Watershed Management and Services for Flood Control

Supervised Research Project

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Executive Summary

The research paper explores the use of ecosystem services, specifically for flood regulation, in order to advance research in community resilience to climate change and decrease the costs of infrastructure repair and maintenance associated to damage from storms. The goal of the research is to contribute towards mainstreaming environmentally sustainable planning practices by creating a scalable and replicable model to evaluate the hydrological landscape of a watershed and provide best management practices to guide decision-makers.

The methods used to evaluate ecosystems services were twofold. The first method uses a hydrological flow accumulation model which provides an understanding of existing and future watercourses, which is essential to understanding the drainage of the watershed. The second method uses the Soil Conservation Service's (SCS) runoff curve number method to compare the effectiveness of different types of land cover types at retaining water. The goal of the methodology section is to provide a template of the workflow in order to replicate this model for any rural watershed. The case study that was chosen to apply these methods is a small, rural community in New Brunswick, Haute-Aboujagane, which has a history of flooding and culvert washout and is extremely vulnerable to climate change.

The research guides a series of planning recommendations that are based on hydrological analysis for Haute-Aboujagane. The plan seeks to improve the community's capacity to adapt. The results of the model are presented in a series of maps which are then used to make informed recommendations for the community in order to best avoid development on future floodplains. In addition, the recommendations include best practices to implement environmentally sustainable designs that mitigate flooding and improve the ecological health of the area.

Introduction

Human civilization has a long standing history of altering landscapes to support the needs of people. As a species, we have more or less succeeded to develop many habitats in areas that would otherwise be hostile living environments. Our ability to adapt to these harsh environments – to develop land and resources, has contributed to incredible progress and gains for human well-being. However, the development of a world that supports an increasingly massive and interconnected civilization is taking a great toll on the environment; meeting the needs of this population threatens the health of ecosystems and the climate of our planet.

The entanglement between human well-being, ecosystems and climate change is involuted. The significance of this research depends upon the acknowledgement that ecosystems are invaluable to humans and even more so under the threat of climate change. Although, it has been long understood that human health is contingent on ecosystems, it remains difficult to prioritize ecosystem health when planning human activity. This is especially true when communities are already under stress and planning is reactive.

Many civilizations, including our own, have prioritized human progress at the expense of ecosystem health. Fortunately, there are many signs that there is a shift in perspective. Practitioners and academics alike realize that tremendous changes must occur in order to ensure the service delivery of the most basic human needs that are derived from ecosystems, such as clean water and air. The birth of ecosystem service valuation techniques, such as *The Economics of Ecosystem Services* and *Ecological Asset Management*, are suggestive of this shift towards a more holistic perspective that equates human and ecological well-being and realizes that progress can no longer occur at the expense of the environment. Despite the frameworks that exist to guide the development of policies that help communities adapt to climate stressors, a gap remains between planning policy and implementation.

Although a systemic shift has been needed for many decades, protecting ecosystems is more important than ever. Increased global temperatures are causing sea-level rise, threatening ecosystem functioning, and increasing the frequency of severe storms. Considering many communities have relied upon observations of past climates and severe storms to inform decision-making concerning development, the increased intensity of storms is likely to undermine the viability of development plans, by introducing unforeseen parameters. Healthy ecosystems have an incredible ability to help communities adapt to the harmful effects of climate change, by increasing their resilience to severe weather events. Moreover, ecosystems often act as carbon sink for atmospheric carbon, making them important to mitigate increases in global temperatures.

The disastrous effects of climate change require adapting to previously unanticipated and unseen climatic stressors, including record droughts, flooding, forest fires, and storm surges, to name a few. While many large cities will have no choice but to implement infrastructure, such as sea walls, to protect their citizens from natural disasters, many small, rural communities will not have the means to do so. However, rural communities have an important advantage: they are often much closer to thriving ecosystems that provide an abundance of services, such as disaster mitigation, which can be capitalized on.

This research investigates how rural communities can incorporate the use of ecosystems for floodwater management services into community planning. It relies on the notions that prioritizing the value of natural infrastructure and ecological assets has the ability (1) to decrease the current flood risk of an area, (2) to help communities adapt to a changing climate, in which intense floods are more frequent, and (3) to decrease the costs of infrastructure repair and maintenance associated to flood damage. The goal is to create a replicable and scalable model for communities to value ecosystem services for floodwater management at the watershed level. The intention is to contribute to the literature and increase visibility on aforementioned topics, in order to continue to underline the importance of mainstreaming ecosystem services into regional planning.

The study relies on two methods to replicate and gain a better understanding of the hydrological dynamics of a watershed. First, a model of the hydrological flow accumulation confirms existing creeks and rivers in a watershed and maps new paths where water will flow up to existing creeks. Secondly, mapping the runoff potential of the land provides a model that may be used to evaluate the effects of alternative forms of land cover in the watershed. The runoff potential model uses different amounts of rain that are from multiple climate change and storm scenarios.

These methods are applied to the Aboujagane Watershed in southeast New Brunswick. Within this watershed lies a small rural community, Haute-Aboujagane, which has a history of culvert washout and infrastructure damage due to flooding. Flooding in Haute-Aboujagane gained visibility in 2012, when one particularly large storm event destroyed an important bridge used to access the community. Flooding is purported to occur on certain roads during regular storm events and there is visible damage to main roads due to erosion. Increases in the intensity and frequency of storms will make this small community particularly vulnerable to extreme storms, due to its geographic location; this will make infrastructure particularly expensive to maintain, especially considering low population densities.

The Aboujagane watershed lies to the south of the Northumberland straight, which is anticipated to be one of the most vulnerable areas to climate change in Canada. New Brunswick, like much of Atlantic Canada, is at particularly high risk of increased sea-level rise and storm impacts. Low population on vast rural territories mean that the province has a very high amount of roadway per capita and residents rely on infrastructure service that are difficult to maintain. The provincial strategy towards adaptation for flooding is currently insufficient to deal with the severity of the issue and protection of wetlands, watercourses and their riparian areas is seen as poorly implemented. Flooding is an important seasonal problem for New Brunswickers, causing major damages to communities, businesses, and municipal infrastructure every year. Previous studies and monitoring of the Aboujagane River make the site an appropriate location for this case study as there is a wealth of knowledge to which the results can be compared.

The findings of the study are a series of maps that demonstrate the most vulnerable areas of the watershed. The hydrological flow accumulation model is used to assess drainage throughout the watershed and runoff potential model allows us to visualize affects the distribution of different volumes of runoff sources in the watershed. The findings provide the basis for the recommendations, which seek to maximize the potential of ecological services for flood managements in the area.

The discussion elaborates on the meaning of these findings for the case study area and the provincial regulation. It discusses the current Rural Plan and the regulation on forest management and wetland protection in the province.

The recommendations attempt to improve on the current plan and the provincial regulations. It includes strategic recommendations to attenuate flood risks in the community, guide development away from areas that pose a high risk of flooding in the future, and decrease the costs of infrastructure repair and maintenance associated to flood damage. The recommendations are organized based on their feasibility and priority. Short-term policy recommendations are most feasible and high priority, whereas the subsequent recommendations (monitoring, long-term recommendation, and zones of vulnerability and improvement) are less probabilistic for the geographic and political context to which this study is applied.

The first chapter of the report begins with a review of the literature, which explores the significance of the research topic, including the current impacts of flooding in New Brunswick, the infrastructure gap, the need for adapting to climate change and applicable techniques. Chapter two, methods**,** provides a detailed workflow of how the research was conducted, including the creation of a hydrological flow accumulation model and a runoff potential model. The case study of Haute-Aboujagane and the Aboujagane Watershed is presented in the third chapter. In chapter four, the findings of the models are described. A discussion in chapter five examines the significance of findings and the limitations of the study. Lastly, in chapter six, the recommendations attempt to improve on the current plan and the provincial regulations to include strategic recommendations to attenuate flood risks in the community.

Chapter 1: Literature Review

Ecosystems are the fundamental building blocks of where the majority of our services are derived. We typically think of these as tangible goods, such as clean air and water, fuel, food, and fiber. The services that ecosystems provide are far more complex and far-reaching than what we can touch. Ecosystems provide many invisible services, such as protecting us against disease and natural disaster, and for creating the soils and nutrients that we depend on for agriculture. In this chapter the focus is on the importance of ecosystems for attenuating the risks of flood, for climate change adaptation and for protecting infrastructure. These are just three factors that make ecosystem services invaluable to planning and development.

1.1 Ecosystem Services: The Role of Ecosystems in Mitigating the Risks of Disaster

In contrast with the rather recent attention received by climate change science, awareness of complex services that ecosystems provide for humans can be traced back as far as Plato, circa 400 BC. Plato acknowledged the linkages between deforestation, soil erosion, and water retention and run-off.[1] The linkages between these ecosystem services would resurface in 1864, when George Perkins Marsh published his theory that the collapse of ancient Mediterranean civilizations was due to environmental degradation, namely deforestation. Marsh's analysis led him to find that deforestation was responsible for desertification and extreme soil depletion in the Mediterranean.[2] Consequently, he argued that better resource management would contribute positively to human welfare, an idea which has had an important impact in American conservation thought and policy.[3] In the late 1940s, Henry F. Osborn, Jr., William Vogt, and Aldo Leopold elucidated human dependence on ecosystem services, creating new waves in ecological thought.[4] It was only in 1973 that the term 'natural capital', which is the world's stock of natural resources that benefit humanity, was coined by Ernst F. Schumacher in his book *Small is Beautiful*.[5] Schumacher argued that Western economic models of endless growth were not sustainable, mainly because they treated

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[1] (Daily, 1997, p. 6)
[2] (Marsh, 1864)
[3] (American Memory, s.d.)
[4] (Robertson, 2012)
[5] (Schumacher E. F., 1973, p. 5)

resources as disposable income, rather than non-renewable capital. He proposed a standard of economic success based on maximizing human well-being and minimizing consumption, as opposed to the status quo, which measured economic success by gross national product.

> *"Far larger is the capital provided by nature and not by man—and we do not even recognize it as such. This larger part is now being used up at an alarming rate, and that is why it is an absurd and suicidal error to believe, and act on the belief, that the problem of production has been solved"*[6]
> *—E. F. Schumacher*

In 2005, the Millennium Ecosystem Assessment (MEA) produced a landmark report that focused on the anthropogenic damage to ecosystems. It popularized the term 'ecosystem services', which are the benefits that humans derive from ecosystems.[7] The report also drew attention to the irreversible damage that rapid advancements in human well-being had taken on the planet's diversity and ecosystems.[8] This report had a resounding impact on policy and decision-making[9] and propagated the typology of four types of ecosystem services:

- **provisioning** services are products obtained from ecosystems, such as food, fiber, and fuel;
- **regulating** services are the benefits obtained from the regulation of ecosystem processes, such as storm protection, erosion control, and the regulation of human disease;
- **cultural** services are the nonmaterial benefits obtained from ecosystems, such as recreation and aesthetic;
- and **supporting** services are the services needed for the production of all other ecosystem services, such as nutrient cycling and soil formation.[10]

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[6] ((Schumacher E. F., 1973)
[7] (Millennium Assessment, 2005)
[8] (Millennium Assessment, 2005)
[9] (Millennium Ecosystem Assessment, 2007)
[10] (Millennium Assessment, 2005)

The importance of natural ecosystems to human well-being has been widely acknowledged, including their role in disaster risk reduction. When healthy and properly managed, ecosystems play a crucial role in mitigating the effects of climate change and increasing our ability to adapt to it.[11] The MEA found that 60% of the world's ecosystems were degraded, which has contributed to a rise in the frequency of floods and major wild fires on all continents.[12] Notably, ecosystem degradation disproportionately affects poor communities, which lack the infrastructure and adaptation strategies to effectively and efficiently cope with natural disasters.[13] Natural infrastructure, which is a natural structure or system that delivers a service, has the potential to mitigate risk of disaster, as well as to replace engineered infrastructure.

The protection of the Catskill/Delaware Watershed in New York State is an example of how ecosystem services can be valued and protected as an alternative to engineered infrastructure. Moreover, it provides a case study for watershed management and Ecosystem Service Valuation, which is the monetary valuation of the services that ecosystems provide. The Catskill/Delaware Watershed is the largest unfiltered water system in the world. It is responsible for providing 1.2 billion gallons of drinking water to nine million people every day, including New York City. The quality of the watershed's filtration was questioned under the federal Safe Drinking Water Act. Without any environmental protection of the watershed, New York City would have been forced to construct a water treatment facility for its residents that could not be afforded within the city's budget. It was determined that protecting the watershed (1.5 billion USD investment) was the only financially viable option - building a water treatment plant would have cost between 8-10 billion USD (plus 300 million USD in annual maintenance and operation)[14]. New York City decided to actively pursue the protection of the watershed by purchasing land. This led to the creation of the 1997 New York City Watershed Memorandum Agreement, which includes best management practices and an ambitious and contentious land acquisition program. The agreement helped Catskill farmers transition to less capital-intensive farming practices and generated interest in improving management practices, such as manure storage, vegetative and forest buffers, as well

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[11] (TEEB in Local Policy, 2010)
[12] (TEEB in Local Policy, 2010)
[13] (TEEB in Local Policy, 2010)
[14] (Kenny, 2006); (Soll, 2013)

as fences to keep livestock out of hydrologically sensitive areas.[15] Between 1997 and 2013, the City signed purchasing contracts with sellers on a voluntary basis for nearly 130,000 acres of land according to five distinct priority areas[16] to ensure the protection of sensitive natural areas affecting water quality and to meet the filtration requirements for the City.[17] New York City's Land Acquisition Program is a hallmark of how regulating services (water filtration) of the watershed were used as a fundamental component of the water supply management plan.

Many agencies are attempting to mainstream Ecosystem Service Valuation into planning frameworks, such as The Economics of Ecosystem Biodiversity (TEEB), the Green By-laws Toolkit (Government of British Columbia), and Making the Value of Ecosystem Services Visible by the Swedish Government Inquiries. TEEB is hosted and organized by UNEP, was commissioned by the G8+5 in 2010, and subsequently launched by Germany and the EU commission. It builds on the analysis of the Millennium Ecosystem Assessment, which set the benchmark for defining ecosystem services, by demonstrating the economic significance of biodiversity loss and ecosystem degradation.[18] The framework acknowledges that healthy ecosystems are often superior and cost-effective at delivering services and provides resources for the argumentation, valuation and decision-making tools to support the protection of ecosystem services.[19] TEEB is advancing a modified typology of ecosystem services[20] and provides an extensive inventory of case-study summaries taken from international examples.[21]

As such, where ecosystem services are properly understood, integrated and strategically managed in planning, there is evidence to justify its efficiency and cost-effectiveness. While it is incredibly complex to create strategies that integrate infrastructural and natural features, our ability to pioneer and build upon this approach is invaluable to our ability to flourish in the face of challenges to infrastructure design in a changing climate.

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[15] (Soll, 2013)
[16] (New York City DEP, 2009)
[17] (Department of State, 2016)
[18] (European Union)
[19] (The Economics of Ecosystems & Biodiversity)
[20] (Wilson, 2012)
[21] (The Economics of Ecosystems & Biodiversity)

1.2 Climate Change: Effects, Strategies, and Adaptability in Scientific Models

It is widely accepted by the scientific community that since rapid industrialization in the mid-20th century, Earth's atmospheric composition has been drastically and unequivocally altered. The most significant change to the Earth's atmosphere has been the rapid, high volume emission of carbon dioxide largely as result of mass fossil fuel consumption. The effect of large scale fossil fuel consumption and greenhouse gas emission is, as the term 'global warming' suggests, an increase in average global surface temperatures. In the 1880's, Svante Arrhenius discovered and studied this warming process, naming it the 'greenhouse effect' and connecting it to human activity. In so doing, he laid the foundations for our current understanding of anthropogenic climate change.[22] He used basic principles of physical chemistry to link human induced increases in atmospheric carbon dioxide levels with increases in global surface temperatures. Despite Arrhenius' early findings, it would take almost a century for climate change to gain popular attention.

Anthropogenic climate change is widely understood to describe the changes to the earth's climate patterns, which are attributable to the rapid release of greenhouse gases by humans above levels that would occur naturally. These gases increase the atmosphere's capacity to retain and release radiation back towards earth that would otherwise dissipate into space. There has been a pronounced acceleration of global warming since the mid-1970s, as seen in Figure 1, which depicts a series of deviations from mean temperatures.[23] The most obvious and direct effect of climate change on Earth is increased global surface temperatures, which is predicted to have far reaching consequences on Earth systems.

[22] (Arrhenius, 1896)
[23] (Daigle, 2011)

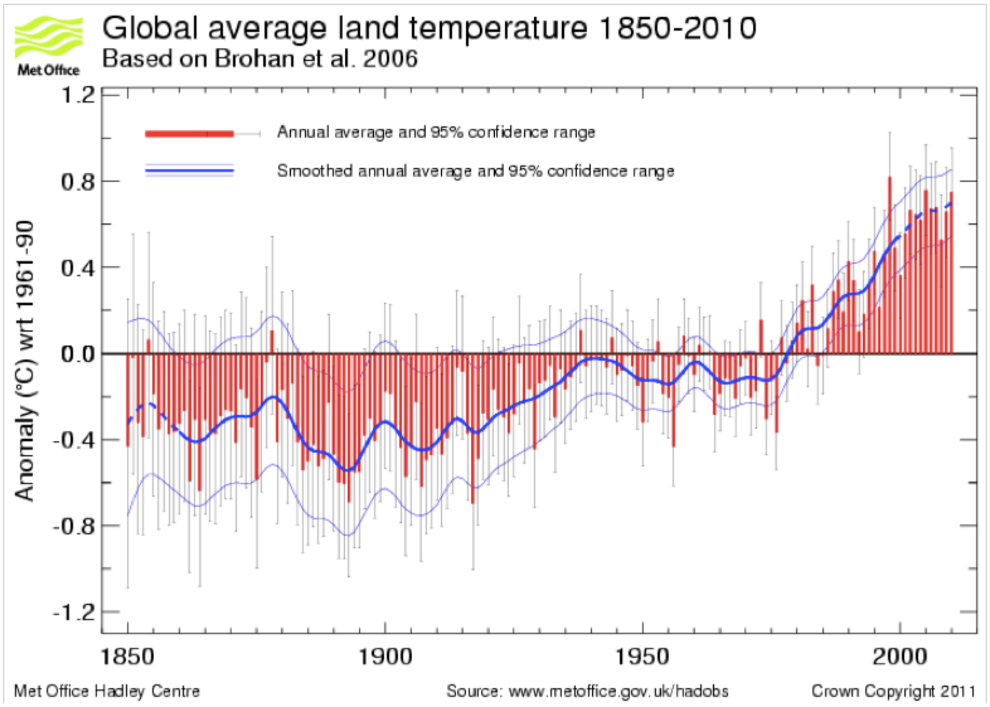

Figure 1. Global annual land temperature departures from the 1961-90 average annual means

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) as the leading, non-partisan body on climate change assessment. In 2015, the IPCC published a Fifth Assessment Report that reiterated the certainty, severity, and extensive reach of anthropogenic climate change, affecting all nations and populations.[24] The Report reiterated the findings of decades of research that anthropogenic carbon emissions have unequivocally increased average global temperature. It is predicted that rising temperatures will have innumerable effects on complex climatic and ecological systems. Two important consequences of a warming climate include sea level rise[25] and climate variability.[26] Half of the world's population will be affected by

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[24] (Contribution of Working Groups I, II and III [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)])
[25] (Daigle, 2011 p.9)
[26] *Climate variability is defined as a deviation from the overall trend or from a stationary state. Climate variability can be thought of as a short-term fluctuation superimposed on the long-term climate change or trend* (Daigle, 2011, p.8).

rising sea levels[27] and climate variability will increase the frequency and intensity of extreme weather events in some areas across the globe.[28] Sea-level rise has important implications on development as it can drastically increase the landward migration of salt water intrusion, especially coupled with climatic conditions where groundwater recharge may be an issue, such as during a drought.[29]

Projections of a future climate must consider complex and interconnected variables and impacts. Global Climate Models are used to develop quantitative projections of future changes in temperature, precipitation and other climate variables.[30] They are based on subjective estimates of future emissions of greenhouse gases and show a consensus that global average temperature will increase. As severe storms become more frequent, climate change will affect watersheds by changing the typical rainfall parameters and increasing the frequency of severe storms. Weather events are likely to continue to become more volatile and unpredictable, including the severity of rainfall and drought.

