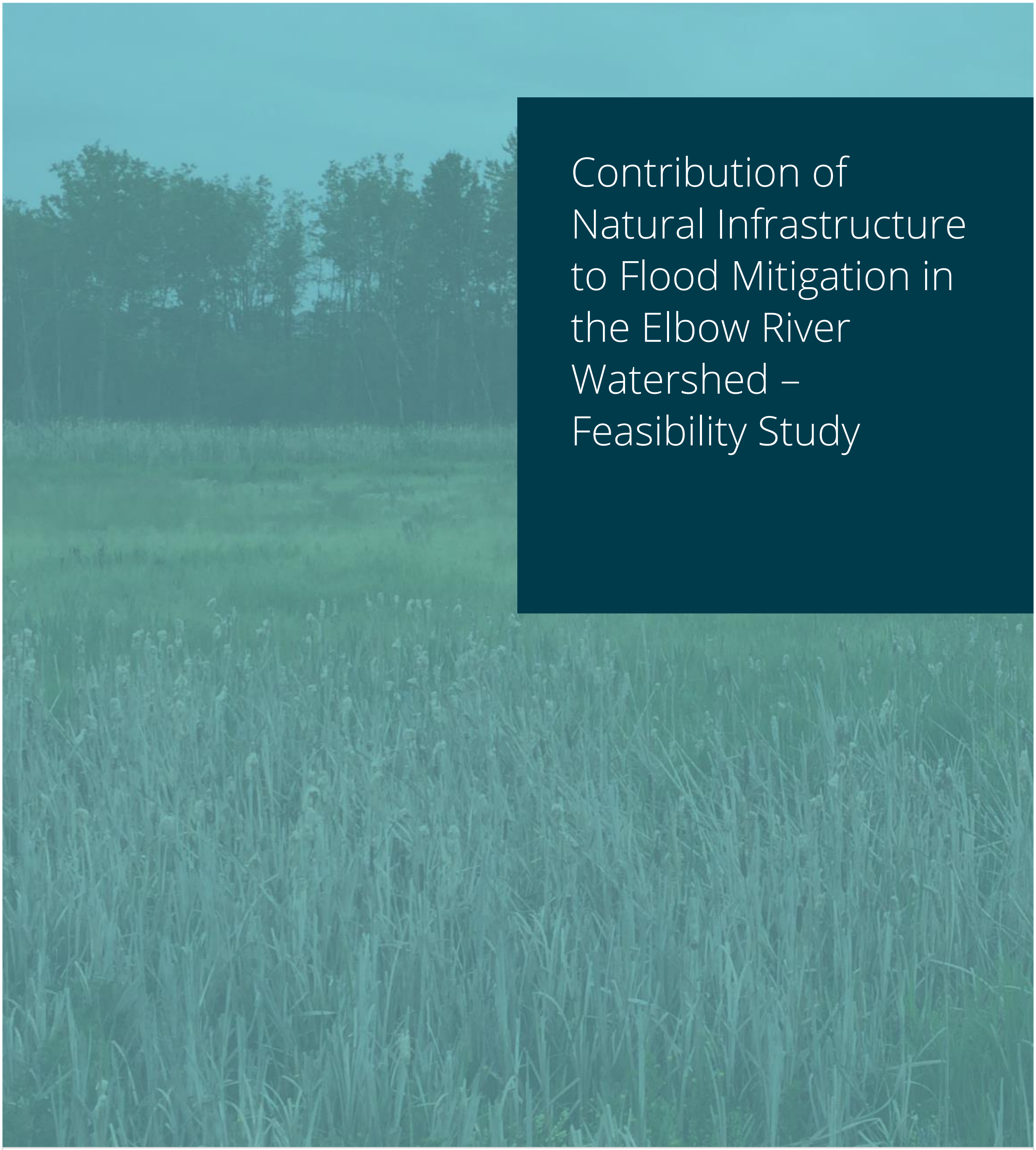

Contribution of Natural Infrastructure to Flood Mitigation in the Elbow River Watershed – Feasibility Study

Miistakis Institute

FIERA Biological Consulting

Contribution of Natural Infrastructure to Flood Mitigation in the Elbow River Watershed – Feasibility Study

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October 2021

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Acknowledgements

This work was generously sponsored by Alberta Environment and Parks' Watershed Resiliency and Restoration Program.

The *Contribution of Natural Infrastructure to Flood Mitigation in the Elbow River Watershed – Feasibility Study* was created in partnership by: Fiera Biological Consulting, the Miistakis Institute, MAGNA Engineering Services Inc., and Nichols Applied Management Inc.

Recommended citation:

Clare, S., Campbell, H., Kinas, H., Koenig, S., Lee, T., Letizia, J., Massig, J., Sanderson, K., Shewchuk, P., Skorobogatov, A., Trzok, J., Duke., D. (2021). *Contribution of Natural Infrastructure to Flood Mitigation in the Elbow River Watershed – Feasibility Study.* https://www.rockies.ca/files/reports/FINAL_NI_Flood_Mitigation_Elbow.pdf

Contents

Introduction

Background

Flooding is one of the most common, widely experienced, and deadliest forms of natural disaster (Richie and Roser 2014; Kumar 2017; WHO 2021). Relative to other natural disasters, the incidence of flooding has increased disproportionately in the last 70 years, and flooding is only expected to continue to increase in frequency and severity under climate change (Daigneault et al. 2016; Moudrak et al. 2019; Horizon Advisors 2019). For example, for many parts of the world, it is predicted that annual minimum daily precipitation amounts that have a 1-in-20 year probability today, are likely to have a probability of between 1-in-5 and 1-in-15 by 2100 (IPCC 2012).

