in duration, the proponent will start their process for a permit application, to which the municipality must make a decision without those legally-binding guidelines in place to justify their choice. Evidently, it is not just acquiring information, but knowing how to leverage it to benefit the community in a strategic way that is an important component of a natural asset management strategy.

To summarize, the following factors have been identified as key to the success of LBMCOC's groundwater/wetland management:

- their reliance on groundwater as their only source of drinking water, providing a strong incentive to carefully manage their natural assets

- their ability to secure funding for environmental consultants and natural asset inventory efforts
- the Gas Tax Fund, federal financial support that incentivizes municipalities to engage in natural asset management efforts
- support from MNAI, who provided LBMCOC with the knowledge and resources to develop their natural asset management strategy
- council and community support for using municipal resources to engage in groundwater/wetland management initiatives
- effective knowledge mobilization, as seen in the municipality’s integration of environmental data into their Municipal Plan and Development Regulations

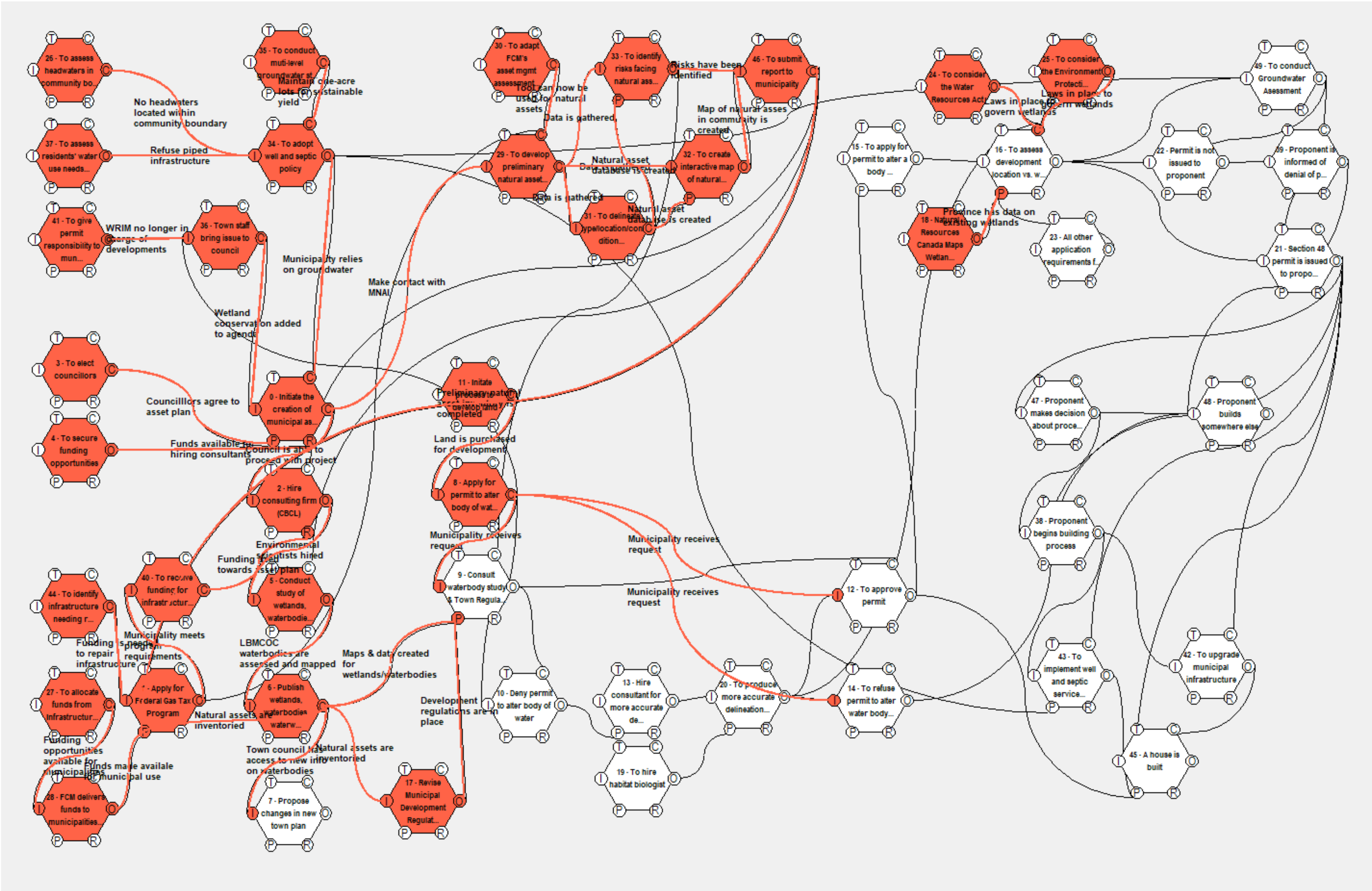


Figure 24: FRAM Model Showing Outcome Without Development Regulations Update (Source: Author's Construct)

# Chapter 5: Discussion

This chapter will summarize the results described in Chapter 4, reflecting on the data analysis process and interpreting the broader implications these results have on groundwater governance at the municipal level in Newfoundland. The chapter will conclude with answering research question 5 by providing recommendations for other municipalities in Newfoundland who might benefit from learning about LBMCOC's approach to groundwater and wetland management.

## 5.1 Results Summary and Reflection

***RQ1: How can the FRAM be used to understand the decision-making processes made across an entire community in regard to groundwater and wetland management?***

This study sought to understand whether the FRAM would be an appropriate tool used in a community context to understand a town as a socio-technical system. The FRAM is often used to describe the daily operations of sociotechnical systems in the fields of aviation, healthcare, and industrial operations, to name a few examples (Patriarca et al., 2020). The challenge in this study was being able to model something as abstract as the process of a town council making a decision about their groundwater resources. After completing the data analysis portion of this study, the FRAM has proven to be an effective tool in understanding the decision-making process surrounding groundwater and wetland management in LBMCOC. The case itself is complex, including many stakeholders, outside influences and factors which affect decision making, yet the FRAM was able to show everything in one cohesive model. As a visual aid, the

FRAM was extremely helpful in the data analysis process—in one quick glance, a large amount of data was easily digestible, which was especially helpful when needing to be familiar with the system during the fact-check process. The policy, approval, and decision-making processes illustrated in the FRAM can be convoluted in reality; policy changes do not happen in a straightforward or linear fashion. The challenge was accurately reflecting these processes in the model without oversimplifying them or misrepresenting how the system operates in reality, while also being able to map it in a coherent way. The purpose of the FRAM, however, is not to create an exact model of a system; rather, it is a tool for researchers to create an approximation of that system to observe variability in a model and experiment through scenarios to learn about how it operates.