Precipitation is typically measures by Intensity, Duration, Frequency tables which provide information on the amount of rain that fell, the length of time it fell for, and the statistical likelihood that the storm occurs in a year. As these three parameters change, this will affect the drainage behavior of the watershed. For this reason, it is important to explore the various precipitation scenarios when considering the hydrology of the watershed, in order to understand how different climate scenarios will affect the flow and drainage of the watershed.

Climate change science has garnered increasing recognition and support since the 1970s and numerous international summits and accords have sought to create consensus, collaboration, and action on global platforms. A popular two-pronged approach to addressing these issues are mitigation and adaptation strategies. Both are used to combat climate change, but these strategies have important distinctions.

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[27] (UNEP, 2005)
[28] (Contribution of Working Groups I, II and III [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)])
[29] (Carreteroa, Rapagliab, Bokuniewiczc, & Krusea, 2013)
[30] (AMEC Earth & Environmental, 2011)

Mitigation of climate change is crucial to ensure human and planetary well-being. It is widely acknowledged that a global average temperature increase of over 2ºC may have catastrophic consequences and may catalyze negative feedback loops that further contribute to temperature rise. At the same time, the effects of climate change are already occurring and adaptive measures must be undertaken in order to minimize the impacts to human health and on communities, which is the role of climate change adaptation strategies.

Mitigation is the action of reducing the severity of a future scenario. It typically incurs costs at the local level, yet the benefits are global. Furthermore, the need for mitigation strategies is less certain and less visible within a given timeframe. It is for this reason that it is very difficult to incentivize climate change mitigation.

Climate change adaptation strategies are relatively localized actions based on the anthropogenic necessity to be better suited to an environment. The costs and benefits of adaptation are both local and the need is tangible and certain. Adaptation is much easier to incentivize because the costs can be viewed as an investment and the benefits can be experienced and valued by stakeholders. Climate change adaptation is increasingly recognized as an essential policy at all levels of government.[31] In the United States, Federal government agencies have been required to produce climate change adaptation plans as part of their mandate since 2009. It has been found that many adaptive strategies can only be practically provided by governments.[32]

Planners play an important role in devising and implementing adaptive strategies by ensuring that communities plan appropriately for future climate change scenarios. The "Model Standard of Practice for Climate Change Planning" by the Canadian Institute of Planners is one resource that seeks to mainstream climate change adaptation strategies into the federal planning framework, demonstrating its recognition as an essential policy directive.

The benefit of an ecosystem services approach in planning is that strategies can accomplish both mitigation and adaptation, thus creating buy-in at the local level and creating local and regional benefits. Focusing on the use of ecosystems and natural assets can help communities adapt

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[31] (Barrage, 2015)
[32] (Barrage, 2015)

to the localized effects of climate change, such as drought and flooding, while simultaneously acting as carbon sinks that mitigate warming.

1.3 The Infrastructure Gap

As ecosystems are being degraded by various human activities, human-made infrastructure is increasingly at risk of degradation as well. The ‘infrastructure gap’ is the difference between the necessary expenditures required to properly maintain infrastructure assets and the finances currently available for this purpose.[33] The global demand for infrastructure investment is estimated to be between US$ 3.3 trillion to US$ 3.7 trillion by the year 2030. Current spending only amounts to approximately US$ 2.5 trillion annually[34].

In Canada, decades of underinvestment, particularly in the 1980s and 1990s, have led to a cumulative, chronic decline of the state of Canadian infrastructure. Ultimately, this has led to service-failures and has directly impacted quality of life of those who depend on intended infrastructure services. Part of the problem is explained by the fiscal imbalance, the mismatch between the revenue powers and expenditure responsibilities of a government, in public capital investment. In the past five decades, responsibility for infrastructure has shifted from Canada’s federal government - the level of government with the largest and most growth-responsive revenue-base - to local governments (see Figure 2) – the level of government with the smallest and least growth-responsive revenue base.[35]

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[33] (Smart Plan: Gibsons Official Community Plan, 2015)
[34] (Woetzel, Garemo, Mischke, Hjerpe, & Palter, 2016); (Introduction: The Operations and Maintenance (O&M) Imperative: The Global Infrastructure Gap, n.d.)
[35] (Mackenzie, 2013)

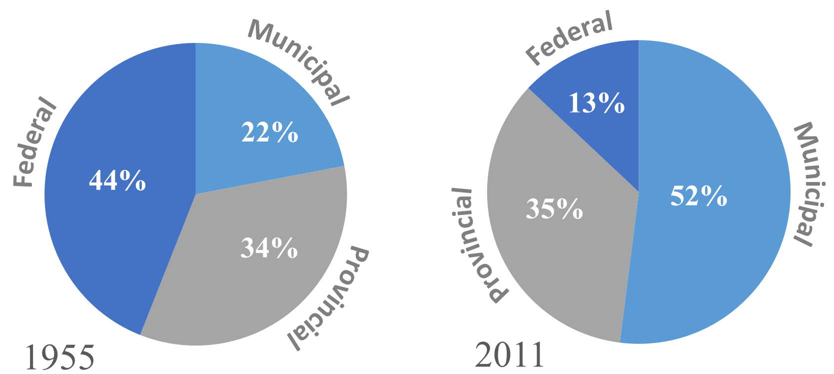

Figure 2. Asset Shares by Order of Government (1955-2011)[36]

Municipalities across Canada are increasingly aware of the need to change the way infrastructure is built and managed to ensure future economic sustainability. In addition to the infrastructure gap, a changing climate will increase the pressure and financial burden on communities to restore, upgrade, and maintain degrading infrastructure.

The theory of valuing and managing ecosystem services has emerged as a means to safeguard essential ecosystems against destruction and development, by realizing and managing the full potential of their services. Ecosystems are able to provide certain services more effectively than their man-made counterparts, at a fraction of the cost, such as the example of the Catskill/Delaware Watershed. Moreover, this strategy has numerous positive externalities that have yet to be fully understood.

According to the Canadian Institute of Planners, climate change is likely to have a dramatic impact on infrastructure maintenance and design, including: damages to roads and housing built on permafrost; require enhancements to coastal flood defenses; require upgrades to storm water systems to meet new extreme weather specification; and require upgrades to energy generation and transmission.[37]

The Municipal Natural Capital Initiative is one strategy that has emerged to incorporate ecosystem services into asset management frameworks. The goal is to improve municipal service

[36] (Mackenzie, 2013)
[37] (Gladki Planning Associates; p. 15)

delivery through integrated management that combines engineered solutions with the non-traditional assets found in nature, also known as natural infrastructure. The Town of Gibsons, British Columbia has adapted the Asset Management for Sustainable Service Delivery framework by Asset Management British Columbia (AMBC). The framework acknowledges Natural Capital as a municipal asset that is equivalent to engineered infrastructure. Numerous strategies have been put forth to support local governments in valuing ecosystem services. However, there is an enormous gap between policy and enforceable by-laws. A large barrier to incorporating ecosystem services into planning is the importance of the local context, accounting for environmental services at a parcel level, and public "buy-in". Although frameworks provide road maps, the evaluation, mapping, and pricing of ecosystem services requires considerable and consistent investment and research. Furthermore, there are few case studies to learn from and the complexity of ecosystems is poorly understood.

1.4 Atlantic Canada: Climate Change Vulnerability Assessment

Atlantic Canada, as a coastal region, has and will continue to be negatively affected by numerous climate change impacts including, rising temperatures, sea-level rise, and increased precipitation. Effective mitigation strategies that capitalize on and integrate naturally occurring ecosystem services are necessary in order to meet the needs of current and future New Brunswick residents.

The Canadian Coupled Climate Model and Analysis (CCCma), which is the model used by Environment and Climate Change Canada to study climate change and variability, predicts an average temperature change of 1-2ºC by 2020, 2-4 ºC by 2050, and 5-10ºC by 2090[38] in most parts of Canada. In the Arctic, these increases will be even higher. An increased average temperature equally increases the frequency of extreme heat events, decreases air quality, alters permafrost conditions, and further reduces snow cover and sea ice, causing sea-level rise. This changing

[38] (Gladki Planning Associates; p. 14)

climate will alter ecosystems, shift the range of species, allow pests and diseases to thrive, and increase the potential for the spread of vector-borne diseases. [39]

Coastal areas in Atlantic Canada are naturally extremely sensitive to sea-level rise and storm impacts.[40] The New Brunswick coast of the Gulf of St. Lawrence is an area with the highest sensitivity (see Figure 3).[41] Climate change and accelerated sea-level rise are anticipated to exacerbate preexisting vulnerabilities to storm surges. As such, increasing the adaptive capacity of the area must be prioritized to minimize damage and costs associated with coastal flooding and subsequent land erosion.[42] Unfortunately, there is a trend of building homes and cottages within close proximity (tens of meters) of coastlines in the area, adding a degree of social complexity.[43]

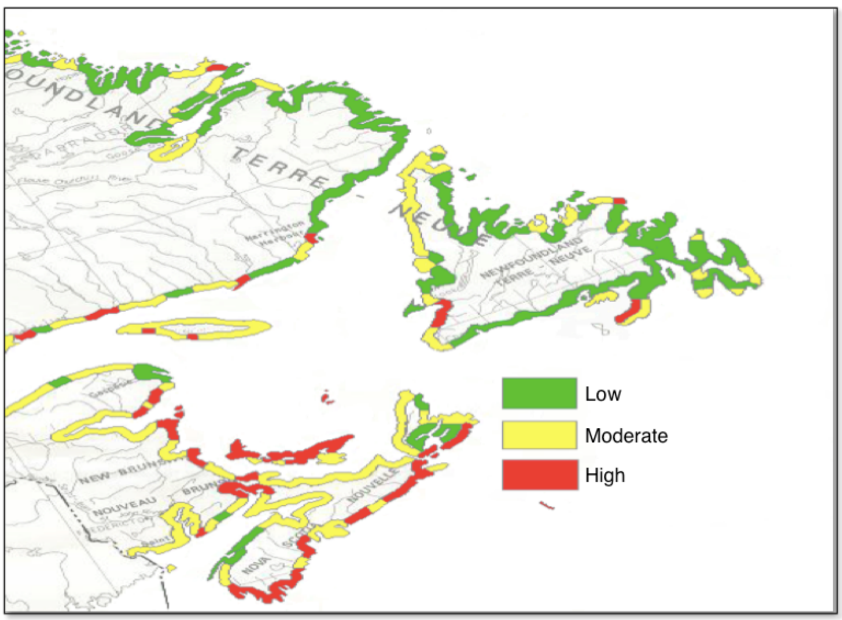

Figure 3. Coastal sensitivity to sea-level rise, Atlantic Canada[44]

Total precipitation and heavy precipitation events are predicted to increase. Increases in average temperature will induce higher rates of evapotranspiration and thus, exacerbate land

[39] (Gladki Planning Associates; p. 14)
[40] (Daigle, 2011)
[41] (Daigle, 2011)
[42] (Daigle, 2011)
[43] (Daigle, 2011)
[44] (John Shaw, Natural Resources Canada,)

aridity. Drought and wildfires will occur with greater frequency, while river and lake resources will become compromised and increasingly less reliable.[45] Changing weather patterns will include more extreme weather events, leading to increases in flooding and weather-related damage to communities. In coastal regions, these effects will be compounded by extreme weather-related storm surges.[46] While these studies are predictive, Table 1 of the next section evidences that such predictions are likely given the history of increased storm events and the profound economic and infrastructural stress these events have put on New Brunswick resources.

Coastal flooding typically occurs between late fall and early spring, as storms occur during high tide. The conjunction of these events can cause catastrophic damages ranging from the destruction of natural and protective habitats, to built-up coastal infrastructure, as well as homes, cottages, and coastal towns. Record storm events in January, 2000 and December, 2010, serve as reminders of the Eastern Canada's vulnerability to coastal flooding, especially considering increased climate variability, storm-surges, and sea-level rise.[47]

The storm of January 21st, 2000 was responsible for producing a storm surge of two meters along New Brunswick's Northumberland Strait coast, which was caused by a combination of extremely low atmospheric pressure and strong onshore winds. Parts of Atlantic Canada are particularly susceptible to sea level rise, estimated to reach between 50 to 70 cm by 2100 in some areas (compared to 18 to 59 cm in British Columbia and the Western Arctic). Sea level rise will lead to coastal erosion and increased vulnerability to flooding. Further, rising sea levels may result in saltwater intrusion into the water table, thereby salinating supplies of water for drinking and irrigation.[48] These changes will have a tremendous impact on ecosystems, infrastructure and the built environment.

New Brunswick's particular vulnerability to flooding, in conjunction with the inevitable increases in climate change induced extreme weather events, means direct and integrated action to mitigate the risks of damage from these events is absolutely necessary.

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[45] (Gladki Planning Associates; p. 14)
[46] (Gladki Planning Associates; p. 14)
[47] (Daigle, 2011)
[48] (Gladki Planning Associates; p. 14)

1.5 Infrastructure and Flood Damage in New Brunswick

According to estimates by the New Brunswick Department of Environment and Local Government, provincial flood damages were estimated at $137 million CAD, between 2000 and 2014 (see Table 1).[49] These figures likely dramatically underestimate the true costs of flooding, as they include costs of damages retrieved from a range of third party sources. The true costs are potentially far higher when considering damages to private residents and minor erosion to roadways that occur every year in the province.

In 2016, the Select Committee on Climate Change of the Fifty-eighth Legislative Assembly of New Brunswick was mandated to engage with the citizens of the province on climate issues and relay findings and recommendations to the Legislature. The committee acknowledged the vulnerability of community infrastructure with respect to climate change, such as storm sewers, sewage treatment facilities, and water supplies which will be affected by increased frequency and intensity of storms. Moreover, there may be disruptions that occur to important services, including road, bridge, port, rail, and airport disruptions, and increased costs for infrastructure repair and maintenance. These disruptions may have severe and far-reaching consequences on productivity, trade, electricity generation, and supply chains.[50]

The Committee produced a series of recommendations, one of which was to build climate-resilient infrastructure which could be adapted to future climate conditions. The following are examples of these important recommendations for climate change adaptation in the municipal and regional planning context:

1. Promote and utilize natural infrastructure (e.g., forests, wetlands, salt marshes, floodplains) as an important tool to buffer against climate change impacts,
2. Ensure that the impacts of climate change and extreme weather are considered in all infrastructure decisions […],

[49] (http://www.elgegl.gnb.ca/0001/en/Flood/Search, 2017)
[50] (Fifty-eigth Legislative Assembly of New Brunswick, 2016)

3. Make the preparation and implementation of climate change adaptation plans mandatory for local and municipal governments […],
4. Conduct climate change adaptation planning at a regional scale and empower regional service commissions to coordinate this exercise."[51]

Throughout the public participation process, the Select Committee on Climate Change found that the vast majority of New Brunswickers acknowledged anthropogenic climate change and the urgency to respond accordingly.

[51] (Fifty-eigth Legislative Assembly of New Brunswick, 2016; p. 12)

Table 1. Storm Surge Events and Cost to Infrastructure[52]

Start date	End date	Description	Cost
Jan 20, 2000	Jan 20, 2000	A storm surge from an intense winter storm causes flooding of low-lying coastal areas along the Gulf of St. Lawrence.	$1,700,000
Oct 29, 2000	Oct 30, 2000	A powerful northeaster storm hits the southern Gulf of St. Lawrence.	$2,400,000
Aug 13, 2004	Aug 14, 2004	Extratropical storm Bonnie causes heavy rains and localized flooding. Flooded basements and roads are reported in Edmundson.	N/A
Mar 29, 2005	May 16, 2005	The Saint John River Basin has above average ice thickness and a heavy snow pack in northern portions of the basin.	$5,600,000
Jan 14, 2006	Jan 20, 2006	Heavy rain and warm temperatures causes ice jams in several water bodies around the province resulting in flooding.	N/A
June 3, 2006	June 4, 2006	Southern New Brunswick has heavy rainfall and flooding throughout the region.	N/A
April 23, 2008	May 2, 2008	Worst spring flooding in 35 years along the entire Gulf of St. Lawrence.	$23,288,000
Aug 1, 2008	Aug 5, 2008	Roads, bridges and culverts are damaged due to torrential rains and flash floods.	$3,289,000
Sept 6, 2008	Sept 7, 2008	Tropical Storm Hanna causes heavy rain and localised flooding in the southern New Brunswick. Coastal areas experience high surf and high winds.	$16,000,000
April 3, 2009	April 7, 2009	Above average temperatures, snow melt, and rainfall causes high water levels along the Gulf of St. Lawrence.	$595,000
Aug 29, 2009	Aug 30, 2009	Tropical Storm Danny causes heavy rain and flooding in many areas of southern New Brunswick, including in dozens of basements.	N/A
Oct 25, 2009	Oct 28, 2009	Heavy rain and high winds affect New Brunswick and contribute to one of the wettest Octobers on record.	N/A
Jan 2, 2010	Jan 3, 2010	New Brunswick is hit by a snow storm accompanied by tidal storm surge of 6-8m.	$1,043,995
Nov 7, 2010	Nov 11, 2010	A succession of low pressure systems bring continuous rainfall for days in southern New Brunswick	N/A
Dec 6, 2010	Dec 7, 2010	A combination of high tides and winds cause damages.	$1,725,000
Dec 13, 2010	Dec 14, 2010	An intense low pressure system with cause heavy rain, especially in southwestern New Brunswick.	$13,830,000
Dec 21, 2010	Dec 23, 2010	An major low pressure system with cause heavy rain, especially in southwestern New Brunswick.	$1,348,000
Mar 23, 2012	Mar 25, 2012	A heat wave sparks an unusually early spring thaw, resulting in ice jam activity.	$25,000,000
Oct 20, 2012	Oct 20, 2012	Heavy rainfall in some central and southern parts of the province cause localized flooding.	N/A
Mar 13, 2013	Mar 15, 2013	Central and southern New Brunswick receive heavy rainfall.	$350,000
July 26, 2013	July 27, 2013	St. Stephen receives heavy rainfall.	$2,100,000
Jan 13, 2014	Jan 15, 2014	Warm temperatures and heavy rainfall contribute to melting snow along rivers in several areas of New Brunswick.	N/A
April 14, 2014	April 20, 2014	Spring flooding damages more than 715 homes and businesses, roads, bridges, and public.	$16,300,000
July 5, 2014	July 6, 2014	Hurricane Arthur transforms into a potent post tropical storm over the maritime provinces.	$12,500,000
2000	**2014**	**Estimate of damages (modest)**	**$127,068,995**

[52] (http://www.elgegl.gnb.ca/0001/en/Flood/Search, 2017)

1.6 Flooding Policy and Development in New Brunswick

New Brunswick has responded to increased disasters and storm events by implementing several policies and laws. Policy provides the framework within which provinces and regions work to anticipate and resolve problems before they arise. However, New Brunswick's current policies have failed to effectively address the province's vulnerability to storm events by omitting the crucial element of capitalization on valuable ecosystem services.