In Canada, there are an estimated 1.7 million homes at risk of flooding, and within Alberta, flooding is one of the most pressing environmental threats to private and public property and municipal infrastructure (Moudrak et al. 2018). In 2013 alone, $5 billion in damages were incurred across southern Alberta as a result of a single flooding event, with $409 million in damages to City of Calgary infrastructure (The City of Calgary 2021a). The 2013 flood served to highlight the extreme vulnerability of this region to flooding, which is expected to increase in frequency, intensity, and severity as climate change impacts continue to compound. As a result, flood planning and mitigation in flood-prone regions, such as Calgary, is critical for climate change adaptation and long-term community resilience (Munang et al. 2013; GOA 2016).

Since the 2013 flood, much attention has been focused on determining what actions should be taken to mitigate against future flooding events in the Calgary region. Because the Elbow River contributed substantially to the 2013 flood damage that was experienced within the City of Calgary, the Elbow River watershed has been a target for mitigation action, with much of the flood mitigation planning being focused on the construction of grey infrastructure such as dams and flood barriers. While this type of infrastructure is effective at reducing flood damage, it also has several drawbacks, including adverse effects on wildlife and ecological processes, ineffectiveness in mostly flat or lightly rolling terrain, limited lifespan, and high construction and maintenance costs (UNEP 2014; Hovis et al. 2021).

While the focus of flood mitigation is often on utilizing grey infrastructure, flood disasters can also be mitigated by natural infrastructure (NI) such as riparian vegetation, wetlands, and forest cover, because these features slow and detain water runoff, especially after heavy precipitation events. Because of this, NI is increasingly being recognized for its important contribution to mitigating extreme flooding events, either as a stand-alone solution or integrated along with grey infrastructure to create a hybrid approach to flood mitigation. Consequently, the conservation and restoration of NI has emerged as a promising approach to mitigating flood damages in theory, but in practice, there has been little practical uptake (Hills et al. 2013). This is in part because quantifying the actual contribution of NI to flood mitigation is complex and requires trans-disciplinarily thinking and multidisciplinary expertise, which has resulted in a general lack of information about the costs and benefits of alternative adaptation options that includes utilizing NI within an ecosystem-based adaptation strategy (Daigneault et al. 2016). As a result, NI is often overlooked in flood mitigation planning, in favour of utilizing more traditional grey infrastructure solutions.

Advancing the discussion about how NI can be utilized and integrated into ecosystem-based flood mitigation planning in Alberta requires collaboration and transdisciplinary thinking, such that the relevant ecological, hydrological, social, and economic variables are identified and considered. As such, the objective of this report is to frame the critical parameters, assess what relevant and supporting information exists, identify policy and management levers, and develop a draft methodology for assessing the contribution on NI to flood mitigation. While this report focuses specifically on assessing NI in the Elbow River watershed, the general approach outlined herein could be applied in other watersheds in Alberta and elsewhere.

Natural Infrastructure & Ecosystem Services

Natural infrastructure is defined as "*the existing, restored or enhanced combinations of vegetation and associated biology, land and water, and naturally occurring ecological processes that generate infrastructure outcomes, such as preventing and mitigating floods*" (ICF 2018). A variation on this definition is "*a strategically* *planned and managed network of natural lands, such as forests, wetlands and other open spaces, which conserves or enhances ecosystem values and functions and provides associated benefits to human populations*" (Gartner et al. 2013). The term natural infrastructure is sometimes used interchangeably with green infrastructure; however, an important distinction between the two is that NI should be considered a subset of the broader category of green infrastructure, with NI being restricted to intact, naturally-existing ecosystem elements (Horizon Advisors 2019). Importantly, because NI is "fully natural", once it is established, it requires little or no human intervention or management, unlike other types of green infrastructure that typically require a period of establishment.

Strategically securing and using natural infrastructure alongside other types of green and grey infrastructure is part of an ecosystem-based adaptation approach. Ecosystem-based adaptation is defined as "*the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at local, national, regional, and global levels*" (CBD 2009). While NI strategies may provide less protection than engineered defenses overall, NI are an important component of a comprehensive land management strategy that includes both grey and green infrastructure, as NI is typically cheaper and easier to maintain, and can provide substantial environmental and social co-benefits, such as habitat for wildlife or aesthetic benefits to a community (Daigneault et al 2016; Moudrak 2019).

Importantly, natural infrastructure offers valuable ecosystem services that result in a wide range of environmental, social, and cultural benefits that are not typically associated with grey infrastructure. Ecosystem services (ES) are at the interface between the environment and people, and provide a variety of benefits to human well-being. The "environment" is typically represented by a habitat type or ecosystem (i.e., NI), and ecosystem functions are the characteristics or properties of that habitat that are potentially useful to individuals or communities (e.g., water storage, filtration). In turn, ecosystem services are derived from ecosystem functions, and represent the realized flow of services for which there is a demand (e.g., flood protection, water treatment) (de Groot et al. 2010; Maes et al. 2016; Potschin & Haines-Young 2017). Notably, an ecosystem service only exists if there is a "good" or "product" that creates a benefit that is experienced by an individual or a community; thus, clearly understanding the beneficiary of an ecosystem service is an important consideration in any ecosystem service assessment.