The process of inputting data into the FRAM helped me define the scope of this study, as well as which stakeholders would be relevant to the model. As previously mentioned, having a visual to refer to throughout the data analysis phase was not only helpful as an organizational tool, but also assisted in answering the research questions when the model was used in conjunction with the DynaFRAM program. The ability to use the DynaFRAM and observe functional signatures, experiment with variables and see how different functions affected outcomes supplied ample data to answer the research questions posed in this thesis. For example, running various functional signatures that either included or did not include the function "Revise Municipal Development Regulations" yielded very different results. In the functional signatures where the municipality completed their natural asset inventory and wetlands study but did not integrate any of this new knowledge in any formal municipal documents, LBMCOC became vulnerable to proponents wanting to develop on a wetland (as they lacked scientific justification to refuse the request). This illuminated the importance of knowledge mobilization and revealed one factor to LBMCOC's success: their ability and capacity to gather and mobilize data. It also revealed why other municipalities struggling with low capacity may not have the resources to engage in groundwater/wetland management. Interestingly, the "Propose changes to new town plan" function did not have any significant effect on the process shown in the model, since the town plan was not a resource directly used in the permit approval process. However, the activation of that function would likely prove valuable in ensuring the long-term protection of wetlands in the event of political change in the municipality (which is outside the scope of the FRAM model used in this study).

While discussing the purpose of the FRAM, Hollnagel (2012) writes, "In order for a system to be understandable it is necessary to know what goes on 'inside' it, to have a sufficiently clear description or specification of the system and its functions". Using the FRAM methodology promoted a focus on the system's functionality. The FRAM is not structured in a linear way; it is not designed to reflect exactly how systems are structured or organized, nor does it show cause-effect relations—the purpose of the FRAM is to promote a focus on the functions within the system such that researchers must ask questions before they can start looking for answers (Hollnagel and Slater, 2018). While developing the FRAM model for this study, asking questions about where work was done in the system, what concrete outputs came out of which functions, and understanding how seemingly unrelated functions were in fact connected helped develop a model that showed functionality rather than organization structure. It also ensured that the model only contained information relevant to the scope of the thesis. Answering the other research questions in this thesis was often done by asking questions about the functionality of certain components in the system and the degree to which their presence influenced certain outcomes. For example, while trying to answer research question 4 (what factors affect the success of LBMCOC's management approach), it was necessary to look at every function and question the system's dependence on it. Functions such as "To secure funding from budget", "To elect councillors", "To revise municipal development regulations" and "To adopt well and septic policy" were all the focus of multiple functional signatures to see how the system operated with them absent, with them present and with different imagined outputs.

As this was the first instance of the FRAM being used to describe a municipality's approach to decision making and policy, there is much room for refinement in the methods used in this study, which will be discussed in more detail in Chapter 6. Regardless, the FRAM was certainly able to be used in the context of this study and was an effective methodology for tackling the main research questions driving this study, which will be described in more detail in the following sections.

***Research Question 2: What are LBMCOC's information and decision processes around groundwater and wetland management?***

Through interviews and a FRAM analysis, a number of sources of information were identified as integral to LBMCOC's decision-making process. Town staff play a key role in liaising with LBMCOC residents, bringing those issues to town council and defining the town's political agenda. MNAI is an external organization which contributed significantly to LBMCOC's natural asset management initiatives and provided the town with the framework to continue pursuing other natural asset projects. The consulting firm CBCL Limited provided environmental services for the town, which lacked the technical expertise to engage in wetland identification, mapping and flood zone reviews among other types of assessments. Additionally, the town's Development Regulations serve as a resource to town council and staff, as it provides guidelines that endure beyond the duration of a councillor's time spent on council or a staff member's employment with the city. The town staff's integration of the CBCL wetlands study results into the Development Regulations ensures the information collected is mobilized and will inform future municipal decisions even when political change occurs.

Evidently, a majority of the information used to make decisions comes from external sources with specialized knowledge in that area. LBMCOC's strength in their natural asset management approach was their recognition that additional support was needed from organizations such as MNAI to engage in their efforts. Collecting data and resources from multiple sources empowered them to choose which approach they felt was best for their municipality. For example, after their initial work with MNAI, they were provided with a variety of options available for future natural asset projects, and they chose to continue the process with a consulting firm that would produce science-based evidence for their policy decisions. Municipalities facing similar issues who have not taken the steps to reach out for additional support may not be aware of some such options. LBMCOC's search for information and additional support was the foundation to their groundwater and wetland management strategy.

***Research Question 3: What are the implications of increased municipal responsibilities around groundwater/wetland management?***

In Chapter 4, research question 3 was answered using functional signatures in the data analysis process to see how the relationships among various functions led to either successful or unsuccessful outcomes in the model. Just by looking at the model, it was already clear that there was a high degree of separation amongst the different stakeholders in the model. The municipal, provincial and federal government function groups are very distinct; it is visually evident that work is carried out separately amongst the different groups. While running various functional signatures through the DynaFRAM and observing the various functions in the process, it became apparent that four different maps are used to assess wetlands by different stakeholders in the system. All the maps being used vary in age, accuracy and detail. It became clear that there are some redundancies in the process that could be streamlined if municipalities and provinces were working together more closely. In the case of LBMCOC, they were doing significant wetlands research and applying it to the permit review process, but there was no opportunity for this data to be shared with the province.

A number of implications in the shift of responsibility were made evident when answering research question 3 through the data analysis process. The downloading of responsibilities onto municipalities to manage the approval of Section 48 permits puts more stress on already-limited municipal capacity. It also may have affected the stringency of the review process, as many municipalities do not have the resources to engage in natural asset management—nor is it a requirement of the province—leaving wetlands vulnerable in some circumstances. Municipalities such as LBMCOC, which have undertaken efforts to manage their wetlands, have done so of their own accord without provincial support; however, as previously mentioned there are not many opportunities to share their findings, maps and data with the province. While the downloading of responsibilities to municipalities empowered them to have more direct control over development within their boundaries, without support from the province it has proven to be more responsibility than some municipalities have the capacity for.