Coastal and inland flood events are among the most serious natural hazards in Canada.[53] New Brunswick has approximately 60,000km of streams and rivers, about 2,500 lakes and ponds, and it is bound by thousands of kilometers of ocean coast,[54] making it particularly vulnerable to major flood events. Flood events are largely triggered by heavy rainfall (43%), but also due to high tides/storm surges (8%), ice jams (7%), snowmelts (7%), or a combination of these (35%).[55] Flooding can cause major damage to development and currently, there are many areas in New Brunswick that become impassable during heavy rains. Climate change threatens to increase the occurrence of heavy rainfall events and consequently increase the risk of infrastructure degradation and service-interruption for residents across New Brunswick.

The province's *Flood Risk Reduction Strategy*[56] and the relevant permits and policies on floodwater management do not present effective low-cost strategies as it does attempt to integrate the role of ecosystems that naturally mitigate flood risk, such as wetlands, watercourses, and forests. The objectives of the provincial strategy include: (1) accurate flood hazard identification; (2) planning for community infrastructure to avoid flood risk; and (3) informed mitigation of flood risk.

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[53] (Province of New Brunswick, 2014)
[54] (Province of New Brunswick, 2014)
[55] (Doherty, Cost Benefit Analysis: Implementing Climate Change Adaptation Into Planning For Flood Risk Areas in New Brunswick, 2012)
[56] (Province of New Brunswick, 2014)

The province's *Clean Water Act*[57] supports the second objective in the *Flood Risk Reduction Strategy*[58] through a thirty-meter buffer zone, prohibiting any disturbance or work in or within 30 meters of a watercourse or a wetland, including its full width and length. The *Clean Water Act* does not mention the importance of the services generated by wetlands or the reason for their protection. Additionally, *Wetland and Watercourse Alteration permit*[59] can easily be acquired from the Department of Environment to perform alterations (i.e. construction) within 15 meters of the watercourse or wetland.

In 2012, new policies and identification of wetlands were anticipated. Reportedly, the program designated 18% (1,314,000ha) of the province's territory as potential wetland area. Complaints that the policy was too restrictive resulted in a mere 4% (300,000ha) of the territory being designated as such.[60] The mapping of these wetlands is outdated, inaccurate, and leaves over 50% of wetlands potentially unidentified.[61] This means that there are currently no measures in place to protect over half of the province's wetlands from development, which would have a large negative impact on flood control, water filtration and groundwater recharge systems if these were to be developed.[62]

While the connection between upstream land use and downstream flood risk has been recognized to some extent, the current approach is reactive, resulting in poor strategic planning. Current strategies largely deal with flood-specific legislation and protective structures. Filing an area near, or in, the existing floodplain leads to higher floodplain levels and contributes to flooding in other areas. A cost-benefit analysis of coastal flooding in Southeast New Brunswick, including a detailed socio-economic analysis, concluded that an approach which combines 'sensible development planning' and 'direct retreat approach' would reduce the amount of damages (each method provides some protection independently, as well). Further, the analysis found that adaptation benefits range from \$118k per event, to between \$220k-\$1.5m in total. Nevertheless,

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[57] (New Brunswick Regulations, 2012)
[58] (Province of New Brunswick, 2014)
[59] (New Brunswick Regulation (WAWA permit), 2012)
[60] (CBC News, 2012).
[61] (Conservation Council of New Brunswick, n.d.)
[62] (CBC News, 2012).

more comprehensive vulnerability assessments are crucial to future cost-benefit analyses and implementation. The study stresses the urgency of incorporating adaptation into local planning ordinances to avoid future costs, as the insurance industry has not yet developed an adequate method to cope with damages.[63]

The Southeast Regional Service Commission has begun to develop adaptive planning policies to guide development away from current and future flood zones. In 2011, the commission established a sea-level rise zone that sets a minimum height requirement for new development based on projections of a 1:100 year storm in 2100. It is the goal of the Southeast Service Commission of New Brunswick to continue this work by adopting a regional climate change adaptation strategy for floodwater management in New Brunswick. This plan is intended to guide development away from hazardous areas, as well as protect valuable ecosystem services and natural infrastructure that mitigates the risks and damages associated with major flood events.

1.7 GIS and Land Suitability Analysis and Watershed management

Land-use suitability mapping and analysis is one of the most useful applications of GIS for planning, as it identifies the most appropriate spatial pattern for future land uses according to specifications or predictions of activity. The GIS-based land-use suitability analysis has been widely applied to a multitude of topics, including landscape evaluation and planning, environmental impact assessment, and regional planning. The analysis involves classifying the units of observation, such as land cover type, according to their suitability for a particular activity, such as flood mitigation. The land-use suitability analysis defines areas that possess characteristics of interest and has become increasingly integral to urban, regional, and environmental planning services. Notably, land-use suitability analysis cannot rely on GIS analysis alone and requires consideration of socio-political dynamics as well, i.e. the analytic – deliberative cycle.[64]

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[63] (Doherty, Cost Benefit Analysis: Implementing Climate Change Adaptation Into Planning For Flood Risk Areas in New Brunswick, 2012)
[64] (Malczewski, 2004)

When evaluating ecosystem services in land-use suitability, especially for flood regulation, watersheds are an instinctive way to understand and evaluate ecosystem services. Watersheds are particularly useful, because they are the cornerstone of many ecosystem generated benefits; there exists a natural hierarchy of spatially nested units of analysis that are directly linked to ecosystem services.[65] Furthermore, watershed hydrology is responsible for the flow of water, and thus the transport of sediment, nutrients, pollutants, and organisms. Anthropogenic alterations to the connectivity of hydrologic systems, via land-use, water-use, and infrastructure, affect the volume and temporal distribution of water as well as sediment movement. Extensive activities such as timber harvest, row-crop farming, livestock grazing, and wetland drainage affect watersheds considerably by catalyzing water infiltration, evapotranspiration, and soil erosion, causing tremendous impacts on servicesheds, which are areas that provides a specific ecosystem services to specific beneficiaries.[66]

When evaluating ecosystem services, it may be useful to consider the capacity, demand, flow, and ecological pressures on and of the service. A change in capacity of an ecosystem to provide such services determines the long-term provision of the service. For example, the change in land cover type will alter the capacity of a landscape to regulate flow of services. Demand is the amount of the service that is desired by society and flow is the amount of service received by beneficiaries. Ecological pressures, such as overuse, constitute the influences that make it difficult for an ecosystem to meet the societal demand for its services.[67] Considering these factors will enable an assessment of the biophysical capacity of the area and the sustainability of the ecosystem service under different scenarios.[68] Generating and analyzing such scenarios is particularly necessary for risk mitigation given the variability of climate change impacts.

Regulating services, such as flood water mitigation, are typically challenging to quantify, as they are made up of interconnected processes. Regulating services are often measured by the services required to produce or maintain a desirable environmental condition. In the absence of

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[65] (Amy M. Villamagna, 2015)
[66] (Amy M. Villamagna, 2015); (Tallisa, et al., 2012)
[67] (Amy M. Villamagna, 2015)
[68] (Amy M. Villamagna, 2015)

data, proxy indicators must be used to evaluate ecosystem services, of which land cover type is the most commonly used.[69]

A simple and widely used method to quantify water runoff, for the purpose of understanding regional flooding, is the Soil Conservation Service (SCS) curve number method. The simplicity of the equation does present some limitations and problematics discussed in the limitations section.

The SCS curve number method requires information on land cover type, the hydrological soil group of the area, and the soil capability. The first step in applying the SCS runoff curve number method is gathering information on soil and ground cover to determine the **runoff coefficient numbers (CN)**. The charts enable CN value lookup by land cover type and hydrological soil group. The CN value is used to solve for **potential maximum retention (S)**, which is vital to the SCS equation (see Figure 4). Additionally, the equation requires the **cumulative precipitation (P)**, which can found in Intensity Duration Frequency (IDF) tables for a given area. These variables enable solving for the **precipitation excess (Q)**, i.e. runoff.

Figure 4. SCS Runoff Curve Number Method

SCS Runoff Equation	$Q = \frac{(P-0.2S)^2}{(P+0.8S)}$ where, Q=0 if P<.2S
Steps	1) Find S value, which is derived from the CN value $S=(1000/CN)-10$ 2) Convert S value from inches to millimeters $S_{(in)}*25.4 = S_{(mm)}$ 3) Solve for Q $Q = \frac{(P-0.2S)^2}{(P+0.8S)}$ (where, Q=0 if P<.2S)

[69] (Amy M. Villamagna, 2015)

	Q= Precipitation excess (runoff) [inches or mm] P= Cumulative precipitation [inches or mm] S= Potential maximum retention [inches] CN=SCS Curve Number

Chapter 2: Methodology

The methods used in this research project seek to integrate watershed management into planning, largely by visually representing the hydrological dynamics of the watershed through maps to determine the location of regulating services in the watershed and identify important regions to runoff and drainage. The main ecological assets for floodwater management include any systems that increases the capacity of the landscape to retain and infiltrate water. Most notably, the canopies and roots of forests and vegetation cover, adequate soil depth and its ability to retain water, and riparian corridors, often play an important role in the ability of a serviceshed to retain stormwater runoff. The methods attempt to discern drainage patterns that should be protected and enhanced, on the one hand, and create a heat map of land that can more or less retain runoff.

The methods are chosen based on their ability to identify and capitalize on the aforementioned ecosystem services. The methodology is comprised of two strategies intended to provide a better understanding of the hydrological dynamics in the area; they are expanded upon in the subsequent sections of the chapter. The first strategy will evaluate the runoff potential per land cover type using the Soil Conservation Service (SCS) curve number method, which compares the effectiveness of different types of land cover types and soil qualities at retaining water. The second method will evaluate the hydrological flow accumulation of runoff, which allows us to map the drainage patterns of the watershed and to see the accumulation of water flow on the landscape. The outputs of these methods will be overlaid to produce a map of the hydrological dynamics, with respect to drainage and runoff, of the watershed.

2.1 Project and Research Question

In order to act on climate change adaptation with urgency, it is essential to increase access to scalable and replicable models to mitigate extreme weather events in vulnerable areas, especially in communities that do not have the capacity or capital to build protective infrastructure.

The Aboujagane River Watershed in New Brunswick has a history of culvert washout and intensive forestry in headwaters. Extensive infrastructure damage has occurred due to flood events, including the washout of important access roads. There is existing interest and data on the flood patterns in the area and an active watershed group (Vision H2O) monitors the area for water quality. By producing a model of the drainage and the runoff potential of the Haute-Aboujagane Watershed and comparing it to development patterns, my research will provide recommendations to policymakers for regional development and storm and floodwater management that protects natural infrastructure. The study will provide a replicable watershed management strategy for small rural communities for policy-makers and planners.

Table 2. Data and Information Requirements

Method	Data/Information
(1) Hydrology	1. Canadian Digital Surface Model (CDSM)
(2) SCS runoff curve number method	2. Runoff Coefficients Numbers (CN) 3. Land cover (watershed) 4. Soil capability 5. Hydrological Soil Groups (HSG)
(3) Development	6. Building Footprints 7. Development Applications
Multiple (method 1 & 2) Multiple (method 2 & 3)	8. Rainfall Intensity Duration Frequency (IDF) 9. Land use zoning (watershed)

2.2 Surface Runoff

The surface runoff is determined using information on the land cover type, the hydrological soil group of the area, and the soil capability. Cumulatively, this information allows us to generate a **Runoff Coefficient Number (CN)**, which is used to create a **Potential Maximum Retention (S)** for the parcel of land. This is used in the SCS runoff equation to generate the **Precipitation Excess (Q)** (in millimetres), i.e. runoff, given a specific precipitation intensity. This method allowed for the classification of different areas based on how much runoff would occur in various types of storm events. The result is a heat map of land that is more or less efficient at retaining water from precipitation.

Table 3. Workflow SCS runoff curve number method			
Land cover (watershed)	Hydrological Soil Groups (HSG)	Soil capability	Rainfall Intensity Duration Frequency (IDF)
Information allows for determination of…			**Identify …**
Runoff Coefficients Numbers (CN)			Cumulative precipitation (P) values for four climate scenarios
CN and P allow you to solve for Q, which is…			
Precipitation excess, i.e. runoff (Q)			

The first step in applying the SCS runoff curve number method is using information on soil and ground cover to determine the **Runoff Coefficient Numbers (CN)**. The CN values can be found in the *TR-55 Curve Number Charts* created by the United States Department of Agriculture[70]. The charts enable CN value lookup by land cover type and hydrological soil group. The CN value is used to solve for **Potential Maximum Retention (S)**, which is vital to the SCS equation (see Figure 5). Additionally, the equation requires the **Cumulative Precipitation (P)**, which can found in Intensity Duration Frequency (IDF) tables for a given area. The **Potential Maximum Retention (S)** and the **Cumulative Precipitation (P)** enables solving for the **Precipitation Excess (Q)**, i.e. runoff.

Figure 5. SCS Runoff Curve Number Method	
SCS Runoff Equation	$Q = \frac{(P-0.2S)^2}{(P+0.8S)}$ where, Q=0 if P<.2S
Steps	1) Find S value, which is derived from the CN value

[70] (United States Department of Agriculture, 1966)

$$S=(1000/CN)-10$$

2) Convert S value from inches to millimeters

$$S_{(in)}*25.4= S_{(mm)}$$

3) Solve for Q

$$Q= \frac{(P-0.2S)^2}{(P+0.8S)} \qquad \text{(where, Q=0 if P<.2S)}$$

Q= Precipitation excess (runoff) [inches or mm]
P= Cumulative precipitation [inches or mm]
S= Potential maximum retention [inches]
CN=SCS Curve Number

2.2.1 Hydrological Soil Groups (HSG)

Soils are classified by the Natural Resource Conservation Service into four Hydrologic Soil Groups (HSG) based on the soil's runoff potential. The four groups are A, B, C and D. These can be found in the columns of the CN lookup tables; A's generally have the smallest runoff potential and D's have the greatest.[71]

The study area consists of Hydrological Soil Group C based on weighted averages of soil properties. Thus, Table 5 only includes the CN values for Hydrological Soil Group C. Group C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water.[72]

2.2.2 Soil Capability as a proxy for Hydrologic Condition

Information of soil capability from the Canadian Land Inventory is used as a proxy for the hydrological condition of the soil. Due to limited information on land cover and soil quality in the area, soil capability is used to weight the CN of low vegetation and high vegetation land cover. By

[71] (Purdue University, s.d.)
[72] (Purdue University, s.d.)

assuming that high quality soils are more effective at retaining water, this increases the resolution of the land's precipitation excess.

The land inventory classifies land into eight categories; Class 1 land has the highest quality soil and Class 7 has the worst, as well as Class "O" for unclassified soil. The soils in the Haute-Aboujagane Watershed range from 3 to 5 (see Table 4). Soil capability provides a proxy for the hydrological condition of the soil (poor, fair, or good). Low and high vegetation cover are assigned differentiated values based on soil condition: Class 3 soil is given a lower (i.e. good) CN value; Class 4 soil is given a neutral (i.e. fair) CN value ; Class 5 soil is given a higher (ie. poor) CN value.

Table 4. Soil Capability Classes[73]

Class 3	Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices. Class 3 soils in this area all fall under the **Subclass W**, which indicates that excess water (other than brought about by inundation) is a limitation to agricultural use. This may be caused by inadequate soil drainage, a high water table, seepage, or from runoff from surrounding areas.
Class 4	Soils in this class have severe limitations that restrict the range of crops or require special conservation practices. Class 4 soils in this area also all fall under the **Subclass W.**
Class 5	Soils in this class have very severe limitations that restrict their capability in producing perennial forage crops, and improvement practices are not feasible. Class 5 soils in this area fall under the **Subclass S**, **D**, **F**, **M**, and/or **N**. These subclasses indicate that land may have: **(S)** undesirable soil structure and/or low permeability; **(F)** low fertility; **(M)** moisture limitations (soils usually have low water-holding capacity); and/or **(N)** excessive soluble salts.
Class O	Organic Soils (not placed in capability classes).

2.2.3 Land Cover

Land cover is the primary information used to find the CN values in the lookup tables and is made possible through the resources of the Southeast Regional Planning Commission (SERCS).

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[73] (Agriculture and Agri-food Canada, 2013)

The study area is classified into five categories: water, barren, built-up, low vegetation, high vegetation, or wetland. These can be found in the rows of the CN value lookup table (see Table 5).

2.2.4 Runoff Curve Number lookup table

Using the information on land cover type, hydrologic condition, and the hydrological soil group it is possible to identify the CN values that correspond to the study area and solve for **Potential Maximum Retention (S)** in the SCS Equation (see Figure 5).

Table 5. Curve Numbers (CN) from TR-55[74]

Land Cover Type	Land Use Zoning Description	Hydrologic Condition (see soil capability)	CN for Hydrological Soil Group C
High Vegetation	Forest	Poor Fair Good	77 73 70
Low Vegetation	Open Spaces: lawns, parks, golf courses, cemeteries, etc. (grass cover 50-70%)	Poor Fair Good	86 79 74
Built-Up	Impervious areas: paved surfaces, roofs, driveways, etc.		98
Water/Wetlands			98*
Barren	Bare Soil		91

** The saturation point of a wetland determines its curve number value. Saturated wetland are often given a 98 curve number, whereas unsaturated wetlands may be given a 0 curve number. It is important to note that despite their CN value wetlands have important implications for floodwater management in terms of quantity and quality.*

The only value that is missing to solve for **Precipitation Excess (Q)** in the SCS equation is **Cumulative Precipitation (P)**, which can be derived from IDF tables (see Table 6).