In many cases, there is a desire or interest in quantifying the value of ecosystem benefits, and because people benefit from ecosystem goods and services across a range of different dimensions (Summers et al. 2012), valuation can be determined using market or non-market valuation approaches. Importantly, the supply of ecosystem services can be impacted or regulated by external pressure or policy action, and land management decisions can positively or negatively impact ecosystem structure and function, thereby affecting the amount and quality of the final service, as well as the benefits derived from that service.

Moderation of extreme events, such as flooding, is an ecosystem service that is provided by different types of NI, including soil, forests, wetlands, rivers, lakes, and floodplains. These natural features moderate flooding by increasing the ability of the landscape to store water through increasing storage capacity and/or by increasing the ability of channels to convey floodwaters by reducing flow velocity and/or increasing channel conveyance. While moderating flood events is a critical ES that is provided by NI, particularly in the Calgary region, these natural features also offer a wide range of other valuable ecosystem services that are often overlooked; for example, wetlands attenuate flooding by storing water, but they also improve water quality, provide critical habitat for plants and animals that are used by humans, and provide aesthetic and educational benefits to communities. Thus, conserving and restoring NI within a watershed has a wide range of benefits that extend beyond flood mitigation alone, and it is important to consider all of these benefits together (e.g., the total economic value, or TEV) when assessing and comparing the flood protection benefits of NI against those of traditional grey infrastructure (Moudrak et al. 2018).

Because natural infrastructure provides a range of critical ecosystem services to human communities, there are growing calls for NI to be integrated into strategies that are aimed at reducing disaster risk and improving climate resilience (e.g., Hills et al. 2013; Daigneault et al. 2016; Renaud et al. 2016; Moudrak et al. 2018). Despite this, strategies that utilize or improve NI for mitigating or controlling flood risk are relatively uncommon. Some of the reasons that have been cited for the lack of uptake include limited technical capacities within government planning agencies, a prioritization of resources directed towards post-disaster response rather than prevention strategies, a general skepticism that ecosystem-based adaptation strategies meaningfully reduce disaster risk, limited guidance on how to assess the business case of NI projects, and a lack of sustainable funding mechanisms and programs to scale NI adoption (Daigneault et al. 2016; Moudrak et al. 2018). As a result, decision-makers are likely to allocate resources sub-optimally when planning for flood mitigation, both in terms of integrating NI into flood mitigation strategies, as well as in making investments in restoration projects to offset the historic loss of natural infrastructure such as wetlands.

Table 1: Comparison of Natural Infrastructure relevant to mitigation of flood events to Green Infrastructure (human-constructed green features) and corresponding Grey Infrastructure. Additional benefits of each type for Natural Infrastructure are provided for context.

Water Management Issue (primary service to be provided)		Natural Infrastructure	Additional Benefits of NI	Other/comparable Green Infrastructure	Corresponding Grey Infrastructure
Moderation of extreme flood events	Riverine flood control	Water bodies (lakes & wetlands)	Water quality; groundwater recharge; climate adaptation; biodiversity; recreation and culture	Constructed wetlands/storm ponds	Reservoirs; stormwater facilities
		Watercourses (rivers, streams, floodplains)	Groundwater recharge; climate regulation; biodiversity; recreation and culture	Ditches	Dams; levees; diversion strategies
		Riparian buffers	Water quality; biodiversity; climate adaptation		Dams; levees; riprap
	Control/regulation of surface runoff	Forest/tree stands	Climate regulation and adaptation; pollution reduction; biodiversity; recreation and culture	Green roofs	Built stormwater systems (pipes, drainage, etc.)
		Grasslands	Groundwater recharge; climate regulation and adaptation; biodiversity; recreation and culture	Green spaces; Permeable pavements	Built stormwater systems (pipes, drainage, etc.)
		Wetlands	Water quality; groundwater recharge; climate adaptation; biodiversity; recreation and culture		Stormwater facilities; reservoirs