***Research Question 4: What factors explain the success of groundwater/wetland management in LBMCOC?***

Section 4.4 used the DynaFRAM analysis to highlight the variables responsible for LBMCOC's successful groundwater/management approach. These include:

- LBMCOC's strong incentive for managing groundwater/wetlands
    - their refusal of piped infrastructure, lack of headwaters within community boundaries and desire to maintain minimum 1-acre resident lots has resulted in their reliance on groundwater as their sole source of water for the community
- Funding availability in the budget for their natural asset inventory initiative, which would later help them secure federal funding for projects with CBCL
- The Gas Tax Fund, which was both a source of funding and also a major incentive for creating a natural asset management strategy

- Reaching out to MNAI for help producing a preliminary natural asset inventory, educating the municipality on their natural assets and informing them of possible next steps to take in their management efforts
- Having support from town councillors and residents who understood the importance of groundwater and wetlands for the community
- LBMCOC's effective knowledge mobilization, including their integration of the wetlands study into their Development Regulations

**5.2 Study Implications on Groundwater Governance**

Historically, groundwater has been a vital yet poorly managed resource due to its lack of visibility and the belief that it is an infinite resource (Kath and Dyer, 2017). While there has been an upward trend in policies designed to protect drinking water, they are often centered around surface water, neglecting the importance of groundwater (Kath and Dyer, 2017). This study sought to understand LBMCOC's approach to groundwater/wetland management to add to the existing body of knowledge on groundwater governance, with a focus on promoting effective groundwater and wetland management policy and strategies at the municipal level.

The FRAM analysis demonstrated the complexity of the case study, and there is more variability to be found in other municipalities, which vary in size, capacity, geography and resource needs. This study has shown that groundwater governance does not have a one-size-fits-all solution, and while lessons can be gleaned from LBMCOC, the results from this study may not necessarily apply to other communities. The same can be said for groundwater governance on a larger scale, where concerns surrounding transboundary water management, population pressures, political differences and other factors complicate groundwater/wetland management efforts. Effective groundwater policy must be tailored to fit the needs of the community it serves, but before this can be done effectively, we need to learn more about groundwater itself. LBMCOC's integrated approach, which recognized how wetland function is intertwined with groundwater supply and recharge, informed their management strategies. Wu, Ma, and Wang (2020) assert that it is vital to understand the interactions between groundwater and wetlands in order to conserve them. LBMCOC's collaboration with consulting firms and non-profits such as MNAI helped them collect data on the natural assets within the community—the first step in groundwater governance should be understanding what you are protecting.

The results from the interviews and data analysis of this study indicated that municipalities do not necessarily want full responsibility of the management of these resources, nor do they want to be excluded from the conversation. In the case of LBMCOC, most interviewees indicated they wanted more support and collaboration among different levels of government. There are often debates as to whether a "top-down" or "bottom-up" approach is better, and it was one of the questions included in my interviews. The answers received from participants never indicated one was better than the other, and I was led to believe that groundwater governance is more nuanced than the dichotomy of bottom-up vs. top-down. As demonstrated in Section 5.1, the downloading of responsibilities to municipalities resulted in a bottom-up approach that overwhelmed municipalities with decision-making for which they were not yet equipped and a siloed process where communication between municipality and province was not promoted. The bottom-up approach was not necessarily empowering when capacity was limited, and guidance was not available. Based on the results of this study, it is likely that more effective governance will be possible when there is more open communication amongst different levels of government and collaboration on approval processes such as that of the Section 48 Permit.

LBMCOC's groundwater/wetland management strategy also highlighted the importance of science-based evidence as an effective management tool. When a development application posed a potential threat to a sensitive wetland ecosystem, the municipality was able to refer to studies carried out by CBCL and other consulting firms and use that data to support their decision to refuse a permit. If developers disagree with the data and wish to contest the decision, their new delineations add to the existing body of knowledge of wetland boundaries. As a result, LBMCOC's approval process centers around the data, rather than the politics, surrounding wetland development. Municipalities are empowered by information, which can often be their most effective tool in groundwater governance. Having information on resources to reach out to for support and knowing how to mobilize knowledge gained from collaborations with organizations such as MNAI are key components of effective groundwater governance.

Another lesson to be taken from this study is the importance of a holistic framework perspective in groundwater governance. When looking to manage groundwater resources, one cannot solely look at groundwater. As explored in this study, it is necessary to look at all the factors affecting groundwater. Not only wetland health, but how developments may affect wetland function and groundwater recharge or how public policy surrounding something seemingly unrelated like resident lot size can have a direct impact on groundwater availability.

LBMCOC's primary strength was in their ability to look at their community holistically and make the connection between wetlands and groundwater and understand the implications of their decisions. Managing their wetlands will contribute to efforts to protect their groundwater. As Kath and Dyer (2017) succinctly write, effective groundwater governance requires that wetlands and groundwater are managed "conjunctively, as 'one water'".

### 5.3 Research Question 5: What best practices can be drawn from this case for potential use by other communities in Newfoundland?

The final research question that has guided this study is: "What best practices can be drawn from this case for potential use by other communities in Newfoundland?". The objective of this research has not only been to understand LBMCOC's response to a shift in responsibility, but also to gather insight on successes in their approach which could easily be applied to other municipalities who are facing similar dilemmas. This section will highlight these recommendations which have emerged from the data analysis, discussion and findings sections of this study. A few steps municipalities can take to engage in effective groundwater/wetland management include:

- Assessing what sources of water are available to the community, now and in the future, and which risks may affect their quantity/quality. An important step in LBMCOC's approach was assessing their water supply options and understanding that groundwater protection was a priority because no other water sources were available to their community.

- Understanding natural assets is a long-term investment in the community. Municipalities who prioritize short-term financial benefit over long-term sustainability will have difficulty allocating funding towards natural asset management efforts. In order to engage effectively in natural asset management, it is imperative that municipalities understand the implications of mismanaging these resources, such as the ramifications of removing a functional wetland.

- Seeking outside support. It is difficult for municipalities to know where to seek help with their management strategies if they are unaware organizations such as MNAI exist. Part of the goal of this study is to draw attention to the outside resources that can assist municipalities in developing tools and resources to draw from when having to make difficult decisions surrounding town development. Some municipalities may be unaware of programs such as the Gas Tax Fund and how they can assist with funding.

- Connecting with other municipalities. There is much to be learned from the approach of other municipalities. Interviewees shared that opportunities for town staff from various municipalities to congregate have provided an avenue for staff to share their natural asset management strategy with others. It can be beneficial to learn how other towns have handled this difficult issue and is another way to learn about helpful organizations such as MNAI or environmental consultants such as CBCL.