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74 (United States Department of Agriculture, 1966)

2.2.5 Rainfall Intensity Duration Frequency (IDF) Tables

Intensity, duration, frequency (IDF) tables enable an understanding of rainfall patterns based on the amount of rainfall that falls (intensity) over a given length of time (duration). Additionally, the tables show the statistical probability that such a rainfall event occurs in any given year (frequency). For example, the Moncton IDF tables indicate that the average amount of rain that falls for a rain storm that lasts 5 minutes, with a statistically probability of occurrence once in every 100 years is 187.8mm (see Table 6).[75]

The IDF tables that are used in this research were commissioned by the Atlantic Climate Adaptation Solutions Association for the Greater Area of Moncton. The tables use historical data and projections to predict changes in precipitation given future climate change scenarios. The study uses historical rainfall patterns to project rainfall for a 2025, 2055, and 2085 scenarios. The study uses information on emissions scenarios, global climate simulation, and downscaled climate projections to formulate its projections.

The **Cumulative Precipitation (P)** used in the SCS equation (see Figure 5), is based on the Rainfall Intensity (mm/hour) derived from a historical IDF table, a projected IDF table for a 2025 Maximum, and a projected IDF table for a 2085 Maximum.[76] The scenarios show storm durations of 5 minutes, 30 minutes, and 6 hours for a storm with a 100 return interval (also referred to as a 100-year storm).[77]

Table 6. Precipitation (mm/hour) for 100-year return interval[78]

	5 minute	30 minute	6 hour
Historical IDF	187.8	69.4	13.8
2025 projected IDF table	193.0	72.3	14.4
2085 projected IDF table	201.6	77.2	14.8

[75] (AMEC Earth & Environmental, 2011)
[76] (AMEC Earth & Environmental, 2011)
[77] (AMEC Earth & Environmental, 2011)
[78] (AMEC Earth & Environmental, 2011)

2.2.6 Creating the Surface Runoff Map

The land cover types, soil capability and land use layers are combined (intersect on ArcMap) so as to allow each parcel to be assigned a weighted CN value (see Table 7). The attribute tables from the intersect are brought into an Excel spreadsheet, where the CN values are weighted based on soil capability. The **Potential Maximum Retention (S)** is computed in one column and the **Cumulative Precipitation (P)** values for each scenario (nine scenarios) is added into the excel table. Finally, the **Precipitation Excess (Q)** is solved based on each precipitation scenario. The excel file is then joined anew into ArcMap. Maps of the runoff potential are created based on the **Precipitation Excess (Q)** values that are found in the attribute tables and that are assigned to each parcel of land.

<table>
<tr><th colspan="2">Table 7. Workflow for creating runoff potential model using ArcMap and Excel</th></tr>
<tr><th>Data set</th><th>Work Flow</th></tr>
<tr><td>Soil types</td><td>Support the determination of runoff CN range (good, fair, or poor) based on soil class.
Intersect between Land Use Zoning and Soil Capability.</td></tr>
<tr><td>Land Cover</td><td>Convert a floating type raster to a polygon feature class and retain the decimal values.

1. Raster Calculator tool to multiply the raster with a multiple of 10 required to remove the decimal values (did not apply, not necessary).
2. Navigate to ArcToolbox > Spatial Analyst Tools > Math > Int.
3. Navigate to ArcToolbox > Conversion Tools > From Raster > Raster to Polygon.[79]</td></tr>
<tr><td>Land Cover, Soil Capability, and Land Use Zoning (Coversoiluse2)</td><td>Intersect created between Land Cover, Soil Capability, and Land Use Zoning in order to export one table with all required information to determine CN values.
<table>
<tr><th>Sample attribute table from intersect</th><th>…</th><th>Soil Capability</th><th>…</th><th>Land Use Zoning</th><th>…</th><th>Land Cover</th></tr>
<tr><td>FID</td><td>…</td><td>class</td><td>…</td><td>Landuse</td><td>…</td><td>GRIDCODE</td></tr>
<tr><td></td><td></td><td>3</td><td></td><td>Commercial</td><td></td><td>2000000</td></tr>
<tr><td></td><td></td><td>3</td><td></td><td>Rural</td><td></td><td>5000000</td></tr>
</table></td></tr>
</table>

[79] (Esri, 2017)

Runoff CN for the SCS runoff curve number method

Export Coversoiluse2 to excel sheet to add runoff CN. Match CN value to land cover types and soil capability.
Add columns for 4 Cumulative Precipitation (P) scenarios. Compute S values and Q values.

FID	Land Use	Soil class	CN	P_1	…	P_4	S_1	…	S_4	Q_1	…	Q_4
1												
2												
…												

Sample table with runoff CN, various precipitation scenarios (P_1-P_4), and corresponding precipitation excess output (Q_1-Q_4) to be attached to Coversoiluse2 table.

2.3 Hydrological Flow Accumulation

The hydrological flow accumulation is based on the Canadian Digital Surface Model,[80] which is a series of points of the topographical elevation of Canadian landscapes. The flow accumulation model calculates the direction and accumulation of water flow as the accumulated weight of all cells flowing into each downslope cell in the output raster.

The initial surface model layer records the coordinates (X and Y) and the elevation (Z) of the terrain. The layer is a series of points with the recorded measurements approximately every 20m. This can be transformed into a raster model in order to perform a spatial analysis of the hydrology of the landscape.

The first step to analyzing the hydrology of the landscape is to fill the sinks in the surface of the raster model to remove small imperfections in the data. Then the flow direction tool is used to determine the direction of slope of each cell (see Figure 6). Lastly, the flow accumulation is used to determine the cumulative value of cells, as if they were to move downstream (see Figure 7).

[80] (Government of Canada, 2012)

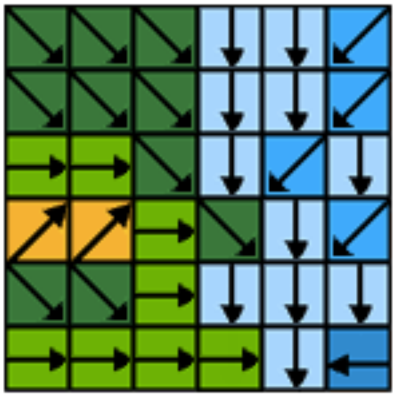

Figure 6. Flow direction

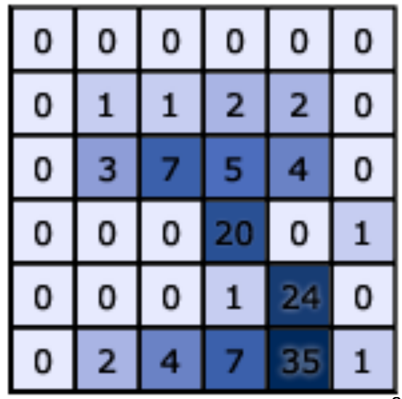

Figure 7. Flow accumulation[81]

This is a proxy for real measurements of flow accumulation (as runoff) after a rainfall event. The hydrological flow accumulation provides a model of the location of the highest concentration of water after a rainfall. These values do not indicate the volume of water running off the land, but the accumulation of cells (unweighted) along the raster grid.

Table 8. Work flow of hydrological flow accumulation model
Canadian Digital Surface Model (CDSM)
Spatial Analysis: Hydrology **Fill → Flow Direction → Flow Accumulation**
Hydrology
Overlay and buffer based on flow accumulation for given P values
Hydrological model of flood prone areas

As previously mentioned, the location and elevation information from the CSDM is imported into ArcMap 10.1 in point format. It is converted into a raster format to allow for analysis using the **Hydrology** toolbox. The computation of the flow accumulation yields a very large range of values in the results and is thus poorly visualized. In this workflow, this is solved

[81] (Esri, 2017)

using the raster calculator to take the log of the values. Taking the log of the values changes the nature of the scale from arithmetic to exponential, which is appropriate for this type of data.

It may be possible to improve the visualization of the data by changing the raster stretch in the layer properties without requiring a change to the pixel values.

Table 9. Work flow of hydrological flow accumulation model

Data set	Work Flow: Hydrology
Canadian Digitial Surface Model (CDSM)	**1) Import XYZ points** **2) Point to Raster** **3) Hydrology toolbox** In order to estimate the hydraulics of the landscape, one method is to use an order of operations in the Spatial Analysis tool **Hydrology** in ArcMap. Starting from the CSDM, we used the "Fill DEM" tool; "Flow Direction Grid" tool; and the "Flow Accumulation Grid." **a. Fill** Fills sinks in a surface raster to remove small imperfections in the data **b. Flow Direction** Creates a raster of flow direction from each cell to its steepest downslope neighbor. **c. Flow Accumulation** Creates a raster of accumulated flow into each cell. A weight factor can optionally be applied. **d. Raster Calculator** The range of contributing is very high (0 to 315,299), therefore we must take the **log10** to get better visualization of the contributing area. Raster calculator → log10: log("csdmacc") **e. Raster Calculator:**[82] The drainage network is not necessarily stable. Hill slope processes may dominate over fluvial process. The transition from hill-slope to fluvial is at the gully head or some critical contributing area, which is estimated at $100m^2$. Raster calculator → Con("csdmacclog" >= 2, "csdmacclog") where 2 indicates 10^2.

2.4 Land Use Suitability Analysis

The overlay of the three series of data provides a better understanding of the hydrological dynamics of drainage and runoff in the watershed. This information can be used to better

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[82] (OpenTopography Facility, 2011)

understand and visualize why some areas are more likely to flood than others. It also provides a basis to make recommendations on best management practices to reduce the impact of lands that have a potential to generate high excess runoff.

Table 10. Work flow for land suitability analysis		
SCS Runoff Curve Number Method	Hydrology	Development (Building Footprints & Development Application)
Overlay of information allows for identification of…		
Vulnerable areas and sites		Areas with high adaptive capacity to flooding

These methods provide an overview of the hydrological dynamics within the watershed. However, there are important limitations that must be considered, including the accuracy of the hydrological flow accumulation (discussed in chapter 4.2) and limitations in the resolution and categorization of the results of the SCS curve number equation method (see section 4.1.2 and 5.1).

Chapter 3: Case Study Area Presentation

3.1 Community Overview

3.1.1 Beaubassin East Rural Community

The rural community of Beaubassin East (see Figure 8) is in Westmorland County, in the southeast region of New Brunswick. It is located East of Moncton, along the northernmost shore of the county and borders the Northumberland Strait. The community was officially incorporated on July 31st, 2006. However, the community has been operating under the consultation of a committee since 1995.[83] It is home to 6,200 people over a territory of 291km². It is divided into 6 Wards, Botsford, Saint-André-LeBlanc, Grand-Barachois, Boudreau West, Cormier Village, and Haute-Aboujagane.

Beaubassin East is responsible for the planning of the community's garbage collection, public street lights, fire protection, and emergency measures. The Southeast Regional Service Commission (SERCS) provides construction and development services to the community.[84]

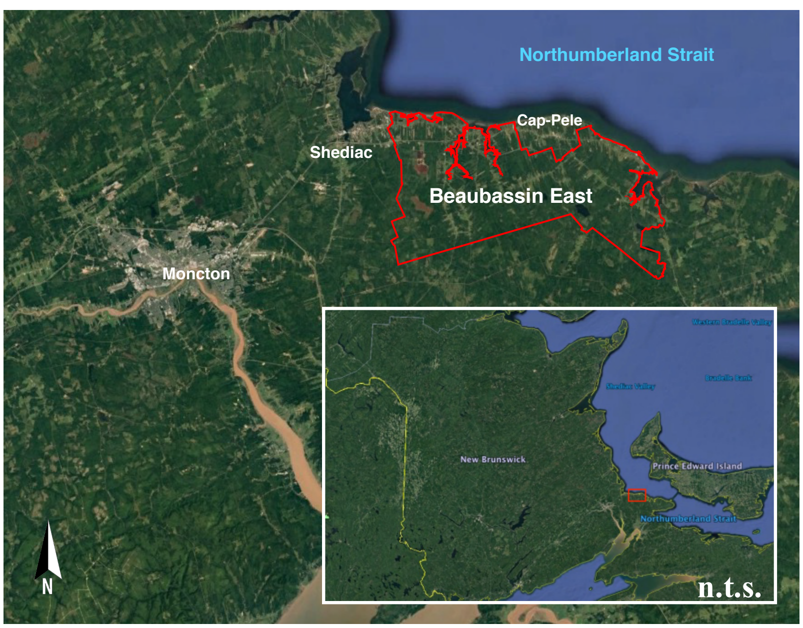

Figure 8. Beaubassin East Rural Community

[83] (Beaubassin-est Rural Community, 2017)
[84] (Communauté rurale Beaubassin-est, 2017)

3.1.2 Haute-Aboujagane

Haute-Aboujagane is the fifth Ward of Beaubassin East. Haute-Aboujagane's 989 residents account for approximately 15% of the population of Beaubassin East. Haute-Aboujagane, Ward 5, is commonly associated with three smaller sectors: Haute-Aboujagane, Basse-Aboujagane and Bourgeois Mills (see Figure 9). There are three main roads that service the community: Aboujagane Rd, Upper Aboujagane Rd, and Malakoff Rd.

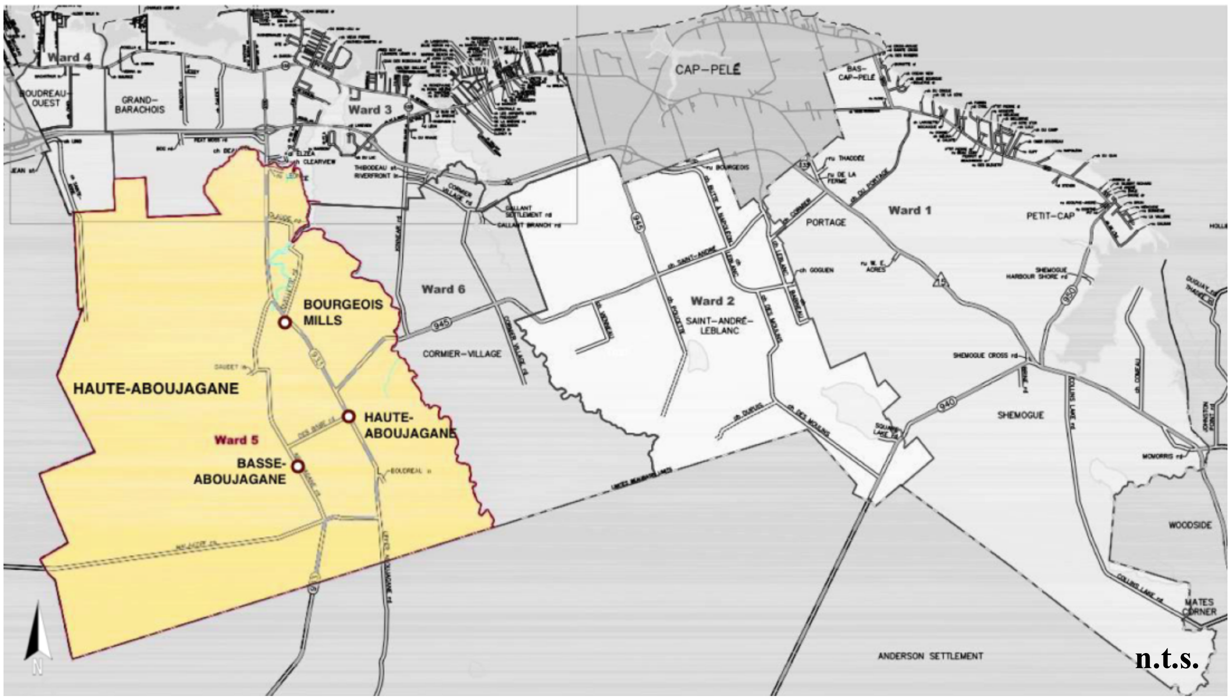

Figure 9. Ward 5 of the Beaubassin East Rural Community

The Ward is divided by a valley and the Aboujagane River. The area may have derived its name, "Aboujagane", from the aboriginal word for "a pearl necklace".[85] Facilities in Haute-Aboujagane include the Golden Age Club, a Hunting and Fishing Club, an antique church, a high quality golf course, a sports field, a Caisse Populaire counter, a post office, a convenience store, as well as the only fire hall in Beaubassin East.

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85 (Haute Aboujagane, s.d.)

East to west, the Ward covers a substantial expanse of rural area along the northern side of Malakoff Rd. The boundary of the Ward runs to the south Malakoff Rd. The natural boundary of the watershed of the Aboujagane River, is different than the political boundary of the Ward. The watershed continues further to the south and is narrower (see Figure 10). The watershed is the area that will be studied, in order to develop recommendations that will directly benefit the community and surrounding areas.

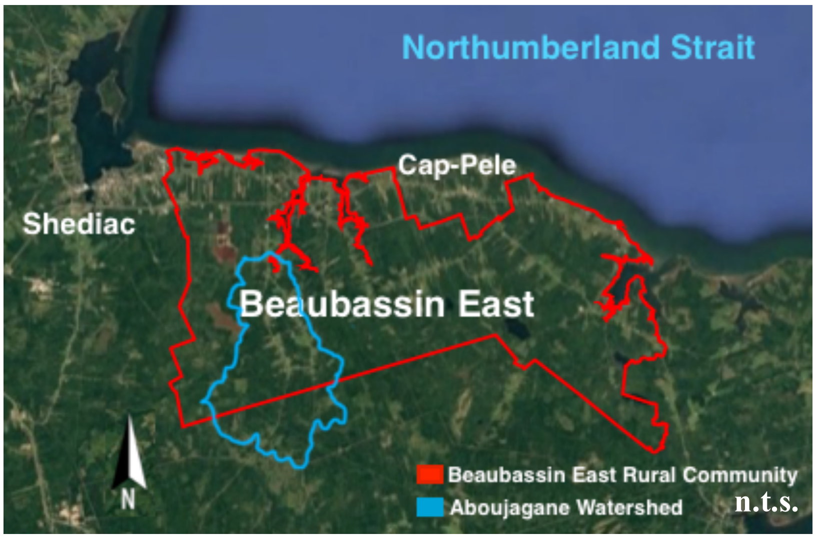

Figure 10. Aboujagane Watershed

3.1.3 Community Statistics

Beaubassin East is a predominantly French-speaking community (87%), although most citizens speak both English and French (79%).[86] The area has a higher proportion of citizens with occupations in trades, transport, equipment operators, manufacturing and utilities compared to provincial and federal averages.[87]

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[86] (CityData, 2012)
[87] (Statistics Canada, 2013)

Table 11. Community Statistics

Community Statistics[88]	Haute-Aboujagane	Beaubassin East	New Brunswick
Population (2011)	840 **	6 200 *	751,171 **
Population (2006)	989 **	6 429 *	729,997 **
Variation: 2006/2011	-15.1 % *	-3,6 % *	2.9% **
Total private dwellings	341 **	3 296 *	348,465 **
Territory Area	77.48 km² **	291.12 km² *	71 377.18 km² **
Population Density	10.8 persons/km² **	21.3 persons/km² *	10.5 persons/km² **
Tax Base 2016	-	609 880 650 $	-
Total Budget 2016	-	1 905 838.92 $	-
Tax Base 2015	-	586 293 700 $	-
Total Budget 2015	-	1 872 663 $	-

** As reported on the Statistics Canada Web site.*
*** As reported on CityData.*[89]
*** Approximate population for each ward.*

3.1.4 Stakeholders

The local government of Beaubassin East is composed of a mayor and nine municipal councilors. There are currently four committee mandates, including: Finance and Personnel, Planning and Public Relations, Public Safety and Environment, and Cultural Development.