Project Context

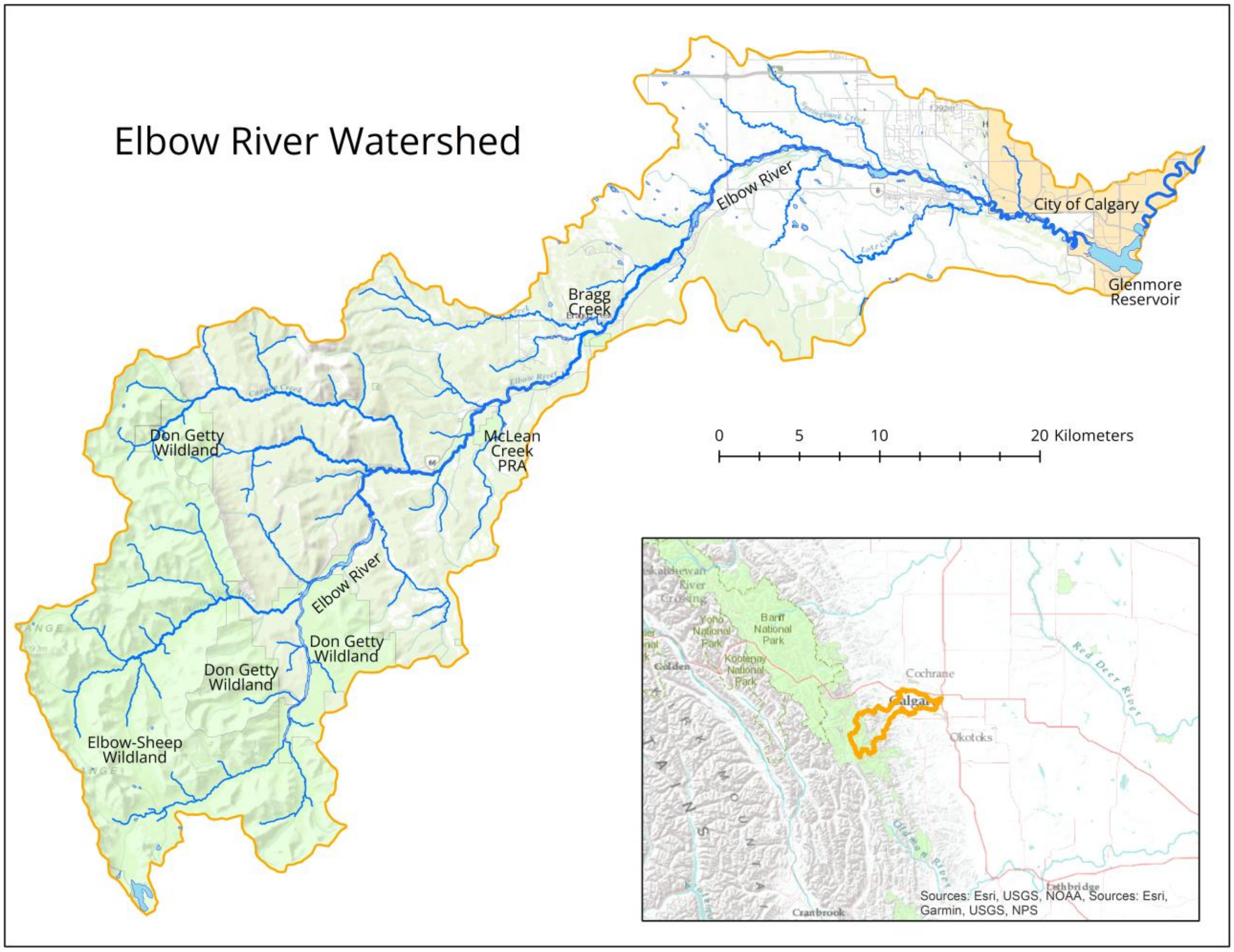
The Elbow River Watershed

The Elbow River watershed is a 1,238 km^2 HUC6 watershed located in southern Alberta that extends from the headwaters in the high elevation Front Ranges of the Rocky Mountains, to the broad, low gradient Alberta Plains (Map 1). The river system is short and steep, with the Elbow River dropping over a kilometer in elevation as it flows ~120 km from its headwaters to its confluence with the Bow River, which is located within the City of Calgary. The watershed is characterized by a complex hydrological regime that includes considerable groundwater–surface water interaction along the river, which occurs mainly through the alluvial aquifer located in the north-east portion of the watershed. The alluvial aquifer is shallow and unconfined, and is composed primarily of sand and gravel in various proportions that covers roughly 5% of the entire area of the watershed (Wijesekara et al. 2012; 2014). In general, the aquifer is very permeable and highly hydraulically connected to the Elbow River, resulting in relatively fast groundwater flow and high hydraulic conductivity through the aquifer (Ibid).

Land use in the watershed is varied and includes urban areas, cropland, rangeland, and provincial parkland, with the vast majority of the land development being concentrated in the eastern portion of the watershed (Wijesekara et al. 2012; 2014). Approximately 65% of the watershed is located in the Kananaskis Improvement District, with the remaining area divided amongst Rocky View County (20%), the Tsuu T'ina Nation (10%), and the City of Calgary (5%) (Ibid). The Elbow River and its tributaries are a critically important source for irrigation and municipal drinking water in the region, with the Glenmore dam located along the lower reach of the Elbow River, within the southwest quadrant of the City of Calgary. Constructed in 1933, the dam and its reservoir provide drinking water to over a million residents within the City, with the reservoir also providing flood storage capacity during spring runoff events (The City of Calgary 2021b).

The Elbow River watershed is under considerable pressure from land-use development, and between 1992 and 2010, built-up areas in the eastern portion of the watershed grew in size by 117%, while forest habitat decreased by 19% (Wijesekara et al. 2014). In the western portion of the watershed, forested areas were reduced by 36%, with the majority of the loss resulting from forestry and conversion to rangeland (Ibid). This historic loss of natural infrastructure, coupled with a projected increase in population growth and a continued increase in built-up areas, primarily within the eastern portion of the watershed, is expected to significantly impact watershed hydrology by increasing runoff and reducing baseflow, infiltration, and evapotranspiration, creating an elevated risk of flash flood events (Wijesekara et al. 2012; 2014).

Historically, severe flooding events have occurred within the watershed in 1996, 2005, and 2013, and these events have caused significant damage to local infrastructure, while also resulting in substantial changes to the flow path of the Elbow River. Generally, the response to these flooding events has been to improve flood resilience through the use of grey infrastructure. In particular, the primary focus of the flood mitigation response following the 2013 flood event was on building hard infrastructure, including tunnels, flood gates, barriers, dredging, diversions, and reservoirs. While there is recognition that natural infrastructure should be considered alongside grey infrastructure in the development of a more comprehensive flood mitigation strategy (e.g., AI-EES 2014), presently, there has been very little investment in conserving or restoring NI within this watershed.