- Due diligence is necessary when scrutinizing potential developments that may alter wetlands. While municipalities are not required by the provincial government to consider wetlands when reviewing Section 48 permits, failure to do so could negatively affect vital wetland ecosystems providing invaluable natural services to the community. LBMCOC's management strategies surpass what is required of them, but ensures a sustainable, protected groundwater supply.

- Groundwater and wetland management should be effectively integrated into Municipal Planning and Development Regulations. As demonstrated in Chapter 4, once data is collected, it is imperative that it is incorporated into a legally binding town document and can be used to justify decisions in case of a dispute.

- Garnering public support. In the case of LBMCOC, there is community buy-in to the idea of rural, low-density living, which depends on their ability to rely on groundwater. Therefore, there is more public support for natural asset initiatives. Other municipalities should identify what water and wetlands mean to their community to understand how to appeal to residents and gain support for conservation and management efforts.

# Chapter 6: Conclusion

This chapter will summarize the results and finding of the study and will conclude with a review of the study's contribution to literature, limitations, and suggestions for future research.

## 6.1 Summary of Findings

The objective of this thesis was to understand how groundwater resources are managed at the municipal level in Newfoundland through observing the case-study community of LBMCOC. The FRAM was used as a tool to understand the community's groundwater/wetland strategies holistically. As more information was gathered, it soon became clear that wetland management was just as integral to the protection of groundwater supplies as the management of groundwater itself, and the scope of this thesis was expanded to include this important consideration. Data from semi-structured interviews and a FRAM/DynaFRAM analysis was used to produce a model of the town's information and decision-making processes around groundwater. Through scenario analyses, answers to the research questions were developed, which were described in depth in Chapter 4 but will be summarized in the following paragraphs.

The first research question was: "How can the FRAM be used to understand the decision-making processes made across an entire community in regard to groundwater and wetland management?". The FRAM methodology informed every step of the study, including the types of questions that were asked in interviews, the structure of the interviews themselves, the number of interviews I conducted and the level of detail that was necessary in the data to produce a useful FRAM model. The model was developed as I interviewed participants, evolving as I collected new data—it was a physical manifestation of what I was learning. The FRAM enabled me to visualize the entire system and observe relationships that I would not have seen if I had not taken the time to synthesize the interview data. When simply looking at the model, my inherent bias often led me to believe some functions were vital to the system's performance but conducting a FRAM analysis would show that the system could continue without it.

In line with the holistic framework approach, the FRAM only allows you to view a system in its entirety. The process of creating the model helped me define the scope of the thesis, as I could set concrete boundaries with boundary functions signaling the parameters of the study. If I had not conducted this study using FRAM methodology, my analysis would likely have remained at the municipal level; it was defining the boundary functions that prompted me to look at outside influences on the system, such as federal incentives, which only came about as I tried to grow the model and understand the influences behind some of the functions.

The FRAM analysis showed which information and decision processes around groundwater and wetland management are utilized by LBMCOC. Open communication between town staff and residents allows for concerns to be heard and shared with council if a major issue is identified. Community support for groundwater protection also incentivizes political action at the municipal level and was identified by an interviewee as a popular campaign platform for councillors. Non-governmental and non-profit organizations such as MNAI are an asset to communities like LBMCOC that want to take on more advanced management strategies but lack the tools and resources to do so. Consulting firms—in this case, CBCL Limited—are another source of data for municipalities who have the funding available to hire environmental scientists and habitat biologists to provide in-depth data on the ecosystem services provided by natural assets in the community. All of this information was incorporated into the town's Municipal Plan and Development Regulations, which become a reference and tool for decision-making that will endure even when turnover occurs.

The newfound municipal responsibilities around groundwater and wetland management in LBMCOC resulted in a number of implications observed in the FRAM model, including increased pressure on already limited municipal capacity. While interviewees indicated a preference for a bottom-up approach to management (as decisions around permit allocations directly affect the municipality), participants were frustrated at a lack of communication and collaboration between the two levels of government. The FRAM analysis showed an application review process which was siloed, resulting in efficiencies that could be remedied by more open collaboration between municipal and provincial levels. This includes redundancies in the information and maps used to review applications. While capacity is limited at both levels, it is possible that streamlining the application review process would not only reduce the load on both levels of government but also lead to more well-informed decision-making.

There were a number of factors which contributed to LBMCOC's success in their groundwater/wetland management approach. The community's decision to refuse piped infrastructure resulted in groundwater being their only source of water, which requires wetlands to support its long-term viability. Thus, LBMCOC has a major incentive for properly managing these resources. If they were to mismanage their groundwater (by overdrawing from wells or developing over wetlands that recharge groundwater supplies) and needed to implement piped services, the town would become vulnerable to high-density development which would drastically change its highly valued rural character. Support from the community and town council was important to justify allocating funding from the town's budget towards natural asset inventory efforts. As discussed in Section 4.5, MNAI identified political pressures and policy changes as a threat to wetlands, which highlights the influence political agendas at the municipal level have on natural asset management initiatives. A strength of LBMCOC was their ability to secure funding for these inventory efforts, but funding can also be an obstacle. Interviewees shared that funding availability prevented the town from conducting functionality assessments of LBMCOC's wetlands due to prohibitive costs. There were a few outside influences on the town's approach which also contributed to their success. The Federal Gas Tax Fund provided incentive for a natural asset plan, as well as partial funding to carry out the CBCL wetlands study. MNAI was able to guide the municipality through the initial inventory process, providing support, data and tools. Their involvement was an important first step in the municipality's venture into natural asset inventories and set them on a path for success. As a result of these efforts, the town of LBMCOC is able to make informed decisions on future development projects which could have adverse effects to the safety and availability of their groundwater.

## 6.2 Contribution to Literature: Applying the FRAM to a Community

Section 2.7 provides an overview of the topics that have previously been explored using the FRAM model, demonstrating that the method has not yet been applied to a municipal context. Therefore, this research has contributed to a growing body of knowledge on the FRAM and its capabilities by exploring a novel approach to the method. While this thesis sought to understand groundwater governance at the municipal level, the research process itself was an exploration of the capabilities of the FRAM. Mapping the work carried out on a factory floor is much different than mapping the decision-making processes of a municipality. The policy process is not linear and rarely happens in a straightforward manner; part of the difficulty in this study was dissecting this process and finding a way to depict it in the model without misrepresenting reality.