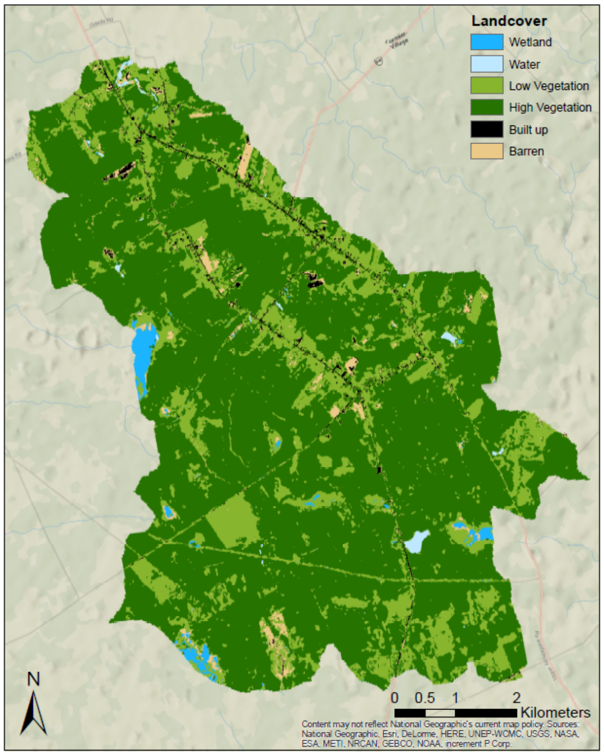
Vision H_2O is an environmental NGO with the mission to work towards maintaining a healthy ecosystem, which ensures sufficient water services meet the needs of Beaubassin East Rural Community and the Village of Cap-Pelé residents. The organization communicates with the Committee of Public Safety and Environment and regularly publishes reports on the quality of water in Aboujagane River and its tributaries.[90]

3.1.5 Land Use Zoning and Land Cover

The land cover types in the watershed, identified using the sentinel data, include: water, barren, built-up, low vegetation, high vegetation, and wetland. As can be seen on the land cover map (see Figure 11) a very large portion of the watershed is highly vegetated. Low vegetation is

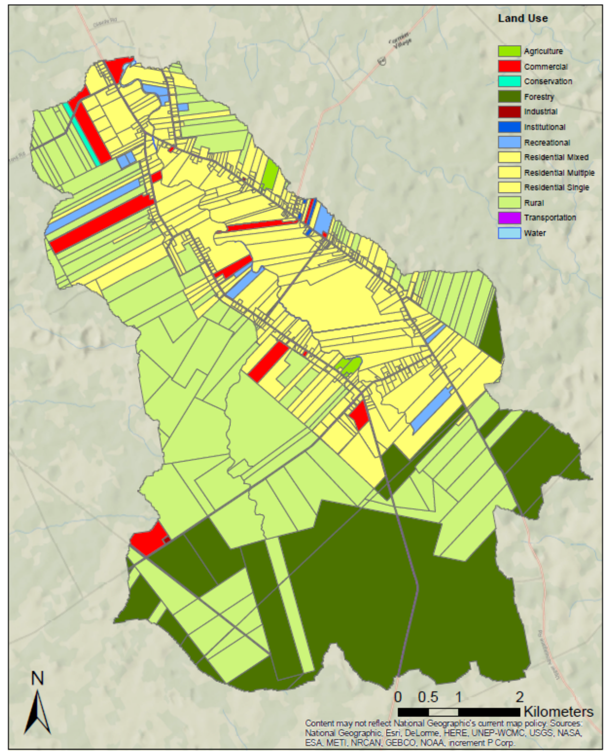
[88] (Beaubassin-est Rural Community, 2017)
[89] (CityData, 2012)
[90] (Communauté rurale Beaubassin-est, 2017)

very common near roads in residential areas. Residential lots have low vegetative cover due to the common practice of completely clearing lots of trees and shrubs.



Data source: SERSC
Author: Laura Bernier, February 2017

Figure 11. Land Cover Map of the Aboujagane Watershed

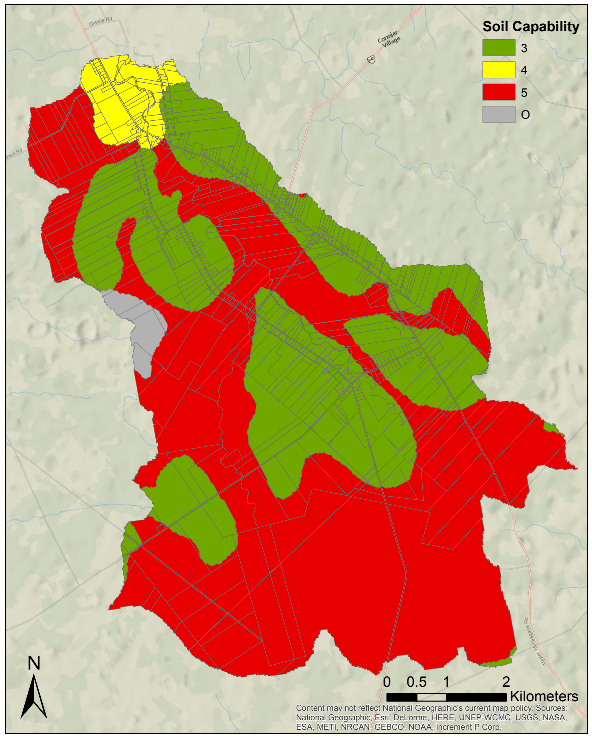


Data source: SERSC
Author: Laura Bernier, February 2017

Figure 12. Land Use Zoning Map of the Aboujagane Watershed

The land-use types in the watershed, according to zoning maps, include: agriculture, commercial, conservation, forestry, industrial, institutional, recreational, residential (mixed, multiple, single), rural, and transportation (see Figure 12). The vast majority of land-use in the watershed is forestry, rural, and residential.

3.1.6 Soil Capability



Data source: SERSC
Author: Laura Bernier, February 2017

Figure 13. Soil Capability

Information of soil capability from the Canadian Land Inventory shows that the soils in the Haute-Aboujagane Watershed range from 3 to 5 (see Table 4). The land inventory classifies land into eight categories; Class 1 land has the highest quality soil and Class 7 has the worst, as well as Class "O" for unclassified soil. The soil classes are used as a proxy for the hydrological condition of the soil. Soils in the community, especially in developed areas, are in poor hydrological condition and/or have poor drainage (see Figure 13)

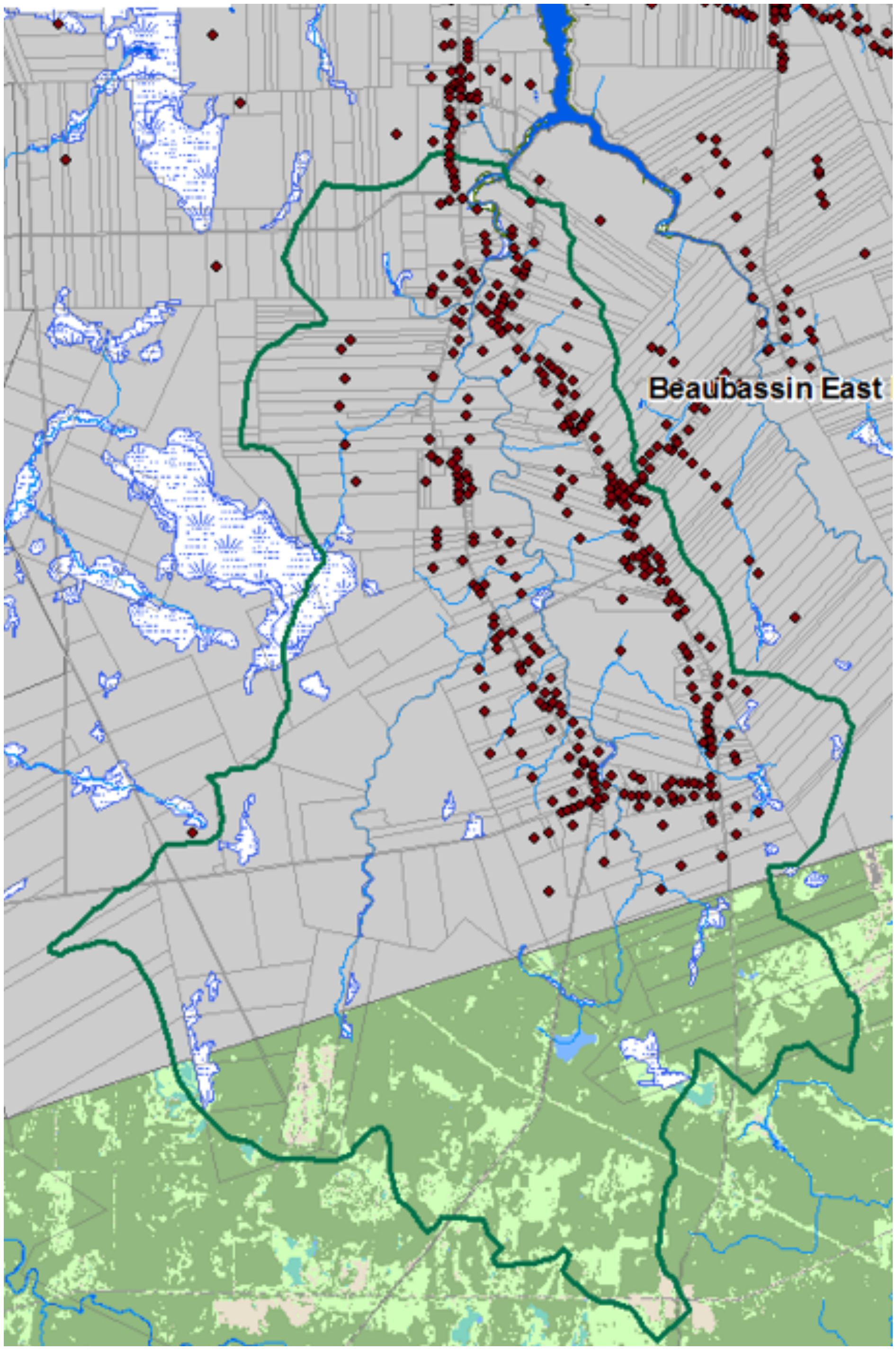


Figure 14. Building Permits between 2005 and 2016[91]

[91] (SERSC, 2017)

Data source: SERSC
Author: Laura Bernier, February 2017

Figure 15. Building Footprints

Development in the Haute-Aboujagane has occurred in an ad hoc manner. Development is largely limited to the only roads to access the community, which are Aboujagane Rd, Upper Aboujagane Rd, and Malakoff Rd (see Figure 14 and Figure 15).

3.2 The Aboujagane River

3.2.1 Ecosystem Services

The Aboujagane River was deemed to be in relatively good health based on an audit of the aquatic species, undergone in 2016. The river provides invaluable ecosystem services to the region, including regulating, provisioning, habitat and supporting, as well as cultural services. These include but are not limited to the following:

i. Plays a vital role in regulating water quality and quantity:
ii. Provides economic value:
   a. local peat bog;
   b. wild Atlantic Salmon habitat.[92]
iii. Supports a diversity of species due to its rich ecological habit, some of which include:
   a. mollusks, which provide water filtration and maintain high water quality;
   b. beavers, which increase water depth in rivers through tunneling;
   c. salmonids, which have cultural importance and tremendous economic value.
iv. Frequently used for recreational and sport fishing of brook trout.[93]

It can be very difficult to evaluate the costs of regulating services, such as flood control, due to their intangible nature. Provisioning services, on the hand, typically provide more visible commodities. In the case of the Aboujagane River, there is an important value in terms of providing recreational fishing. The River is a habitat for juvenile salmonids, notably wild Atlantic Salmon. The presence of Atlantic Salmon generates important cultural, recreational, and economic value for communities in Atlantic Canada. Unfortunately, the species and their habitat is threatened.

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[92] (Paquette, 2016)
[93] (Haute Aboujagane, s.d.)

In Canada, the average number of wild Atlantic Salmon between 2003 and 2012 has declined two and a half times from a peak in 1975. The rivers that have suffered the greatest losses tend to be in southern areas and many spawning rivers no longer have any salmon return.[94] Conservation limits, implemented to increase salmon numbers, are not reaching their targets.[95] Approximately 135 km north of the study area, the Miramichi River is an important producer of salmon in North America. Since 2014, the river has not reach sustainable spawning levels for three years and saw a historically low estimated adult salmon return in 2014. A moratorium on commercial Atlantic salmon fishing in Canada has been in place since 2000, with exceptions to Indigenous communities, subsistence fishing in Labrador, and recreational fishing in certain areas.[96]

A study found that, in 2010, $166 million was spent on wild Atlantic Salmon in Eastern Canada. Over three-quarters of this spending was on recreational fishing and 43% of spending was in New Brunswick. The study estimated that additional economic activity was generated through direct and indirect impacts, including $150 million in Gross Domestic Product (GDP), approximately 4,000 full time jobs and $128 million in labour income. In addition to its economic value, Wild Atlantic Salmon has important cultural significant for local communities.[97]

Figure 16. Salmon smolt (top) and trout smolt (bottom) caught in Bear Creek[98]

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[94] (Standing Committee on Fisheries and Oceans, 2017)
[95] (Standing Committee on Fisheries and Oceans, 2017; p. 6)
[96] (Standing Committee on Fisheries and Oceans, 2017; p. 6)
[97] (Standing Committee on Fisheries and Oceans, 2017; p. 6)
[98] (Paquette, 2016)

According to a report by Vision H_2O in 2016, the predominant issues observed in the river were blockages to fish migration caused by the accumulation of debris and a beaver dam. The report includes an evaluation of the state of the river and prioritizes watercourse restoration for the maintenance of favorable conditions for fish reproduction and to maintain and improve the quality of water in the regional rivers and watercourses.

3.2.2 Flood Sites and Site Visit Description

Haute-Aboujagane is a rural residential community with virtually no commercial activity. There are large expanses of property with typically single dwelling homes which line the main roads. Houses are typically on very large lots which are almost all completely barren of trees. The lack of vegetation on these large lots has a dramatic effect on the landscape. In addition to completely clearing the vast lots, residents commonly mow their lawns to their property line, even when it borders streams and watercourses (see Figure 17). Removing vegetation has an important negative effect on the watercourses as it increases the risk of soil erosion and chemical runoff entering the steam.

Figure 17. Private lawn abutting stream[99]

[99] (Paquette, 2016)

There is a quarry along Des Babe Rd. The quarry is located only a few hundred meters from: (1) an area that was deforested (see Figure 18: point 5); and (2) a problematic culvert that routinely becomes blocked and floods during heavy rains. There is a wetland and a peat bog to the west and the northwest of the study area, which provide important ecosystem services.

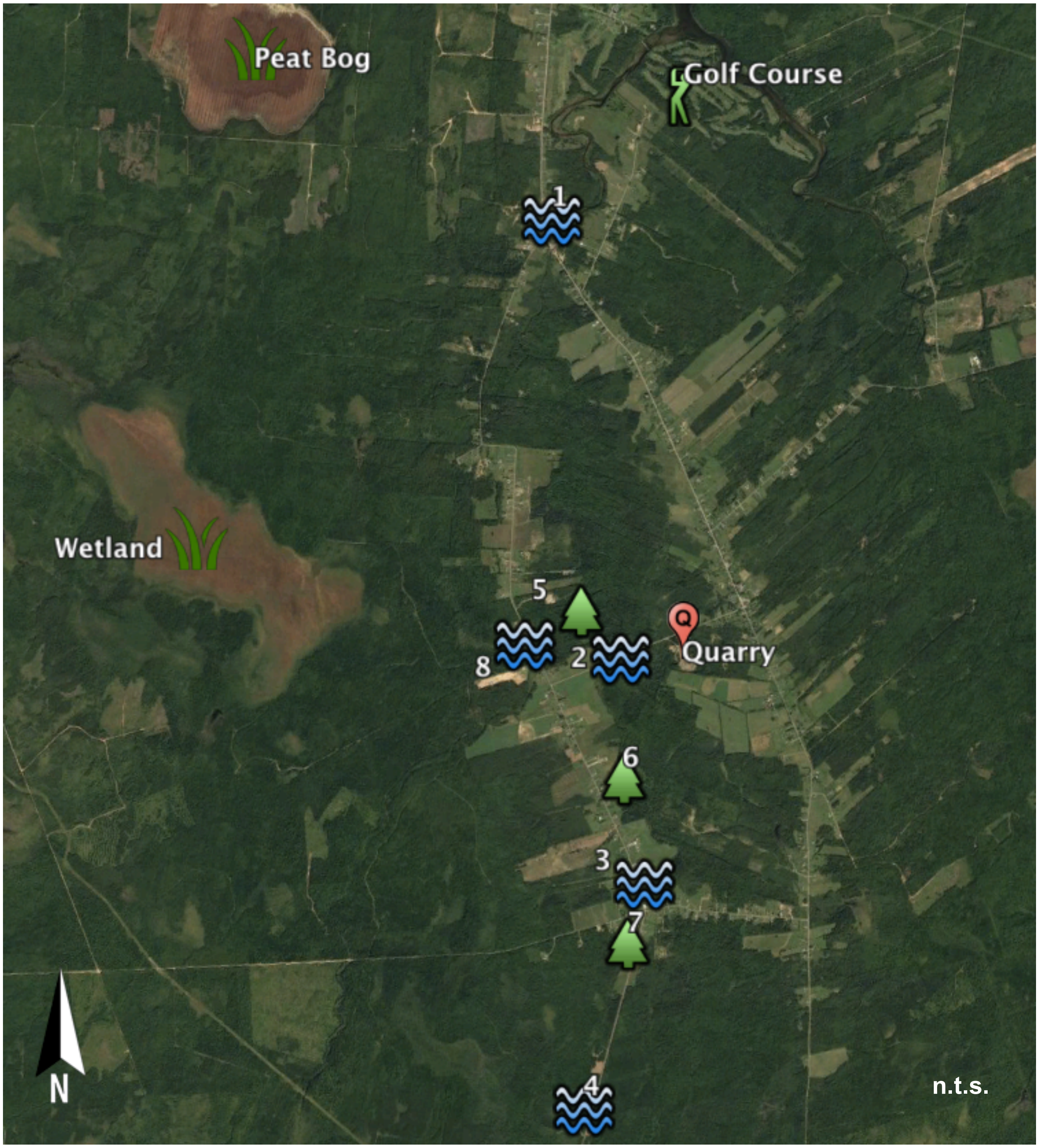

Figure 18. Map of points of interest

Figure 18, site 1: Bridge

In 2012, the bridge along route 933 was washed out by a major storm. Reconstruction of the bridge took place over the summer and fall of 2015, which coincided with one of Vision H_2O's water quality testing sites. The collapse of the bridge significantly disrupted the community as it is one of the main bridges that service the rural community. Residents were forced to detour the collapsed bridge for three years while it was under reconstruction. This bridges lies at the northern point of the community, closest to the coast.