General Framework for Assessing Natural Infrastructure

In this section, we outline a general approach for undertaking an assessment of how natural infrastructure contributes to flood mitigation. This approach includes four primary steps, each of which include important considerations that should inform the planning, design, and implementation of an assessment that aims to quantify the contribution of NI to flood mitigation. In chapter 4, we illustrate how this framework could be applied, using the Elbow River watershed as an example.

Step 1: Define the Question (Modelling Scenarios) & Geographic Area of Interest (Study Area)

In order to quantify the contribution of NI to flood mitigation, a clearly articulated question must be developed to inform the modelling scenario, or scenarios, that will be examined. This includes defining the temporal component of the modelling, as well as the specific NI elements that will be included in the model. For example, the study may be focused on quantifying the contribution of all types of NI present within the study under the "current" conditions, or the focus may be on quantifying the contribution of a single type of NI (e.g., wetlands) to flood mitigation (e.g., Moudrak et al. 2017). Alternatively, the study may be focused on quantifying the change in the contribution of NI to flood mitigation between distinct timesteps. In this case, the contribution of NI to flood mitigation could be examined between a historical and a current timestep to understand how flood mitigation services have been lost or impacted by land use in the watershed. The potential for improving flood mitigation services could also be examined by assessing change between the current conditions and a future timestep under a "restoration" scenario and/or "business as usual" scenario. Notably, the questions that can be addressed by a particular study will likely be influenced by the type and quality of data that is available, as well as the cost of acquiring the required data (see step 3).

An important component of this step is also defining the geographic area of interest, which will identify the spatial extent and boundary conditions for the hydrologic/hydraulic modelling exercise. This step requires careful consideration of who the "end users" or beneficiaries are, and where they are located relative to the flood mitigation service that is under consideration. The geographic extent could include the entire watershed upstream of the end users, or it could be limited to a particular upstream reach. In either case, the study area must be ecologically and hydrologically relevant to the flood damages that are being considered. If the entire watershed upstream of the end users is not included within the study area, then hydrologically relevant break points should be selected where available flow data exist.

Step 2: Define the Natural Infrastructure Elements of Interest (Typology)

Based on the scenario(s) that have been selected for analysis, the next step is to identify and define the natural infrastructure elements that will be included in the study. While there are existing typologies for green infrastructure, there is no single authoritative source for defining NI. Further, "naturalness" exists on a continuum, particularly in landscapes that have been heavily modified by human activity. Thus, clearly defining what constitutes a "natural" feature is an important step in the assessment.

For the purpose of assessing the contribution of NI to flood mitigation, it may be useful to organize NI elements into two general categories of "Blue NI" or "Green NI" (e.g., Barbosa et al. 2019; Gunnel 2019). Blue NI includes water bodies (i.e., lakes and wetlands) and watercourses (i.e., rivers, streams, creeks, floodplains). Water bodies primarily aid flood regulation through their storage function, and watercourses primarily aid in flood regulation by improving conveyance, while also providing additional flexible banked and floodplain storage during larger rainfall events. Green NI includes natural vegetation, such as riparian buffers, forest/tree stands, and grasslands. Green NI features reduce runoff through enhanced infiltration via root works, interception of precipitation by temporarily storing it on surfaces (e.g., leaves, branches, litter layer), and through transpiration and evaporation back into the atmosphere (Attarod et al. 2015; Berland et al. 2017). Wetlands and riparian vegetation play an additional role in flood regulation through increasing surface roughness, which slows down water runoff and reduces the rate of conveyance (Gunnel et al. 2019).

Step 3: Gather the Required Data

This step requires consideration of the typology that will be used to identify the NI that was defined in the previous step, which should be informed by the overall purpose of the assessment, and will be constrained by the type of data that is available and the required scale of the modelling. Datasets that are utilized in the assessment should be reviewed with the following considerations in mind:

- Spatial resolution and coverage: Determining the size of the smallest habitat feature that is of interest to the assessment will dictate the required resolution of the data. Alternatively, understanding the minimum mapping unit of the available data will allow users to understand the size of features that will be excluded from the assessment, and the resulting limitations, if any, of using the data. Another important consideration is whether the existing and available data cover the entire area of interest, and if not, what implications this might have on project costs if new spatial data must be created.
- Vintage: For most assessments, up to date (or reasonably so) data should be used if an assessment of the "current" condition is desired. If the aim of the project is to assess historical conditions, then consideration must be given to what type of historical data exist, including the reliability of the data if it is being compared to current conditions.
- Thematic resolution: In most cases, an evaluation of NI will require a land cover or habitat inventory dataset, and the classes used to define the various habitat types is a critical consideration. For example, if the NI assessment aims to evaluate the specific contribution of wetlands to flood mitigation, then having a wetland inventory or a land cover dataset that differentiates wetlands from other surface water bodies is essential.

- Condition: If a primary question of the study is to assess how habitat condition influences flood mitigation, then habitat condition data will be required. Any available habitat condition data should be evaluated to determine if and how it can be used in the modelling.

Clearly understanding the reliability of existing and available datasets is critical to identifying any limitations to the modelling, such that conservative assumptions can be applied to the results to produce actionable recommendations. Notably, there is no “perfect” dataset, and all models are simplified representations of the world that include a number of assumptions. What is important is that these limitations are acknowledged and documented, such that decision-makers can evaluate the results and use this to manage both uncertainty and risk (Gartner et al. 2013).