As mentioned in Section 2.4.2 of the literature review, there are academics urging policy makers to take a more holistic approach to groundwater governance (Famigilietti, 2014; Kath and Dyer, 2017; Rivera, 2005). This entails recognizing that surface and groundwater are connected, and policies should reflect this relationship. This thesis has recognized wetland conservation as an integral component of groundwater management and has aimed to contribute to the body of literature on this subject (Kath and Dyer, 2017).

### 6.3 Limitations of Study: Areas for Future Research

This study has a number of limitations that merit mention, as they are also areas for possible future research. The scope of this thesis was limited by the relatively short duration of a master's program. If time permitted and a researcher wished to further explore the capabilities of the FRAM, conducting a multi-town case study may have yielded additional insights into how municipalities have dealt with the difficult issue of groundwater and wetland management. This would entail creating a FRAM model for each community and contrasting and comparing their approaches, which could shed light on the different types of challenges faced by other communities. This study sought to understand the actions taken by LBMCOC, using the FRAM to show the community their process in a different light, but also to gain insight for other municipalities. While recommendations for other towns were extracted from this work, every municipality in Newfoundland faces their own challenges, unique resources, capacity and geography. A multi-town case study could possibly yield a wider breadth of data that could be applied to more communities.

This thesis is the first instance of applying a FRAM to a municipality in order to understand their policy and decision-making process. Therefore, the approach was experimental in a sense, as I attempted to map an intricate, complex community as a socio-technical system. This is only the first instance of doing so, and there is room for the methodology to be improved upon and refined. The FRAM is easier to view in video form, which presented a challenge when trying to communicate the movement of paths in a functional signature through text and images. Another challenge of the FRAM is the length of time and training needed to understand and interpret a model; it is not necessarily intuitive or easy to read. While a large component of this thesis was developing ways to make the FRAM easier to understand at first glance, there is an opportunity for future researchers to be creative with how FRAM models are presented so that readers can better engage with them. It is also recommended that future FRAM researchers expand on the application of the FRAM to novel systems such as municipalities, as it encourages viewing complexity in a holistic manner. Rather than viewing a system in silos, the FRAM encourages researchers to consider the purpose of every function of a system. Expanding the functionality of the FRAM by applying it to increasingly diverse scenarios will push the boundaries of the method and hopefully lead to further discoveries.

### 6.4 Final Reflection

Possibly the most valuable lesson that can be learned from the case of LBMCOC is the power of local government and residents to take control over the future development of their community. Faced with a newfound responsibility to assess permits for developments within LBMCOC, the municipality was resourceful in seeking out new information, external resources and support to help them where their own capacity was limited, and empower themselves with scientific evidence. Unfortunately, there are many communities in Newfoundland struggling with similar development pressures, who have groundwater supplies vulnerable to a changing climate and who may lack the capacity to take the same steps as LBMCOC. There is no easy answer to these problems, and while this thesis has provided best practices that could possibly be adopted by other communities in Newfoundland, every community and the challenges it faces require unique solutions. At the minimum, attention can be brought to these issues, and studies such as this one can highlight the importance of learning more about how groundwater, wetlands and the ecosystems they exist in are interconnected.

While more than 2 billion people globally rely on groundwater for their everyday use, there is still much that is unknown about this precious yet hidden resource (Famiglietti, 2014). With a rapidly changing climate, unpredictable weather events, population growth and development pressures, it is increasingly important that groundwater and its relationship with wetlands is better understood, that they are better protected and that humans consider the impacts of their actions.

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## APPENDIX I: Recruitment Text

**Subject:** Invitation: Interview for Research Project on Groundwater Management

**Email Body:**

Dear [participant's name],

My name is Julia Fracassi. I am a master's student in the Environmental Policy program at Memorial University of Newfoundland's Grenfell Campus and I am the principal investigator for this study which will focus on the issue of groundwater management in [Community Name]. Under the supervision of Dr. Garrett Richards (grichards@grenfell.mun.ca), we are working to understand how communities make decisions and how best to manage groundwater resources that are essential to community members.

**Who can participate?**

We are looking for participants who are involved in the community and have interest in and/or knowledge on the topic of groundwater use, local government decision making, and current challenges in groundwater management. This may include: community residents and businesses, municipal staff, town council members, and Federal/Provincial government employees.

**What is involved?**

Participants will be invited to participate in a one-on-one interview with me (virtually, via phone, or possibly in person). I plan to be in the area for a week around early May, which is when I would be conducting interviews in person. The interviews are expected to last roughly an hour but can be adjusted based on your availability.

If you are interested in participating (virtually, via phone, or possibly in person), or have any questions/concerns, you can contact me at jccsfracassi@grenfell.mun.ca or +1(647) 460-9620. You can also contact the Grenfell Campus Research Ethics Board (gcethics@grenfell.mun.ca) if you have any additional questions or concerns regarding the study.

Thank you for considering participation in this project!

**Response Email for Those Interested in Participating:**

Hello [insert first name here],

Thank you for showing interest in this project! If you have any questions, I have attached a consent form that provides more details on what is involved. I will collect your signature at the bottom of that form at the beginning of the interview, should you choose to proceed. If you still have more questions or concerns, I’m happy to answer them here or you are welcome to call me at +1 (647)-460-9620.

If you are comfortable with continuing, we can schedule an interview at a time and location that is convenient. Due to the ongoing pandemic, participants are free to choose to complete the interview virtually or possibly in-person. My availability is [insert available interview times]. Please let me know how you would like to proceed.

Thank you for your time.

## APPENDIX II: Informed Consent Form

GRENFELL CAMPUS | MEMORIAL UNIVERSITY | Informed Consent Form

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You are invited to take part in a research project entitled: **“Groundwater Governance in Atlantic Canada”**.

**Researcher:** Julia Fracassi, Environmental Policy Institute; Grenfell Campus, Memorial University of Newfoundland; jccsfracassi@grenfell.mun.ca, +1 (647) 460-9620

**Supervisor:** Dr. Garrett Richards, Assistant Professor, Environmental Policy Institute; Grenfell Campus, Memorial University of Newfoundland; grichards@grenfell.mun.ca, (709) 639-6534

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**Project Summary:** This project is part of a larger research program called “Future Ocean and Coastal Infrastructures” (FOCI) and is funded by the Ocean Frontier Institute (OFI). This study will focus on the issue of groundwater management, a problem that is becoming increasingly difficult to manage. Understanding the decision-making process in communities may shed light on how best to manage this dwindling resource that is integral to community members. We are seeking participants who are involved in the community and have interest in and/or knowledge on the topic of groundwater management to help us better understand:

- The present state of the community
- Its local government and its level of capacity
- Challenges it is currently facing
- Approaches it is taking (if any) towards groundwater management.