Vision H_2O performed tests at this site in July and September 2015. They reported higher levels of *E.Coli* in the river and a marked difference in fish numbers. Vision H_2O reported a drastic decrease in fish stocks around the newly constructed bridge. Their study attributed this decrease in fish stocks to the newly engineered bridge, which made the watercourse too shallow and hot for fish to inhabit.[100]

Figure 18, site 2: Culvert

Underneath Des Babes Rd, there is a culvert that was backed up in August 2016 due to blockages cause by a beaver dam combined with heavy rains (see Figure 19, Figure 20 and Figure 25). It has been reported by sources in the community that the area has frequently become flooded during heavy rainfall, rising high enough to flood the elevated road.

Figure 18, site 3: Bridge

Although there is no running water under this small bridge, the area underneath the bridge fills up with water during rainfall events.

Figure 18, site 4: Road

The road, an entry point in the community, is built through a marsh. According to sources in the community, floodwater routinely inundates the road during heavy rainfall events.

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[100] (Cormier & Paquette, 2016)

Figure 18, site 5: Forest

A large expanse of territory, which was forested, has recently been cleared of all trees.

Figure 18, site 6-7: Forest

These sites denote forestry, reportedly managed by Irving. These forests are mono-cultures of softwood trees and have been planted in straight rows. Sources in the community claim that the hardwood trees that were previously on the land had been chemically sprayed in order to make clearing for softwood timber more efficient.

Figure 18, site 8: Riverbank restoration

Vision H_2O has planted trees along the riverbanks in this area in order to restore the vitality of the riverbanks and rivers (see Figure 21).

Figure 19. Culvert A060 on chemin Babé, Haute-Aboujagane (August 9, 2016)[101]

Figure 20. Culvert A060 after a storm combined with a beaver dam caused flooding (August 17, 2016)[102]

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[101] (Paquette, 2016)
[102] (Paquette, 2016)

3.2.3 Watershed Initiatives

In 2016, Vision H_2O completed a 2632m watershed cleanup, during which they removed debris, including pollution, garbage, and large obstacles, such as wood debris and logs.[103] Blockages and flood areas were recorded; these can contribute to overflow in other areas, obstacles to fish migration, and reduced river flow.

Additionally, the organization planted indigenous trees along Bear creek, in order to improve the quality of the river bank, reduce sedimentation, and provide shade for fish species that spawn in this creek. Trees were planted along Bear creek every 15m over 134m (see Figure 21). Maintaining an abundance of indigenous species is crucial, as they are adapted to the climatic changes of the region.[104]

Figure 21. Before and after planting indigenous trees to stabilize river banks near a salmonid pool in Bear stream[105]

3.3 Infrastructure

Highway, road, and street infrastructure is operated and maintained by the provincial governments. Public asset ownership and public spending has increased to accommodate a growing transportation network. In Canada, the length of public roads grew by 15.8% between

[103] (Paquette, 2016)
[104] (Paquette, 2016)
[105] (Paquette, 2016)

1996 and 2008. In 2009 to 2010, it was estimated that all levels of government spent $28.9 billion on roads and highways, which is 80% more than five years earlier.[106]

Following years of high expenditures on transportation infrastructure and economic downturn, governments across Canada are managing deficits and are thus limiting expenditures on roads. The effects of the economic crisis have also made it more difficult for private capital to fund transportation projects. For this reason, jurisdictions are attempting to implement alternative methods of financing public infrastructure, such as user charges and public-private partnerships.[107]

Figure 22. Storm water washes out sections of roads in southeast New Brunswick[108]

As is the case with many rural areas in Canada, and especially so in Atlantic Canada, New Brunswick has a very high proportion of roads for the population it services. Moreover, Atlantic Canada's hostile climatic conditions, which will be exacerbated by climate change vulnerability, are not conducive to maintaining already underserviced infrastructure.[109]

[106] (Transport Canada, 2012)
[107] (Transport Canada, 2012)
[108] (Radio-Canada, 2014)
[109] (Transport Canada, 2012)

Figure 23. Storm water washes out sections of roads in southeast New Brunswick[110]

The Haute-Aboujagane frequently experiences flood events and heavy precipitation that contribute to roadside erosion (see Figure 22 - Figure 24), washing out road sections, or even entire bridges, as was the case in 2012[111].

Figure 24. The effect of storm waters and soil erosion after large storm even in Haute-Aboujagane[112]

Figure 25. Beaver dam blocking culvert A060[113]

Infrastructure costs to the community include damage caused by flooding as a result of debris accumulation under culverts and bridges, which can block stormwater drains (see Figure 25). This exacerbates the already severe flooding that occurs in some areas and causes infrastructure damage, inevitably elevating infrastructure costs.

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[110] (Radio-Canada, 2014)
[111] (Cormier & Paquette, 2016); (Radio-Canada, 2014)
[112] (Paquette, 2016)
[113] (Paquette, 2016)

Haute-Aboujagane is an area that is currently highly susceptible to flooding. These risks will be exacerbated under future climate change scenarios. Moreover, this rural community has a very high proportions of road kilometers per person which is likely expensive to maintain and repair, and reduces budgets for other services. The community has a wealth of ecosystem services that are available and that are not currently maximized to their potential. In particular the river, is a valuable source of water filtration, flood control, and is a habitat for salmonids. These services present an opportunity for the community.

Chapter 4: Findings

Studying Haute-Aboujagane demonstrated that the tools to analyze the hydrological dynamics of a watershed are relatively accessible. With the appropriate knowledge, these tools can be applied to estimate the drainage and excess precipitation of a watershed. The results of the research are separated according to the hydrological flow accumulation model and the runoff model. They are presented visually by the maps that were produced throughout the process. The hydrological flow accumulation is an approximation of existing creeks and rivers; it allows us to identify areas of higher flow accumulation in conjunction with the presence of roads and development. The maps also provide a basis to better understand what the most important determining factors of the SCS equation are.

4.1 Runoff Curve Number

The outcome of the SCS equation method is a visual representation of how the landscape produces and retains excess precipitation (i.e. runoff) for a 1 in 100-year storm event – i.e. a storm that has only a one percent chance of occurring in any given year. The amount of runoff is determined by the land cover type, which was weighted by soil capability (quality for agricultural production). The maps are created for three precipitation durations (5 minutes, 30 minutes and 6 hours) and three climate change scenarios (historical trends, a 2025 climate change projection, and a 2085 climate change projection) (Figure 27, Figure 28 and Figure 29).

The maps provide a visual hierarchy of land cover types that are more or less effective at mitigating run-off, i.e. a comparison of which land contributes to flood control the most. This information facilitates a visual understanding of terrain that is less likely to retain water runoff.

The land cover types with the highest runoff coefficients were respectively; built, water, barren, low vegetation, and high vegetation. Upon analyzing the soil capabilities of the area, which were used to qualify the hydrological conditions of the soils, many soil classes in the area had agricultural limitations due to poor hydrological soil conditions or lack of drainage. The combination of this information allows for a better characterization of the land's ability to drain water after rainfall.

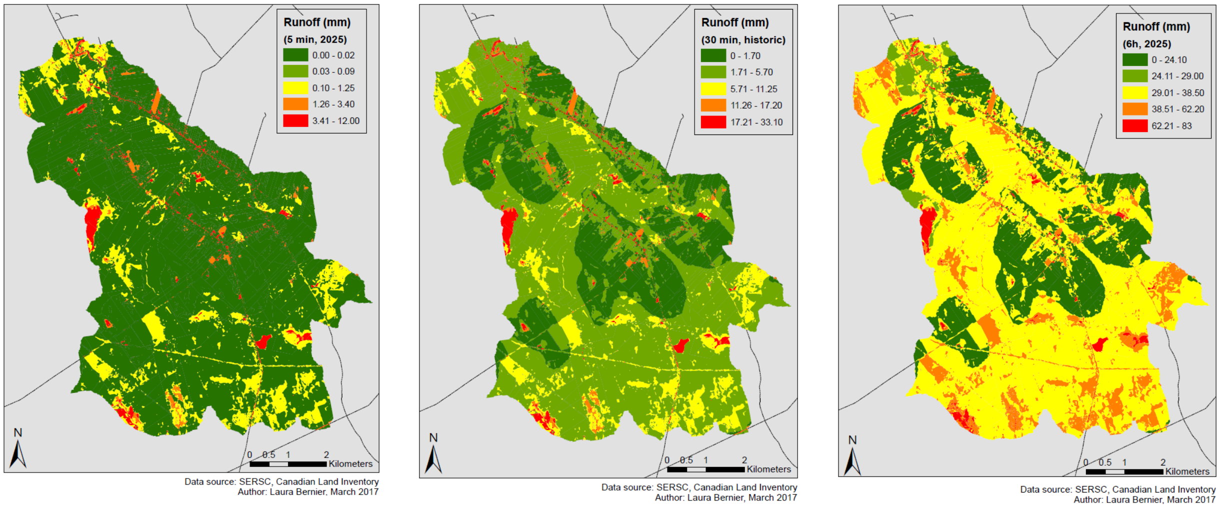
The southern portion of the watershed generally has higher runoff rates than the center and northern areas. However, the number of roadways that intersect the drainage paths or streams is highest in the community. Additionally, the lawns on lots, which is low vegetation cover, increases the rates of runoff in the community.

4.1.1 Duration

The most meaningful finding is the increase in the amount of runoff by landcover type as determined by precipitation duration (Figure 26). The maps precipitation classes, which are not standardized due to the large range of values, are classified by natural break in each respective dataset. Evidently, the longer duration storms drastically increased the total value of runoff generated for every type of land cover. However, the maps demonstrate that the longer duration storms increase the range of runoff that is generated by each parcel and decreases the proportion of land that has relatively lower values of runoff (Figure 26). The 5-minute precipitation event shows little variation between soil capability and vegetation cover; whereas the 6-hour storm demonstrates the importance of the parcels that have both high vegetation cover and high soil capability. These parcels, which remain dark green, maintain relatively low runoff values while the runoff value of other parcels is greatly affected by the increased storm duration.

Figure 26. Summary of runoff curve number results for 2025 climate change projection

5-MINUTE, 100-YEAR STORM	30-MINUTE, 100-YEAR STORM	6-HOUR, 100-YEAR STORM



Data Source: SERSC, Canadian Land Inventory
Author: Laura Bernier, March 2017

Table 12. Area of land cover by runoff quantity for 2025 projection (in m^2)

Runoff (volume in mm)	**Land Cover Type (area in m^2)**					
5 min, 100-year storm	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 0.02					5,099,686	39,843,614
0.03 – 0.09					857,322	
0.10 – 1.25					6,185,267	
1.26 – 3.40	1,021,673					
3.41 – 12.0		597,467	209,624	554,238		
30 min, 100-year storm	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 1.70						13,184,917
1.71 – 5.70					5,957,008	26,658,697
5.71 – 11.25					6,185,267	
11.26 – 17.20						
17.21 – 33.10	1,021,673	597,467	209,624	554,238		
6h, 100-year storm	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 24.10						13,184,917
24.11 – 30.00					5,099,686	1,201,619
30.01 – 37.85					857,322	25,457,078
37.86 – 62.50	1,021,673				6,185,267	
62.51 – 82.83		597,467	209,624	554,238		

4.1.2 Climate Change Projections

The results from various climate change scenarios show an increase in the total runoff generated (see Figure 27 to Figure 29). The results generally show that land uses that already have high runoff rates worsen with increased precipitation. The resulting maps appear visually striking due to the chosen runoff categories, which were selected by natural breaks according to the 2025 climate scenario projection. The projections between various climate change scenarios found that there was not a significant change in the amount of runoff generated by different land cover types in the various scenarios. All land cover types undergo a comparable incremental increase in runoff. The visual cues on the maps do represent the variation in the excess precipitation generated compared to a 2025 projection baseline.

The historical rainfall and the 2025 climate projections yielded similar results: land uses that already had high runoff rates worsened. The 2085 climate scenario shows an overall increase in runoff rates and a subsequent reduction in the ability for land to retain water runoff. This is explained by the fact that the difference between the intensity of precipitation between the 2025 projection and the 2085 projection is greater than that of between the historical trends and the 2025 projection.

The drainage and runoff models that were applied to the Aboujagane Watershed are scalable and replicable models which can be applied to virtually any watershed. The data used is almost all publicly accessible, except for the land cover and building footprints that are provided by SERSC. Land cover is available at a lower resolution through Natural Resources Canada.[114] It may be possible to approximate data that is not publicly available to some extent by creating a geospatial database using digital satellite imagery from Google Earth.

The combination of the results of the analysis will be discussed in the next chapter and can be visualized in a final map that comprises the flow accumulation, runoff, and existing development (see Figure 32). By visualizing the dynamics of water over the landscape using flow

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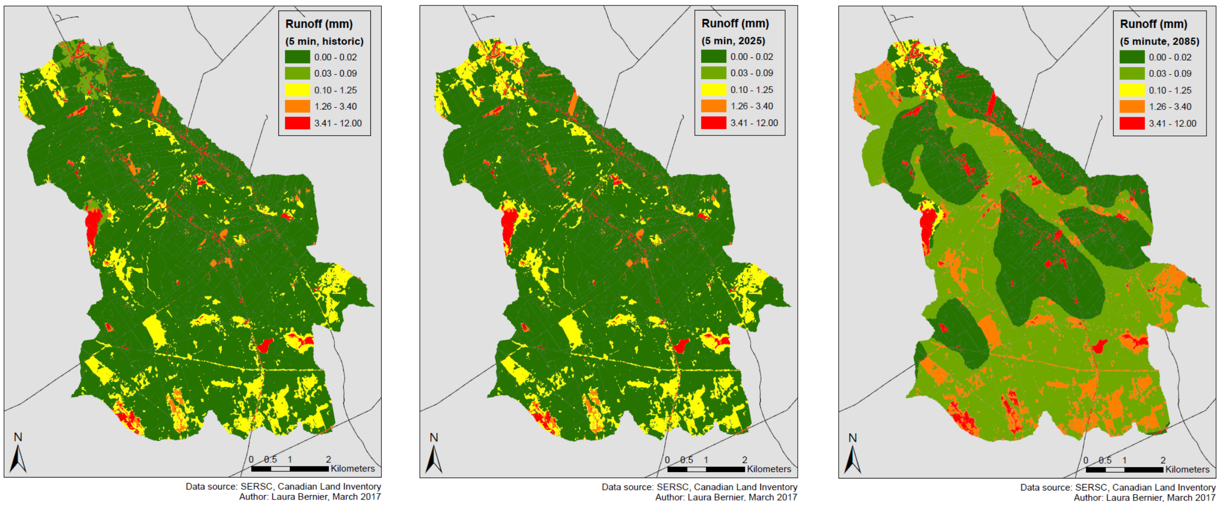
[114] (Natural Resources Canada, s.d.)

accumulation and runoff, a qualitative assessment of the significance of land cover in the watershed is explored in the discussion chapter.

Figure 27. Summary of runoff curve number results for 5 minute, 100-year storm

HISTORICAL	2025 PROJECTION	2085 PROJECTION



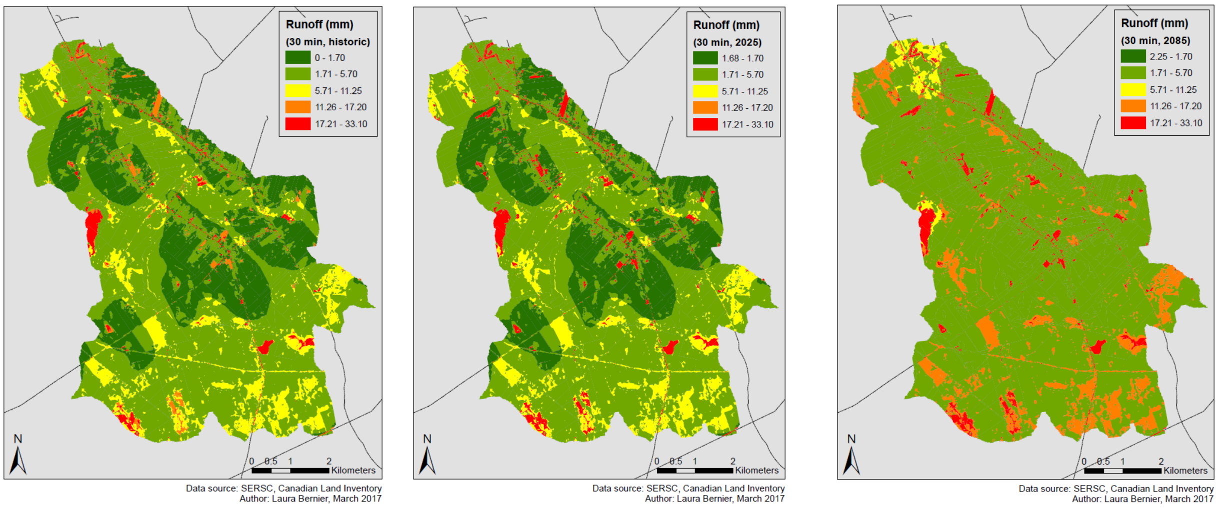
Data Source: SERSC, Canadian Land Inventory
Author: Laura Bernier, March 2017

Table 13. Area of land cover by runoff quantity for 5 minute, 100-year storm (in m^2)

Runoff (volume in mm)	**Land Cover Type (area in m^2)**					
HISTORICAL	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 0.02					5,099,686	14,386,536
0.03 – 0.09					857,322	25,457,078
0.10 – 1.25					6,185,267	
1.26 – 3.40	1,021,673					
3.41 – 12.0		597,467	209,624	554,238		
2025 PROJECTION	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 0.02					5,099,686	39,843,614
0.03 – 0.09					857,322	
0.10 – 1.25					6,185,267	
1.26 – 3.40	1,021,673					
3.41 – 12.0		597,467	209,624	554,238		
2085 PROJECTION	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 0.02					5,099,686	14,386,536
0.03 – 0.09						25,457,078
0.10 – 1.25					857,322	
1.26 – 3.40					6,185,267	
3.41 – 12.0	1,021,673	597,467	209,624	554,238		