Step 4: Hydrologic/Hydraulic & Economic Modelling

Any evaluation of how NI contributes to flood mitigation will require some type of hydrologic and hydraulic modelling. Hydrologic modelling is defined as the characterization of real hydrologic features and system by the use of small-scale physical models, mathematical analogues, and computer simulations to characterize the likely behaviour of real hydrologic features and systems, while hydraulics is the study of the motion of liquids, including fluid mechanics and dynamics (Allaby 2015). Hydrologic modelling includes consideration of individual flows within a system; thus, models include various features that control the amount and intensity of water flow, such as soil, vegetation, climate, and river properties. Additionally, models include an estimation of a number of parameters, including precipitation, evapotranspiration, interception, infiltration, and runoff (Anees et al. 2016).

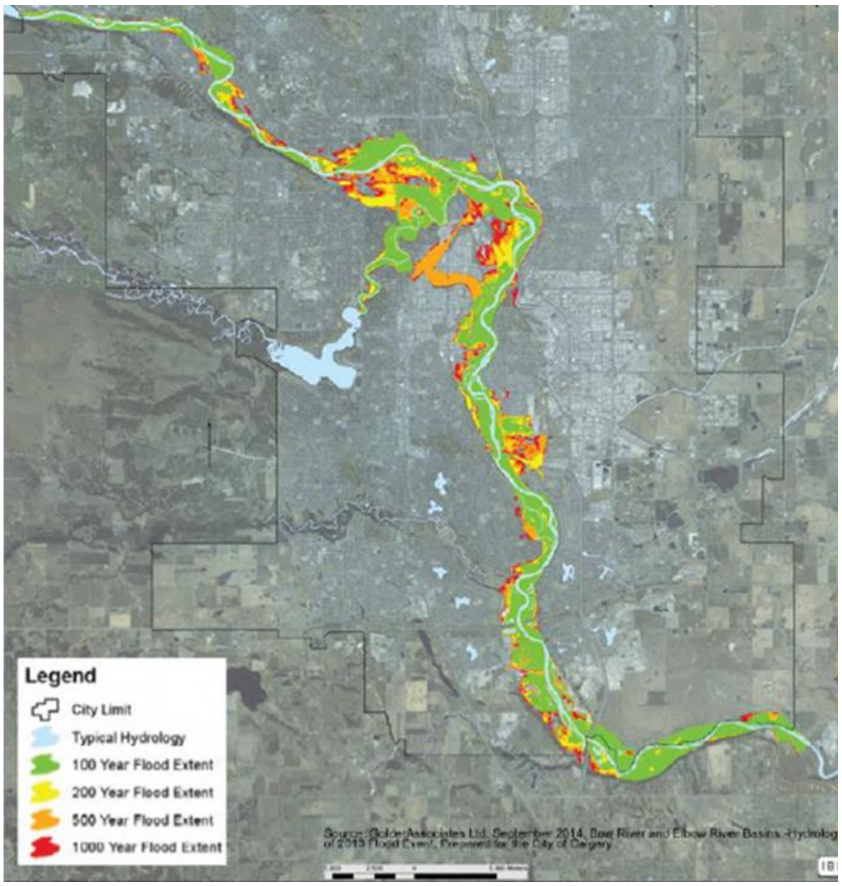
The simplest approach to evaluating the contribution of NI to flood mitigation is to construct a hydrologic and hydraulic model that would analyze the cover of each distinct NI type on a per hectare basis. The modelling outcomes can then be analyzed for peak flow, velocity, and overall volume. Key outputs include flood maps that show the extent of inundation reach, and analysis could be carried out to determine flood height and inundation periods for each of the inundated areas. Depending on data availability and quality, a set of criteria could also be developed to evaluate and weigh the hydrologic benefits associated with each distinct NI feature. For example, an assessment of the volumetric or peak flow reduction associated with the extent and type of NI collectively or individually could be undertaken. The specific approach to the hydrologic modelling and the NI features examined by the model would be informed by the overall objective defined during step one.

If the objective of the modelling is to assign an economic value to the flood mitigation services delivered by NI, then the outputs from the hydrologic and hydraulic modelling must provide data that are relevant to and can be integrated into an economic analysis of flood damages. One of the most common approaches to quantifying the value of natural infrastructure is through the use of ecosystem classification frameworks applied to per acre or per hectare land values. Conceptually, this approach consists of describing an ecosystem’s natural infrastructure, such as acres of forest cover, and then applying market determined values to that land area to quantify the goods and services provided by that ecosystem. There are, however, several challenges associated with this approach:

- The potential monetization of an ecosystem service for which no endpoint use is provided. For example, a policy maker would have limited interest in valuing the improvement of water quality in a location that no one uses when resources could otherwise be deployed to improve an area that is often used by residents.
- The interconnected nature of ecosystem services. For example, a reduction in water quality in a lake would impact several ecosystem services, such as reducing fish abundance and productivity, and increasing the algae population.

Due to the challenges presented above, we suggest that an assessment of the contribution of NI to flood mitigation should focus on the endpoints of use as they pertain to human well-being. Specifically, this includes modelling and quantifying the economic damages associated with various flood events (i.e., 1:X year floods) with and without the mitigation provided by natural infrastructure.