**Interview Procedure**

- Participate in a one-on-one interview with the principal investigator, Julia Fracassi
- Interview length is roughly an hour but can be adjusted based on your availability
- Due to the ongoing pandemic, you may choose to do the interview either virtually (via video conferencing software such as Cisco Webex Meetings or Zoom), by telephone, or in person
- With your consent, these interviews will be recorded to assist with the data analysis process (If you do not consent to being recorded, indicate so on this form and let the principal investigator know before the start of your interview)
- Participants are welcome to request a copy of the interview recording to review and revise

**Withdrawal from the study**

- Participation is voluntary
- You may choose to answer only questions you feel comfortable responding to, withdraw responses after they have been given, and end the interview at any time
- You are free to withdraw from the project at any point in time, for any reason, with no negative consequences
- If you choose to end your participation, your data, record of involvement, interview recordings and any other material tied to you will be deleted securely and removed from the research analysis if possible (you will be notified of this removal)
    - Should you withdraw after one month of your participation, removal of your data may still be possible but is not guaranteed (there are limitations to the data that can be removed if you choose to withdraw after data analysis has been completed or if the findings have already been published publicly)

**Confidentiality and Anonymity**

- Researchers will make every reasonable effort to maintain privacy and protect the confidentiality of participants' identities
- All information collected through interviews will be stored on a password-protected device, which only the principal investigator will have direct access to
- Interviews will be conducted solely by the principal investigator with the participant in a one-on-one interview in a private setting (your involvement is confidential to other participants)
- If your comments are quoted or paraphrased in either a presentation or publication, they will not be directly attributed to you. As participants will all be members of the case study community, it may be possible that others can discern your identity based on your interview responses (although every effort will be made to keep data confidential and anonymous)
- For participants who wish to review a recording of their interview before it is used in the data analysis, a copy (only visible to the principal investigator and participant) will be sent via OneDrive

**Questions or Concerns**

If you would like more information about this study or have any concerns, please contact either the principal investigator or supervisor listed at the beginning of this form. The proposal for this research has been reviewed and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research, such as the way you have been treated or your rights as a participant, you may contact the Grenfell Campus Research Ethics Board (709-637-7193, research@grenfell.mun.ca).

**Consent**

Your signature on this form means that you have read the information about the research, you have been able to ask questions about this study and are satisfied with the answers, and consent to participation.

I consent to audio/video recordings being made of my interview with the principal investigator:

☐ Yes ☐ No ☐ Audio Only ☐ Send me a copy of my recordings to review

**Your signature:**

| ______________________ | ______________________ | ______________ |
|---|---|---|
| *Name of Participant* | *Signature of Participant* | *Date* |

***One copy of this consent form will be left with you, and one copy will be taken by the researcher.***

## APPENDIX III: Semi-Structured Interview Guide for Researcher

(Not shared with participants – internal guide only)

*Groundwater Governance in Atlantic Canada: Using FRAM to help coastal communities in Newfoundland develop forward-looking adaptation strategies*

Introduction

Thank you for taking the time to meet with me today. My name is Julia Fracassi and I am the Principal Investigator for this study. Before we begin, I'd like to confirm that you've read and agreed to the Consent Form and that your signature is at the bottom of the form. I'd also like to confirm that you consent to being audio recorded during this interview, which will be used for data analysis. The recordings will be transferred to a secure computer and deleted from the handheld device following the completion of our interview. This interview will be kept anonymous and confidential, therefore your comments will not be connected with your name and personal information. You may choose to end the interview at any point, without consequences, in which case I will confirm whether I am permitted to use the information you've already shared or if everything should be deleted.

This interview will likely take up to an hour, but we can adjust the length based on your preferences.

Before we begin, do you have any questions or concerns you'd like to discuss?

---

1. **What led you to participate in this study?**

2. **Can you tell me a bit about yourself?**

3. **What is your connection to [Community Name]?**

   Prompt

   i. How long have you lived/worked in this community?
   ii. Have you observed any significant changes in the community over time?
   iii. What made you want to live in [Community Name]?
   iv. What are some pros and cons to living in the community?
   v. Is there a change you would like to see in how decisions are made in the community?

4. **What do you currently know about groundwater management in [Community Name]?**

   Prompt

   i. Do you know how residents get access to water, and where that water comes from?
   ii. Would you define current groundwater levels as scarce, moderate, or abundant?
   iii. Do you know who makes decisions surrounding groundwater? Please elaborate.
   iv. Are there currently any public outreach efforts to educate the public?
   v. How are community members engaged in this issue?

**<u>Additional Questions for Government Employees:</u>**

5. **How are groundwater issues managed at different levels of government?**

   Prompt

   i. How do problems make it on to the political agenda?
   ii. What factors affect decisions for future infrastructure?
   iii. What are common obstacles to resolving an issue?
   iv. Is a top-down or bottom-up approach better for tackling groundwater use? Can you provide an example to justify your answer?

6. **What are some obstacles to effective groundwater management?**

   Prompt

   i. What challenges have you encountered when addressing this issue affecting multiple municipalities?
   ii. Who are the various stakeholders engaged in this issue?
   iii. How could land use regulations be changed to promote sustainable groundwater use?

7. **In what way could inter-governmental communication and/or collaboration be improved?**

   Prompt

   i. How do you feel about the effectiveness of current government structures?

ii. What are some obstacles to collaborating with different levels of government, in regard to managing groundwater usage?

**8. What role do researchers play in the decision-making process in regard to groundwater management?**

Prompt

i. What sources of data are currently used to inform decisions?
ii. How can researchers help produce more valuable information for the decision-making process?

**9. Is there anything else you would like to share?**

Thank you for taking the time to speak with me today. You are more than welcome to contact me at a later time if you think of anything else you would like to add to this interview.