Figure 28. Summary of runoff curve number results for 30 minute, 100-year storm

HISTORICAL	2025 PROJECTION	2085 PROJECTION



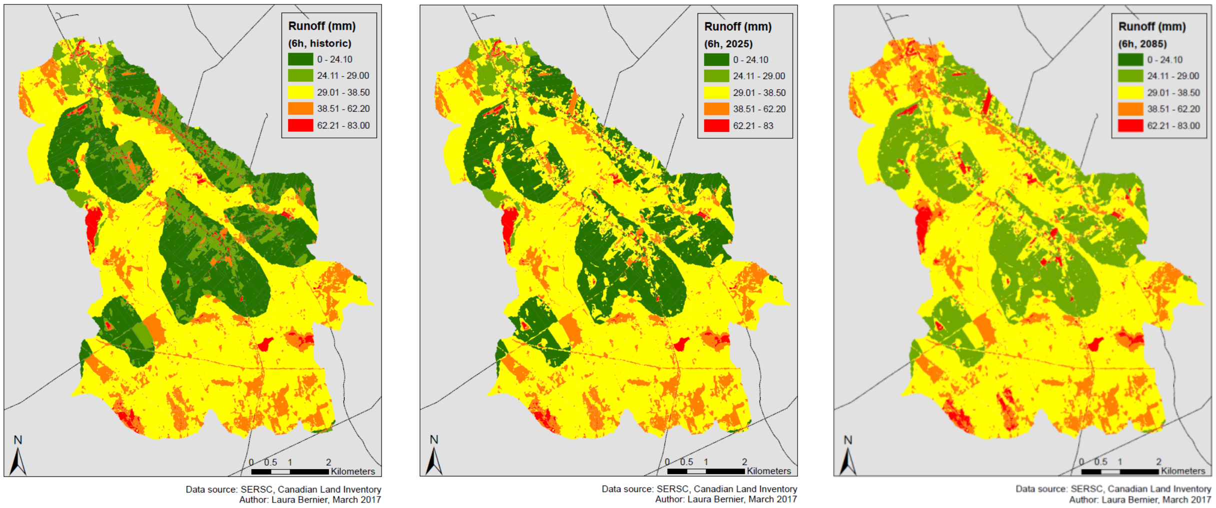
Data Source: SERSC, Canadian Land Inventory
Author: Laura Bernier, March 2017

Table 14. Area of land cover by runoff quantity for 30 minute, 100-year storm (in m²)

Runoff (volume in mm)	**Land Cover Type (area in m²)**					
HISTORICAL	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 1.70						13,184,917
1.71 – 5.70					5,957,008	26,658,697
5.71 – 11.25					6,185,267	
11.26 – 17.20	1,021,673					
17.21 – 33.10		597,467	209,624	554,238		
2025 PROJECTION	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 1.70						13,184,917
1.71 – 5.70					5,957,008	26,658,697
5.71 – 11.25					6,185,267	
11.26 – 17.20						
17.21 – 33.10	1,021,673	597,467	209,624	554,238		
2085 PROJECTION	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 1.70						
1.71 – 5.70					5,099,686	39,843,614
5.71 – 11.25					857,322	
11.26 – 17.20					6,185,267	
17.21 – 33.10	1,021,673	597,467	209,624	554,238		

Figure 29. Summary of runoff curve number results for 6-hour, 100-year storm

HISTORICAL	2025 PROJECTION	2085 PROJECTION



Data Source: SERSC, Canadian Land Inventory
Author: Laura Bernier, March 2017

Table 15. Area of land cover by runoff quantity for 6-hour, 100-year storm (in m^2)

Runoff (volume in mm)	Land Cover Type (area in m^2)					
HISTORICAL	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 24.10						13,184,917
24.11 – 30.00					5,099,686	1,201,619
30.01 – 37.85					857,322	25,457,078
37.86 – 62.50	1,021,673				6,185,267	
62.51 – 82.83		597,467	209,624	554,238		
2025 PROJECTION	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 24.10						13,184,917
24.11 – 30.00					5,099,686	1,201,619
30.01 – 37.85					857,322	25,457,078
37.86 – 62.50	1,021,673				6,185,267	
62.51 – 82.83		597,467	209,624	554,238		
2085 PROJECTION	Barren	Built	Water	Wetland	Low veg	High veg
0.00 – 24.10						
24.11 – 30.00						14,386,536
30.01 – 37.85					5,099,686	25,457,078
37.86 – 62.50					7,042,589	
62.51 – 82.83	1021,673	597,467	209,624	554,238		

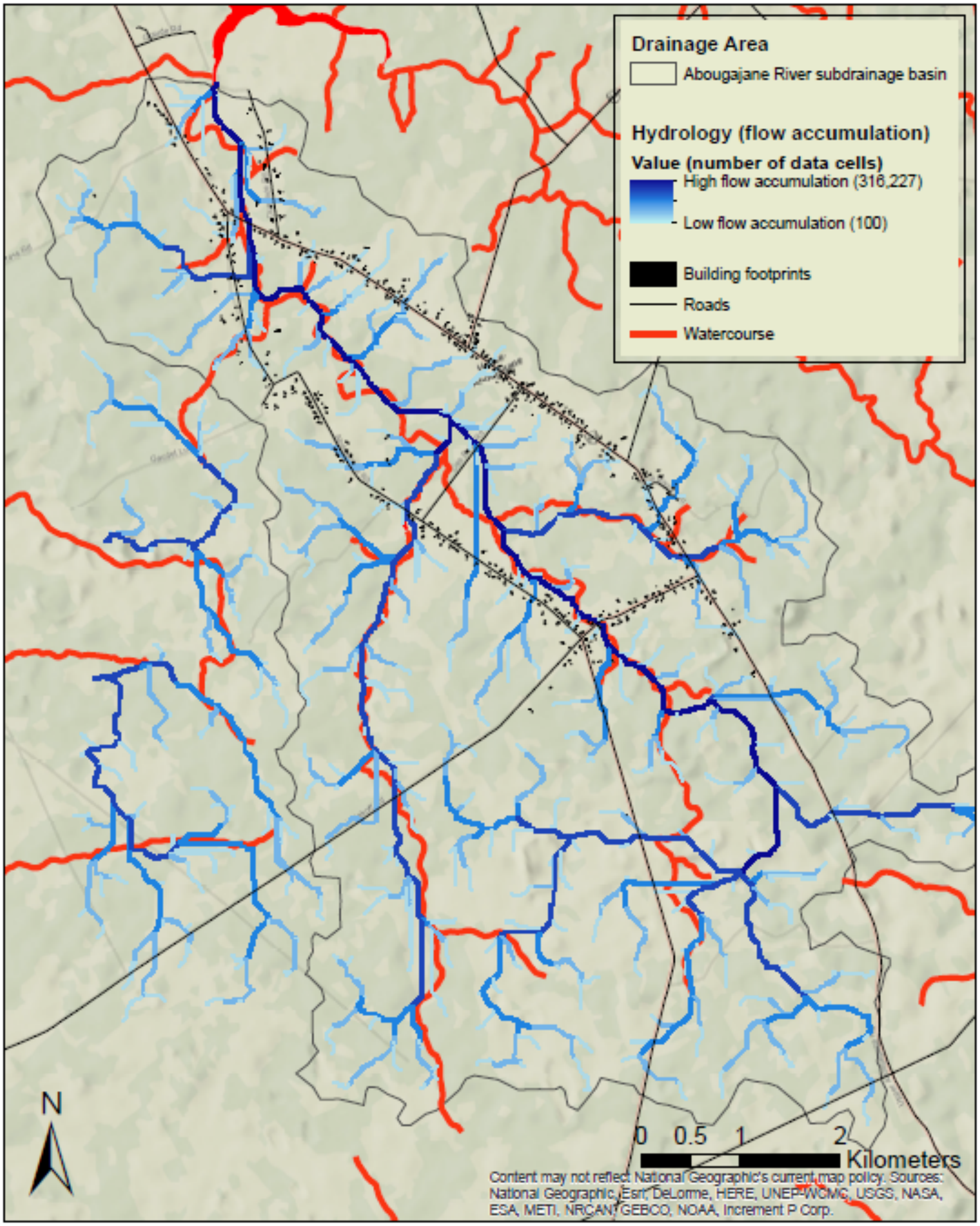
4.2 Hydrological flow accumulation

The hydrological flow accumulation (see Figure 30, in blue) is a model of the flow of water across the surface of the Aboujagane Watershed. The model is derived from a digital surface model which records the coordinates and elevation of the landscape every 20m. The hydrological flow accumulation shows the number of cells that are accumulating as they move down the slopes of the terrain. In other words, Figure 30 demonstrates how water would accumulate along the path of least resistance. This allows the patterns of drainage from runoff after a storm to be determined.

The highest value is where there is the most accumulated water (316,227 raster cells), which occurs in the northern area of the site, where streams flow into the Aboujagane River and eventually into the Northumberland Straight. The lowest value is where the least amount of water has accumulated. Low values show where water begins to accumulate on the landscape and is the source of streams which later flow into larger waterways. Low hydrological flow accumulation was conditionally set so that the minimum accumulation that can be seen is 100 raster cells (see Table 9).

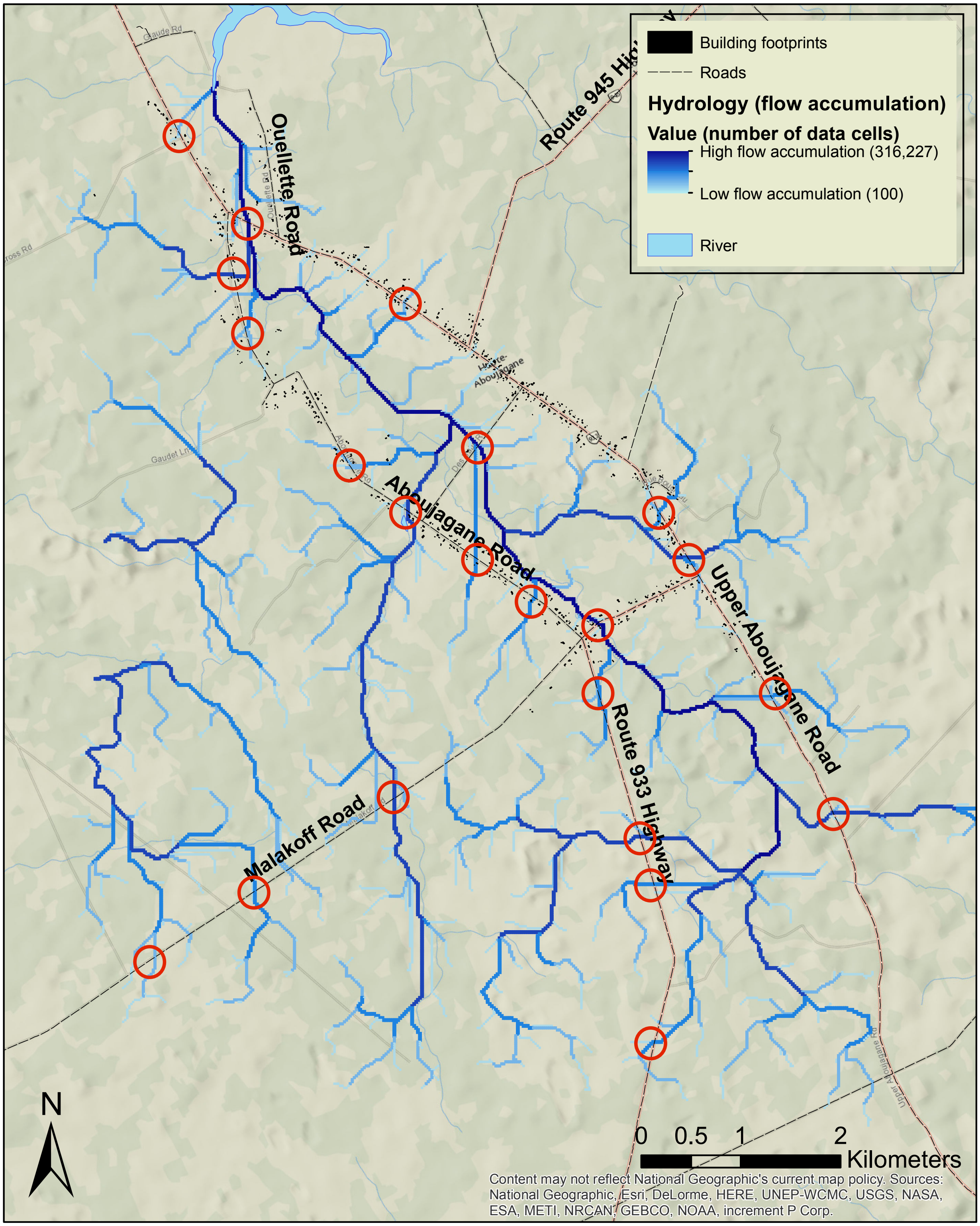
Hydrological flow accumulation shows that the majority of the water accumulates between Aboujagane Rd. and Upper Aboujagane Rd, explaining the presence of an existing watercourse (see Figure 30). It also identifies areas further upstream that may be susceptible to flooding, soil erosion, and landslides. However, there are inaccuracies in the model and not all the hydrological flow is accumulating where existing rivers are shown. This may also be in part due to the nature of the landscape, which contains many low-lying areas of land.

The model shows major drainage channels originating in the southeast and southwest portions of the watershed and meet northwest of Des Babes Rd. The channel on the southeast side has a higher flow accumulation. The map shows water flow accumulation across access roads, including Aboujagane Rd., Upper Aboujagane Rd., and Malakoff Rd (see Figure 31). Water flow accumulation is very high where the channel intersects with Malakoff Rd. Additionally, high flow accumulation runs parallel to Aboujagane Rd. To the southwest there is another long channel that also transports water across Aboujagane Rd (see Figure 31).



Data source: SERSC, Canadian Land Inventory
Author: Laura Bernier, March 2017

Figure 30. Hydrological flow accumulation v. existing rivers



Data source: SERSC, Canadian Land Inventory
Author: Laura Bernier, March 2017

Figure 31. Hydrological flow accumulation and street intersections

The goal of the research is to provide a relatively simple model that small communities can use to make better management decisions as they pertain to the functions of runoff retention and drainage in their watershed. Improving the accessibility to understanding watershed dynamics facilitates better decision-making with respect to developing away from areas that are or may be vulnerable to flooding. It also improves the ability for planners to identify natural assets that may benefit the community, such as the added value of areas that are at once highly vegetated and have high quality soils.

Chapter 5: Discussion

The watershed perspective is crucial to regional planning to ensure the vitality and appropriate maintenance of ecosystem services. Human activities, such as deforestation, agriculture, and urbanization, alter land cover and soil properties. [115] This affects the volume and temporal distribution of water and sediment movement across landscapes, which can have a profound impact on ecosystem service deliveries, such as flood regulation and clean water delivery. The hydrological movement found in watersheds is responsible for the transportation of sediments, nutrients, pollutants and organisms.[116] These changes to the distribution and quality of water and soil can affect the integrity of land for development and the lifecycle of municipal infrastructure, amongst a wide range of other impacts. Monitoring the dynamics of aquatic ecosystem services has been identified as a priority to ensure their sustainable management.[117]

The results display previously mapped and unmapped waterways using very limited tools. The limitations of the hydrological flow accumulation over existing creeks and rivers are reflected in the results. Although the maps show a similar trend to the drainage patterns of the watershed, there are important discrepancies in some areas. Although a warmer climate may lead to a lower baseflow, the hydrological flow in the watershed may see unprecedented surges during precipitation events as severe storms are more frequent. This could potentially create intermittent streams in new areas and/or compromise soils along the mapped hydrological flow accumulation model (see Figure 32).

The runoff potential allows us to derive information on the importance of land use in the watershed. The maps demonstrate that land which lies adjacent to watercourses has a higher runoff potential than other areas. Soils in the community, especially in developed areas, are in poor hydrological condition and/or have poor drainage (see Figure 13 and Table 4). Measures to improve drainage, where it may affect the community, should be prioritized through strategic measures and policies. Although the land cover type is distributed fairly evenly throughout the watershed (see chapter 2, Figure 11), we can see that runoff potential in the southern portion of

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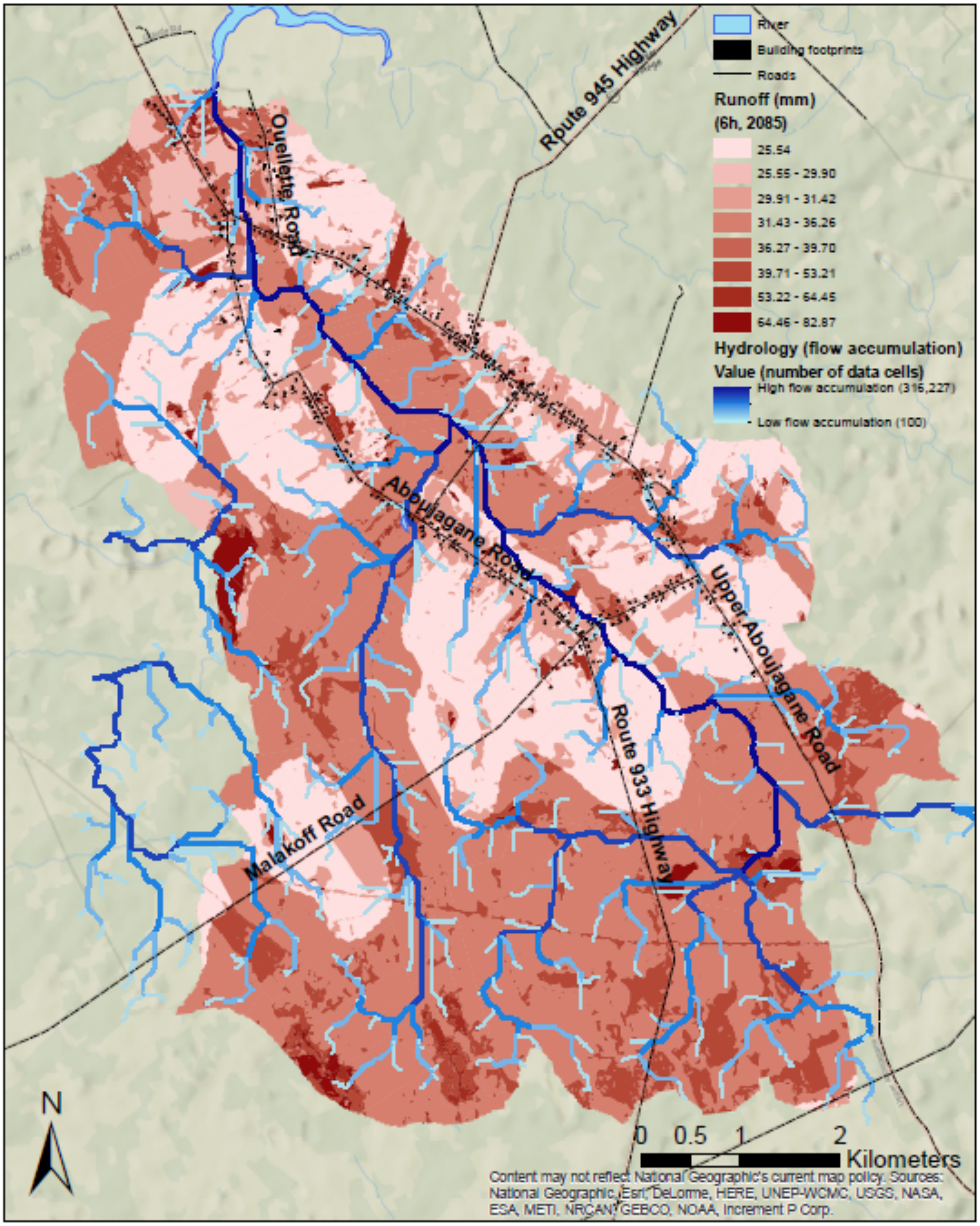
[115] (Villamagna & Angermeier, 2015)
[116] (Villamagna & Angermeier, 2015)
[117] (Villamagna & Angermeier, 2015)

the site is much more important (Figure 32). As previously mentioned, this is likely due to the poor drainage in the soils in this area (Figure 13) as the area is connected to the majority of the watershed's hydrological drainage course. Constructing wetlands has shown to effectively control runoff and be extremely cost effective in some cases.[118]

[118] (De Laney, 1995)



Data source: SERSC, Canadian Land Inventory
Author: Laura Bernier, March 2017

Figure 32. Hydrological flow accumulation and runoff potential 2085 climate change scenario (6-hour storm)

Although runoff rates are lower near the Haute-Aboujagane community, this is the area where runoff is most critical. The presence of high quality soil plays an integral role in increasing the land's potential to retain water. The area also has the highest amount of flow accumulation in the stream itself, due to larger catchment size, but also in the floodplains around the stream. Incidentally, flooding along roads has been reported during heavy rainfall. The large amount of low vegetation cover on residential lots contributes to an impressive increase of potential runoff rates. These poorly vegetated areas, largely lawns, are along access roads, which have high runoff rates themselves.