When quantifying potential flood damages for a particular geography, economists will typically estimate an annualized value of total potential damages (market and non-market) from any given flood event. These damages are estimated using modelling data that describe the spatial extent of flooding (e.g., Figure 1), and this information is used to create an Average Annual Damages (AAD) curve for each flood event under consideration. For example, in a Cost-Benefit Analysis (CBA) conducted by IBI Group for proposed flood mitigation projects on the Elbow River, an AAD curve was developed to estimate the total market and non-market damages to the City of Calgary for a variety of flood events ranging from 1:5 to 1:1,000 year floods in the absence of existing grey flood mitigation infrastructure (Figure 2). The authors then proceeded to estimate the AAD curve under an alternative flood mitigation scenario that included grey infrastructure as a means to estimate the benefits provided by the existing infrastructure (Figure 2). Notably, the existing mitigation shifts the AAD curve downwards, resulting in less total damages for a given flood event. The difference between the two AAD curves ($50 million) ultimately represents the benefits provided by existing grey mitigation infrastructure.



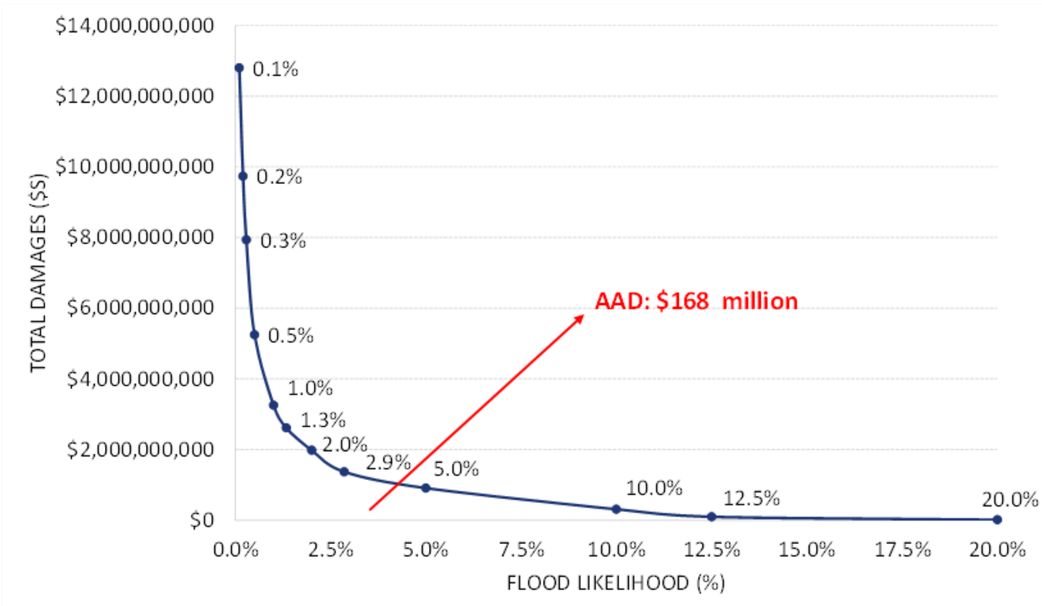
A 1:100 year flood has a 1% chance of occurring in a given year, and a flow rate of 2820 m^3/s on the Bow River downstream of the Elbow confluence.

A 1:200 year flood has a 0.5% chance of occurring in a given year, and a flow rate of 3520 m^3/s on the Bow River downstream of the Elbow confluence.

A 1:500 year flood has a 0.25% chance of occurring in a given year, and a flow rate of 4600 m^3/s on the Bow River downstream of the Elbow confluence.

A 1:1000 year flood has a 0.1% chance of occurring in a given year, and a flow rate of 5600 m^3/s on the Bow River downstream of the Elbow confluence.

Figure 1: Example of flood modelling that was previously developed for the City of Calgary. The study area included all of the flood prone areas within the city limits on the Bow and Elbow Rivers, up to a 1:1,000 year flood. Source: Adapted from the City of Calgary 2017.



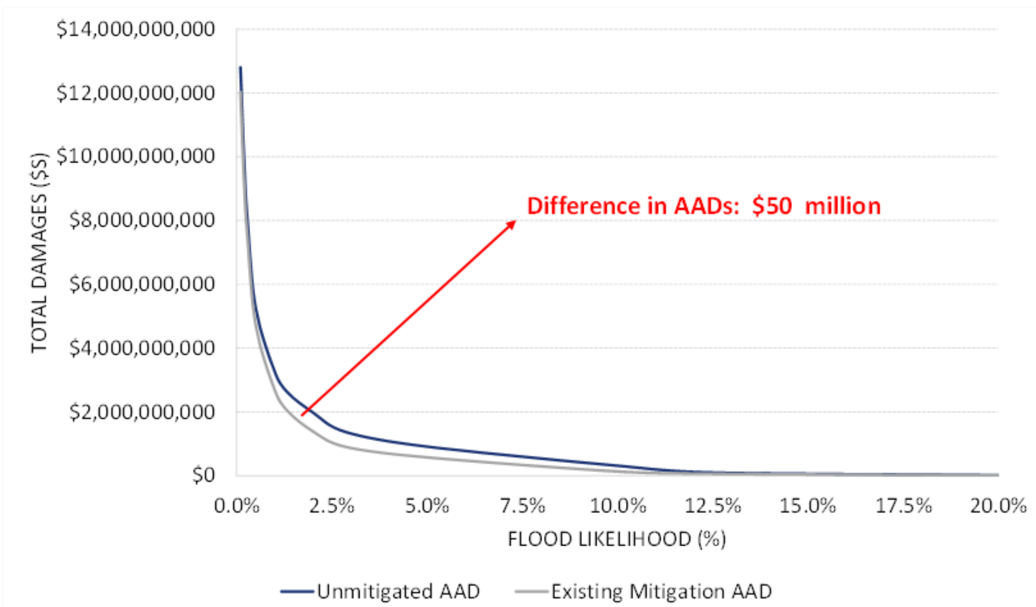


Figure 2: Unmitigated AAD Curve (TOP) and existing mitigation AAD curve (BOTTOM) for flooding of the Bow and Elbow Rivers, City of Calgary. Source: Adapted from IBI Group 2017.