## APPENDIX IV: FRAM Model in Table Format

| | |
|---|---|
| Name of function | Initiate the creation of municipal asset inventory |
| Description | |
| Aspect | Description of Aspect |
| Input | Wetland conservation added to agenda |
| Output | Council is able to proceed with project |
| | Make contact with MNAI |
| | Asset plan lays groundwork for study |
| Precondition | Councillors influence political agenda |
| Resource | Funds available for hiring consultants |
| Control | Municipality relies on groundwater |
| Time | |
| Name of function | Apply for Federal Gas Tax Program |
| Description | The core federal funding stream for municipalities. Provides long-term funding for infrastructure projects |
| Aspect | Description of Aspect |
| Input | Funding is needed to repair infrastructure |
| Output | Municipality meets program requirements |
| | Natural asset inventory needed for application |
| Precondition | Funds made available for municipal use |
| | Preliminary natural asset inventory is completed |
| Resource | |
| Control | |
| Time | |
| Name of function | Hire consulting firm (CBCL) |
| Description | |
| Aspect | Description of Aspect |

| | |
|---|---|
| Input | Council is able to proceed with project |
| Output | Environmental scientists hired |
| Precondition | |
| Resource | Funding used towards asset plan |
| Control | Preliminary natural asset inventory is completed |
| Time | |

| Name of function | To elect councillors |
|---|---|
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Councillors influence political agenda |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To secure funding from budget |
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Funds available for hiring consultants |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | Conduct study of wetlands, waterbodies, waterways |
| Description | |

| Aspect | Description of Aspect |
|---|---|
| Input | Environmental scientists hired |
| Output | LBMCOC waterbodies are assessed and mapped |
| Precondition | |
| Resource | |
| Control | Preliminary natural asset inventory is completed |
| Time | |

| Name of function | Publish wetlands, waterbodies, waterways study |
|---|---|
| Description | |
| Aspect | Description of Aspect |
| Input | LBMCOC waterbodies are assessed and mapped |
| Output | Town council has access to new info on waterbodies |
| | Maps & data created for wetlands/waterbodies |
| | Natural assets are inventoried |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | Propose changes in new town plan |
| Description | |
| Aspect | Description of Aspect |
| Input | Town council has access to new info on waterbodies |
| Output | |
| Precondition | |
| Resource | |
| Control | |

| | |
|---|---|
| Time | |
| Name of function | Apply for permit to alter body of water (municipal level) |
| Description | |
| Aspect | Description of Aspect |
| Input | Land is purchased for development |
| Output | Municipality receives request |
| | Municipality has no data to make decision |
| Precondition | |
| Resource | |
| Control | |
| Time | |

| | |
|---|---|
| Name of function | Consult waterbody study & Town Regulations |
| Description | |
| Aspect | Description of Aspect |
| Input | Municipality receives request |
| Output | Study shows wetland is present |
| | Study shows wetland is not present |
| Precondition | Development Regulations are in place |
| | Maps & data created for wetlands/waterbodies |
| | Asset plan lays groundwork for study |
| Resource | |
| Control | Development potential risk to wetland assets |
| Time | |
| Name of function | Deny permit to alter body of water |
| Description | |
| Aspect | Description of Aspect |

| | |
|---|---|
| Input | Municipality receives request |
| Output | Proponent contests decision |
| Precondition | |
| Resource | |
| Control | Study shows wetland is present |
| Time | |
| Name of function | Initate process to develop land |
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Land is purchased for development |
| Precondition | |
| Resource | |
| Control | |
| Time | |

| | |
|---|---|
| Name of function | To approve permit |
| Description | |
| Aspect | Description of Aspect |
| Input | Wetland is not functional |
| | Municipality receives request |
| Output | Proponent can now apply at provincial level |
| | Land is allowed to be developed |
| Precondition | |
| Resource | |
| Control | Study shows wetland is not present |
| Time | |

| | |
|---|---|
| Name of function | Hire consultant for more accurate delineation |
| Description | Must be prepared by professional engineering firm with input from habitat biologist |
| Aspect | Description of Aspect |
| Input | |
| Output | Wetlands are mapped |
| Precondition | Proponent contests decision |
| Resource | |
| Control | |
| Time | |
| Name of function | To refuse permit to alter water body |
| Description | |
| Aspect | Description of Aspect |
| Input | Wetland is functional |
| Output | Proponent decides not to continue |
| Precondition | |
| Resource | |
| Control | |
| Time | |

| | |
|---|---|
| Name of function | To apply for permit to alter a body of water (provincial) |
| Description | Submitted to Manager, Water Rights, Investigations and Modelling Division<br>(Water Resources Management Division) |
| Aspect | Description of Aspect |
| Input | |
| Output | Application is submitted to Manager at WRIM |
| Precondition | Proponent can now apply at provincial level |

| | |
|---|---|
| Resource | |
| Control | |
| Time | |
| Name of function | To assess development location vs. wetland map |
| Description | Water Rights, Investigation and Modelling (WRIM) |
| Aspect | Description of Aspect |
| Input | Application is submitted to Manager at WRIM |
| Output | Provincial authority approves delineation |
| | Provincial authority rejects delineation |
| | Development adjacent to wellhead water supply |
| Precondition | Province has data on existing wetlands |
| | Application is completed properly |
| Resource | |
| Control | Laws in place to govern wetlands |
| | Proponent prepares separate delineation |
| Time | |
| Name of function | Revise Municipal Development Regulations |
| Description | Development Regulations 2005-2015 |
| Aspect | Description of Aspect |
| Input | Natural assets are inventoried |
| Output | Development Regulations are in place |
| Precondition | |
| Resource | |
| Control | |
| Time | |

| | |
|---|---|
| Name of function | Natural Resources Canada Maps Wetlands |

| | |
|---|---|
| Description | Natural Resources Canada prepares 1:50,000 scale National Topographic System Maps |
| Aspect | Description of Aspect |
| Input | |
| Output | Province has data on existing wetlands |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To hire habitat biologist |
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Input provided by habitat biologist |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To produce more accurate delineation |
| Description | |
| Aspect | Description of Aspect |
| Input | Wetlands are mapped |
| Output | Wetland is functional |
| | Wetland is not functional |
| | Proponent prepares separate delineation |
| Precondition | Input provided by habitat biologist |
| Resource | |

| | |
|---|---|
| Control | |
| Time | |

| Name of function | Section 48 permit is issued to proponent |
|---|---|
| Description | |
| Aspect | Description of Aspect |
| Input | Provincial authority approves delineation |
| Output | Province allows land to be developed |
| | Permit has been obtained |
| Precondition | Development will not affect groundwater |
| Resource | |
| Control | |
| Time | |
| Name of function | Permit is not issued to proponent |
| Description | |
| Aspect | Description of Aspect |
| Input | Provincial authority rejects delineation |
| Output | Land is not allowed to be developed |
| Precondition | Development will negatively impact groundwater |
| Resource | |
| Control | |
| Time | |
| Name of function | All other application requirements fulfilled by proponent |
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Application is completed properly |