It is important to note that despite the fact that wetlands have a very high curve number (CN), they are imperative to flood water management. In some instances, wetlands are given a curve number of 0 until they are saturated, while other studies use a curve number of 98. For this reason, the results associated to the ability of wetlands to retain water are limited, without knowledge of the level of saturation of the wetland. In addition, the runoff potential of a saturated wetland (98, which is equivalent to built-up land) does not imply that wetlands are a poor use of land, nor that they should be drained. Wetlands serve very important ecological functions and maintain water quality, in addition to serving as a sink for excess rainwater.

Basse-Aboujagane and Bourgeois Mills sectors have a higher occurrence of hydrological flow accumulation than the Haute-Aboujagane sector. The pattern of the hydrological flow accumulation upstream from Basse-Aboujagane and Bourgeois Mills coincide with lands with poor water retention properties.

The hydrological flow accumulation demonstrated that there is a high amount of flow that runs parallel to residences along Aboujagane Rd. between Des Babes Rd and Malakoff Rd. Although the area around this land has relatively low runoff potential compared to the surrounding areas, an important portion of the watershed is draining at the intersection of Malakoff Rd. and Aboujagane Rd. This is a high priority area for future work in the community. Notably, there is a significant number of barren lots surrounding this intersection (see Figure 32).

In Haute-Aboujagane, a rural area that is regularly subject to inundation, many residents depend on ecosystem services to guarantee access to high quality water and to ensure flood water drainage. The costs associated to culvert washout, erosion, and damage to infrastructure is significant, whereas the population benefitting from these services is very small. The area is particularly vulnerable to the effects of climate change. North of Haute-Aboujagane are the shores of the Northumberland straight, which is considered one of the most vulnerable areas to sea-level rise and storm surges in Canada. As the frequency of extreme weather events increase, infrastructure will require more costly and frequent maintenance and repair, or it risks falling into disrepair. This is especially true for infrastructure that is not engineered for the intensity of storms under future climate change scenarios.

5.1 Limitations

The techniques that exist for simple, modern mapping of flood extent typically rely upon the availability of LIDAR data. Due to the fact that LIDAR data only existed for half the site, this was an important limitation to the study. The method to apply flood extent could not readily be used over the whole area and fell outside the scope of the study.

Additionally, the land cover data lacked resolution. The data only included five categories, which failed to accurately represent the reality on the ground. For instance, many tree farms are visible from the ground and large expanses of "would-be-forest cover" covered by saplings and juvenile soft wood trees, which have been planted in rows for timber production. This land cover type will greatly affect rainwater retention in the area. Yet, these tree farms will be classified with the same characteristics of an untouched mixed forest, with a much denser canopy. Land cover could have provided some insight into how land is managed, but it does not provide information on the types of material covering the surface of the terrain.

Land cover type is a useful estimate for large expanses of lands, it is recommended that a similar study use more accurate data on land cover type or create a geodatabase of important land covers that are not represented on the data that is available. Furthermore, the creation of a geodatabase has the ability to solve other issues: (1) the identification of wetlands in the community appeared to be underestimated, (2) some agricultural fields were classified as barren land rather than low vegetation, (3) localized best-management practices to reduce runoff, such as soil conservation farming for example, may not be captured in land cover data.

The following elements were not included within the scope of the study, but are highly recommended:

1. A Cost Benefit Analysis of the recommendations was not within the scope of the study, however, this is necessary for the consideration of the recommendations.
2. Using the runoff values from the land in order to weight the values of the hydrological model in order to quantify the relative risk of land cover change of a given area.

The use of curve numbers (CN) in the SCS equation has been subject to controversy. These values are very sensitive. Without a very strong understanding of the hydrological conditions of the soil, these values can be misrepresentative. However, this method is widely used and accepted for hydrological studies on watersheds.

The hydrological flow accumulation model is severely limited in terms of the accuracy of the model. Juxtaposing the flow accumulation and existing rivers (see Figure 30) shows that there are major discrepancies between the model and reality in some areas. Some of this error may be due to bogs that embank some areas of the river. However, further investigation is required to determine a definite cause of this error.

Chapter 6: Recommendations

There is a growing body of literature on the services that ecosystems provide at little to no cost to society. Increasingly, many urban areas are attempting to mimic natural systems in order to manage water runoff by using Green Infrastructure. Rural areas can learn from the policies implemented in urban areas, yet capitalize on their proximity to nature to maximize services by identifying, valuing, restoring and/or protecting ecosystems. The recommended policies seek to accomplish three main goals: to value ecosystem services that attenuate flood risks in the community, to encourage development to consider current and future vulnerability to flood risk in the area, and to decrease the costs of infrastructure repair and maintenance associated to flood damage.

6.1 Review of Community Policies

The official planning document for a community is intended to guide the orderly development of the region by providing standards and regulations for development. A Rural Plan, as is the case in Beaubassin-est, is typically more permissive in terms of the restrictions that are placed on landowners, than urban or suburban community plans. This is one of the many reasons that a Rural Residential Zone, for example, may be a very attractive residential area to some.

The Beaubassin-est Rural Community Rural Plan begins by declaring that quality of life, environmental protection, and community development are basic pursuits of a community that seeks coordinated and steady development. The Plan follows by stating that it is intended to ensure that the community meets the current needs of its citizens, without compromising the quality of life of future generations, which is the way the Brundtland Report defined sustainable development in 1987.[119]

The Beaubassin East Rural Community Rural Plan, as one might expect from the name, places great importance on maintaining the rural characteristics of the community. The majority of the land in the Aboujagane Watershed is zoned Rural, or Rural Residential. The Rural Zone

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[119] (Beaubassin East Rural Community Rural Plan, 2009; UN, 2007).

allows a very wide diversity of land uses, while the Rural Residential Zones must, for the most part, be used primarily as a dwelling.

The plan encourages low density development and allows a diversity of land uses. The Rural Plan has five overarching objectives, which are: to maintain population growth with regard to infrastructure capacity; control development; protect the environment; maintain quality of life; and establish building standards.

The Beaubassin-est Community Pan suggests that the community values sustainable land use and land stewardship. The general policies contained therein promote maximizing the use of land and encouraging sustainable development as primary objectives. However, none of the land-use policies support this directive. However, as in the case of many other rural areas, the regulations on land-use are liberal and there is very little responsibility for land-owners to practice environmental stewardship. Environmental planning in the area is reactive, rather than proactive. In other words, the policies and regulations are in place to prevent hazards, such as waste and pollutants, but not to ensure the environmental health of the area.

Policies concerning the environment state that the community should aim to “maintain and enhance the quality of life of its residents, to preserve the natural beauty of the environment and to protect it against hazards”. In order to practice environmental stewardship and sustainable development, policies on the environment should be concerned with the function and health of the ecological landscape, rather than simply its aesthetic appeal. The policies seek “to control developments carried out in ecologically sensitive areas in order to prevent erosion, flooding, pollution, and other events that pose a threat to the fauna, flora, and other aspects of the environment”, yet there are no measures of ecological health. These policies fail to capture the complexity of ecosystems and the importance of ecological protection to the safeguarding of human infrastructure, safety, and sustainability in the community.

6.2 Recommendations

Provincial Strategies

6.2.1 High level policy commitment to building community resiliency

Commitment by the Province of New Brunswick to improving community resilience to climate change communicates the important of new environmental standards to municipal departments, developers, landscapers, property owners and underpins cross-departmental cooperation and community partnerships.[120]

6.2.2 Incorporating vegetative buffers around road infrastructure, culverts, and bridges can reduce erosion and increase the lifecycle of infrastructure.

The roots of plants are very effective at mitigating erosion of soil and roads. Increasing vegetation improves water retention, soil infiltration rates, and can reduce the velocity of water. Creating a vegetative buffer around roadways, culverts, bridges, and other infrastructure will increase the infrastructure life span and the quality of service delivery by preventing erosion and degradation during storms. In severe cases, culverts and roadways have been so damaged that they are impassible. This can be devastating and extremely dangerous during extreme storm events.

Berms and swails can be used to divert strong headwaters into retention ponds temporarily. This further attenuates the impact of storms by increasing water retention, and decreasing its velocity before it re-enters a river. Maintaining an abundance of indigenous species may be advantageous, as they are typically well-adapted to the climatic changes and soil conditions of the region. Moreover, trees along riverbanks improve the quality of the river bank, reduce sedimentation and provide shade for fish species.[121]

The Governemnt of New Brunswick owns the roads and right-of-ways in Haute-Aboujagane. Thus, improving roadside vegetation for stormwater management would require inter-governmental cooperation, including a special schedule for roadside maintenance in the

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[120] (Green Communities Canada, 2016)
[121] (Paquette, 2016)

community. A cost-benefit analysis of the lifecycle of infrastructure with or without a vegetative buffer is needed to determine the feasibility of the necessary maintenance schedule.

6.2.3 Assess the current state of infrastructure, engineering standards, road elevation, and alternatives and ensure standards for new infrastructure meet a 2100 climate change scenario for a 1 in 100-year return storm.

There are already intersections and roads in Haute-Aboujagane that reportedly flood during precipitation events (see Figure 18) in the current climate. These sites are hazardous and should be reported by residents for inspection by the provincial government. It is recommended that the Government of New Brunswick investigate the need for increasing the infrastructure standards to meet current and future needs. It is important to note that if the lifecycle of infrastructure is less than about 20 years it may have less exposure to the impacts of climate change. Decision-making for a period of fifty years or more is much more likely to exist in a substantially different climate.[122]

Local Strategies

6.2.4 Develop a Stormwater User Fee

Stormwater user fees are gaining traction as a method to price the usage of stormwater management services at the municipal level. A user fee makes the real value of best management practices for rain water retention visible by charging land owners for the amount of runoff their property is estimated to create. The fee is not a new charge; it takes existing taxes for stormwater management and redistributes the payment method based on the impervious surfaces on private properties.

Although applying this policy in a rural community is far more complex, it is feasible for the Beaubassin-est Rural Community to create a weighted system that places higher value on more efficient uses of land. Fees increase based on the proportion of impervious surfaces or surfaces that are inefficient at retaining water and decrease for managing rainfall on-site.

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[122] (AMEC Earth & Environmental, 2011)

Stormwater user fees have existed since at least the 1970s, when they were implemented in Portland, Oregon. They have been recently implemented in the City of Guelph, Mississauga, and Kitchener and Waterloo. [123]

6.2.5 Encourage the development of ecological assets and discourage unsustainable resource management; collaborate between municipal Council Committee mandates to develop and incorporate ecological assets into community planning and management.

The community should investigate and evaluate its ecological assets that contribute to economic sustainability. For instance, the community has valuable provisioning services (fishing, peatland development), recreational activities (parks and trails network), and regulating services (flood management). Evaluating these resources will provide a better understanding and management of the natural capital that is present in the community. Furthermore, by comparing the value of ecosystem services to others, such as intensive forestry, there may be sound financial reasoning to invest in improving the sustainability of resource use.

The community should continue to collaborate with municipal Council Committee mandates, such as creating combined priorities between finance, planning and environment, and cultural development to increase mainstreaming of municipal natural assets into budgets and planning.

6.2.6 Promoting education on the role of land use and vegetation in stormwater management and leadership in best management practices.

Changing the norms of behavior on private land is an important and difficult task. In Haute-Aboujagane, large private lawns are the norm. The Community can show leadership by enlisting the help of Vision H_2O to create a small educational campaign to promote sustainable landscaping practices for stormwater management. This can be reinforced by prioritizing the implementation

[123] (Blakelock, 2016)

of best management practices in municipal facilities or by supporting the initiatives of local champions.

6.2.7 Protecting the function of land that has a high capability of retaining water.

The presence of high vegetative cover and high soil capability plays an integral role in reducing runoff during storms that have a higher value of total precipitation. The Southeast Regional Service Commission can help the community capitalize on ecosystem services that these areas provide by discouraging their development. Areas that possess high soil capability and vegetation cover should be conserved and managed as best as possible. Improving park networks and recreation improves the recreational value of natural landscapes. These services can be further appreciated when maps of trail networks are made publicly available.

6.2.8 Improve the function of land that has a low capability of retaining water and where hydrological flow is high.

Land that has a low capability of retaining water (where there is poor quality soils and low vegetation cover) should be improved on, especially where hydrological flow is high. This is the case in the southern part of the watershed, where there is little development. The hydrological soil conditions imply that drainage in this area is relatively poor. The flow accumulation shows that a large amount of water downstream originates from this area, it is recommended that this zone be used to improve water retention to help mitigate flooding downstream.

There are many strategies that can be used to attenuate water flow, one of which is to increase the amount of high vegetative land cover, such as forests. However, this strategy is not always feasible. A more strategic option is the construction of wetlands, terraces and check dams. Check dams have been widely used for centuries. They are typically situated at regular intervals and reduce the velocity of water. Check dams can be constructed for temporary use and have been shown to prevent silting. Additionally, policies suggested by the Southeast Regional Service Commission should seek to promote sustainable forestry management practices that are sensitive to runoff and more stringent policies of deforestation.

6.2.9 Collaboration to monitor water quality and floodsites.

The community should continue to work alongside Vision H_2O to promote their work monitoring water quality and recording the location of flooding. The community should continue to communicate and work with the Regional Service Commission to map assets for floodwater management and flood extent caused by 100-year storm events for a 2100 climate change projection.

6.2.10 It is recommended that the community ban the domestic use of harmful herbicides, fungicides and insecticides for cosmetic purposes on lawns and gardens.

Pesticides and fertilizers have important impacts on water quality, as well as human and ecological health. These harmful chemicals pose a serious threat to water quality. As a habitat for Atlantic salmon and other salmonids, the Aboujagane River should maintain the highest standard of water quality. This can be accomplished though the adoption of restrictive bylaws into the community plan.

Conclusion

Environmental concepts, such as sustainability, ecosystem services, and resilience are neither novel concepts, nor are they important merely in the abstract. Rather, they have significant effects on the actual functioning and health of landscapes and communities. While larger cities are increasingly adopting sustainable initiatives to improve the quality of life of their citizens, it has proven more difficult to mobilize behavioural change in rural areas. In some instances, the sustainable initiatives that receive the most visibility may be impractical, impossible, or not applicable in a rural context. Citizens often choose to live in rural areas because there is a sense of freedom, space, and proximity to nature. It is crucial to investigate and communicate how environmental sustainability can have a meaningful impact in a rural context, without forcing citizens to compromise their lifestyle.

Haute-Aboujagane, the rural area under study, is responsible for altering a very large amount of land for a disproportionately small number of citizens. It is important that research in planning and development does not overlook strategies that would include rural communities in sustainable development initiatives. Beaubassin East is an example of a community which has incorporated sustainable development goals into the Rural Plan. However, there has been little implementation via by-laws to support these aspirations. This may be due to the lack of traction that new regulations would have with the community and the difficulty of enforcing by-laws over an expansive, low population-density territory.

As the climate changes, small communities can anticipate more intense and frequent precipitation events. It will be difficult for communities to adapt and respond to these changes quickly, without major investments in infrastructure, such as shelters and community drainage plans. Ecosystem services have been proven to help communities that are vulnerable to unanticipated environmental stressors. If ecosystem services are damaged via overdevelopment or overuse, the impact of natural disasters will be exacerbated. Citizens in rural communities are as reliant on infrastructural services. In the event of severe storm events, citizens in small communities may be easily cut off from necessary services. This has important implications on their access to basic human needs and safety. Improving knowledge on how ecosystem services can improve service delivery can help make better decisions regarding both maintaining ecosystem services and proper sizing of infrastructure to reduce risk.

Although rural and suburban areas may be more resource-intensive than cities, they have different strengths that can be capitalized on to initiate more sustainable planning practices. Rural communities draw on the abundance of ecosystems services and natural assets, in order to replace or extend the lifecycle of engineered infrastructure. This research demonstrates that the tools to incorporate ecosystem services are readily available to practitioners. However, environmental land-use planning has not been mainstreamed into regional and municipal planning settings and these tools are thus historically poorly applied.

The methods in the paper are viable for any watershed or community. They are scalable, replicable, and most of the data is publicly available. This particular watershed has the potential for economic value, making the case for preservation and integration into land-use management far easier to prove. The work done by Vision H_2O to survey fish populations in the Aboujagane River may be helpful to support environmental policies to preserve Atlantic Salmon populations.

The recommendations apply a hydrological analysis and best practices to a rural residential site that is vulnerable to storms and likely to become more so due to climate change. Best management practices will rely on the active participation and education of citizens, in order to garner support for a more mindful perspective of the impact of land use in a rural setting. Demonstrating the impact of land use on the life cycle of municipal infrastructure can be an effective way of mobilizing community concern for sustainable land use; this is an area that could be potentially further studied.

The goal of the recommendations is not to dictate how individuals should manage their land. On the contrary, the recommendations should create community consensus concerning the crucial role of every parcel of land in its role of reducing runoff. Additionally, the recommendations should serve as a warning to those developing in areas that have a high potential to flood in the future.

To conclude, rural communities can use this research as a guide for managing the types of resources that may help them map ecological assets for flood control. The ultimate goal of the research is to mainstream environmental planning practices, to guide environmentally sound decision-making, and improve the resilience of communities in preparation for a volatile climate. When ecosystem services are valued by the planners and by the community, we can expect a more holistic, sustainable approach to regional planning.

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