| | |
|---|---|
| Precondition | |
| Resource | |
| Control | |
| Time | |

| Name of function | To consider the Water Resources Act |
|---|---|
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Laws in place to govern wetlands |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To consider the Environment Protection Act |
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Laws in place to govern wetlands |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To assess headwaters in community boundary |
| Description | |
| Aspect | Description of Aspect |
| Input | |

| | |
|---|---|
| Output | No headwaters located within community boundary |
| Precondition | |
| Resource | |
| Control | |
| Time | |

| Name of function | To allocate funds from Infrastructure Canada to NL |
|---|---|
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Funding opportunities available for municipalities |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | FCM delivers funds to municipalities |
| Description | Federation of Canadian Municipalities (FCM) |
| Aspect | Description of Aspect |
| Input | Funding opportunities available for municipalities |
| Output | Funds made available for municipal use |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To develop preliminary natural asset inventory |
| Description | Municipal Natural Assets Initiative (MNAI) |
| Aspect | Description of Aspect |

| | |
|---|---|
| Input | Make contact with MNAI |
| Output | Data is gathered |
| Precondition | |
| Resource | |
| Control | Tool can now be used for natural assets |
| | Natural asset inventory needed for application |
| Time | |

| Name of function | To adapt FCM's<br>asset mgmt assessment tool |
|---|---|
| Description | FCM (Federation of Canadian Municipalities) |
| Aspect | Description of Aspect |
| Input | |
| Output | Tool can now be used for natural assets |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To delineate type/location/condition of natural assets |
| Description | |
| Aspect | Description of Aspect |
| Input | Data is gathered |
| Output | Natural asset database is created |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To create interactive map of natural assets |

| | |
|---|---|
| Description | |
| Aspect | Description of Aspect |
| Input | Data is gathered |
| Output | Map of natural assets in community is created |
| Precondition | Natural asset database is created |
| Resource | |
| Control | |
| Time | |

| Name of function | To identify risks facing natural assets |
|---|---|
| Description | |
| Aspect | Description of Aspect |
| Input | Data is gathered |
| Output | Risks have been identified |
| | Development potential risk to wetland assets |
| Precondition | Natural asset database is created |
| Resource | |
| Control | |
| Time | |
| Name of function | To adopt well and septic policy |
| Description | (look up earlier versions of town development plan) |
| Aspect | Description of Aspect |
| Input | Refuse piped infrastructure |
| | No headwaters located within community boundary |
| Output | All housing in municipality relies on well and septic |
| | Municipality relies on groundwater |
| Precondition | |

| | |
|---|---|
| Resource | |
| Control | Maintain one-acre lots for sustainable yield |
| Time | |
| Name of function | To conduct muti-level groundwater study |
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Maintain one-acre lots for sustainable yield |
| Precondition | |
| Resource | |
| Control | |
| Time | |

| | |
|---|---|
| Name of function | Town staff bring issue to council |
| Description | TC now has to develop process for approving permits to alter bodies of water |
| Aspect | Description of Aspect |
| Input | WRIM no longer in charge of development permits |
| | Municipality has no data to make decision |
| Output | Wetland conservation added to agenda |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To assess residents' water use needs |
| Description | |
| Aspect | Description of Aspect |
| Input | |

| | |
|---|---|
| Output | Refuse piped infrastructure |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | Proponent begins building process |
| Description | |
| Aspect | Description of Aspect |
| Input | Proponent decides to build house |
| Output | Surrounding infrastructure upgraded to support development |
| | Minimum size of lots are one-acre |
| Precondition | Permit has been obtained |
| Resource | |
| Control | |
| Time | |

| | |
|---|---|
| Name of function | Proponent is informed of denial of permit |
| Description | |
| Aspect | Description of Aspect |
| Input | Land is not allowed to be developed |
| Output | Proponent decides not to continue |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To receive funding for infrastructure projects |
| Description | |

| Aspect | Description of Aspect |
| --- | --- |
| Input | Municipality meets program requirements |
| Output | Funding used towards asset plan |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To give permit responsibility to municipality |
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | WRIM no longer in charge of development permits |
| Precondition | |
| Resource | |
| Control | |
| Time | |

| Name of function | To upgrade municipal infrastructure |
| --- | --- |
| Description | |
| Aspect | Description of Aspect |
| Input | Surrounding infrastructure upgraded to support development |
| Output | Infrastructure upgraded for lot safety |
| Precondition | |
| Resource | |
| Control | Permit has been obtained |
| Time | |
| Name of function | To implement well and septic services on lot |

| | |
|---|---|
| Description | |
| Aspect | Description of Aspect |
| Input | Minimum size of lots are one-acre |
| Output | Developer has followed mun. + prov. dev regulations |
| Precondition | All housing in municipality relies on well and septic |
| Resource | |
| Control | Permit has been obtained |
| Time | |
| Name of function | To identify infrastructure needing repair in municipality |
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | Funding is needed to repair infrastructure |
| Precondition | |
| Resource | |
| Control | |
| Time | |

| | |
|---|---|
| Name of function | A house is built |
| Description | |
| Aspect | Description of Aspect |
| Input | |
| Output | |
| Precondition | Province allows land to be developed |
| | Developer has followed mun. + prov. dev regulations |
| | Land is allowed to be developed |
| | Infrastructure upgraded for lot safety |

| | |
|---|---|
| Resource | |
| Control | |
| Time | |
| Name of function | To submit report to municipality |
| Description | |
| Aspect | Description of Aspect |
| Input | Risks have been identified |
| | Map of natural assets in community is created |
| Output | Preliminary natural asset inventory is completed |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | Proponent makes decision about proceeding |
| Description | |
| Aspect | Description of Aspect |
| Input | Province allows land to be developed |
| Output | Proponent decides to build house |
| | Proponent decides not to continue |
| Precondition | |
| Resource | |
| Control | |
| Time | |

| | |
|---|---|
| Name of function | Proponent builds somewhere else |
| Description | |
| Aspect | Description of Aspect |

| | |
|---|---|
| Input | Proponent decides not to continue |
| Output | |
| Precondition | |
| Resource | |
| Control | |
| Time | |
| Name of function | To conduct Groundwater Assessment |
| Description | |
| Aspect | Description of Aspect |
| Input | Development adjacent to wellhead water supply |
| | Municipality relies on groundwater |
| Output | Development will not affect groundwater |
| | Development will negatively impact groundwater |
| Precondition | |
| Resource | |
| Control | |
| Time | |