While the example presented above describes the assessment of the value of utilizing grey infrastructure for flood mitigation, it could be applied to estimate the flood mitigation value of NI. For example, Moudrak et al. (2017) used hydrologic and hydraulic modelling that included an analysis of flood extents and flood depths for a range of precipitation events (2-year, 5-year, 10-year, 25-year, 50-year, 100-year, and Regulatory Storm) for different regions in Ontario, under various wetland loss scenarios (Figure 3). These flood extents were then analyzed in a GIS to assess the number and types of buildings that would be inundated under each scenario, which then informed an estimate of the total value of annual flood damages with and without wetlands. While the Moudrak et al. (2017) study examined a baseline scenario (wetlands maintained in current state) versus a "worst-case" scenario (all wetlands lost through conversion to agricultural land use), a wide range of other scenarios could be examined. For example, scenario modelling could include an evaluation of different rates of wetland loss and/or restoration, as well as an examination of how the spatial configuration of wetland loss or restoration (e.g., headwater wetlands versus riverine wetlands) may impact model outputs. This same approach could be applied to other types of NI individually (e.g., forest), or in combination (forests + wetlands).

*Information requirements differ based on the method of flood damage estimation chosen. For example, the inputs required for flood damage estimation using Ontario's *Flood Damage Estimation Guide* (2007) differ from the inputs required for flood damage estimation using Alberta's *Provincial Flood Damage Assessment Study* (2014).

Figure 3: Process workflow for assessing the financial value of wetland conservation for flood damage reduction in Ontario (source: Moudrak et al. 2017).

Example Case: Quantifying the Contribution of NI in the Elbow River Watershed

In this chapter, we illustrate how the general framework presented above could be used to evaluate the contribution of NI to flood mitigation in the Elbow River watershed. This example includes what we consider to be a workable approach given the data that is currently available.

Step 1: Define the Question (Modelling Scenarios) & Geographic Area of Interest (Study Area)

Question:

How does natural infrastructure in the Elbow River watershed contribute to the mitigation of flood damages in the City of Calgary?

Modelling Scenarios:

In order to estimate how NI in the Elbow River watershed contributes to flood mitigation in the City of Calgary, the area and depth of flood waters must be determined under two scenarios: one in which NI is present and another in which NI is absent. Once the flood extents and depths in the "with NI" and "without NI" scenarios have been determined, this information can be used to identify the number and types of structures that would be directly impacted by the flood events, as well as indirect impacts to the health and wellbeing of residents and disruptions to normal activities and typical service-levels. The information from the direct and indirect impacts can then be used to estimate flood damages, which is the monetary cost associated with the flood events. The difference between the flood extents, depths, and damages can then be used to inform our understanding of the overall contribution of NI to flood mitigation.

Notably, the question of "how much" NI contributes to flood mitigation can be answered using a wide range of different modelling scenarios. This could include a comparison of a chosen historical benchmark to current conditions, or forecasting a future state (e.g., business as usual scenario, restoration scenario, etc.) and comparing this predicted future state to current conditions. While these modelling approaches are all valid, they do not provide information about the *gross contribution* of existing NI in the Elbow River watershed to flood mitigation.

In order to understand gross contribution of NI to flood mitigation in the Elbow River watershed, flood extents, depth, and damages must be compared between a "with NI" and "without NI" scenario, as follows:

- **Scenario 1 – "With NI":** Estimation of the flood area and depth in the City of Calgary under "current" conditions, including the existing extent and type of NI present within the watershed. A number of flood events should be examined (e.g., 1:20, 1:50 and 1:100 year flood).
- **Scenario 2 – "Without NI":** The existing level of flood mitigation offered by NI is lost through the conversion of existing NI other land use/cover types. Assumptions and criteria related to how permeability and storage is impacted as a result of the loss of NI would need to be set as part of the scenario development.

The data derived from the hydrologic models under each scenario and for each flood event can then be used to determine the economic value of NI in mitigating flood damages in the City of Calgary by calculating the value of avoided damages attributed to natural infrastructure.

Study Area:

Because this modelling is focused on the end users who benefit the most from the flood mitigation services offered by NI in the Elbow River watershed, the flood modelling will be focused on the City of Calgary. Specifically, the modelling will focus on the inundation areas that are adjacent to the Elbow River, downstream of the Glenmore Reservoir, and within the limits of the City of Calgary. To evaluate flood events within this focus area, the watershed study area must include NI upstream of the Glenmore Reservoir.

Step 2: Define the Natural Infrastructure Elements of Interest (Typology)

As per the defined question and modelling scenarios, the NI that will be the focus of this modelling exercise will include both blue and green elements, as identified and defined in Table 2.

Table 2: Natural infrastructure typology for assessing the contribution of NI to flood mitigation.

Natural Infrastructure Element	Description
BLUE	
Floodplain	The part of a river valley that is made of unconsolidated, river-borne sediment and is periodically flooded. It is built up of relatively coarse debris left behind as a stream channel migrates laterally, and of relatively fine sediment deposited when bankfull flow discharge is exceeded.
Rivers, creeks, streams	Water courses that contain flowing water that is typically contained within a channel. May include riverine wetlands.
Lakes	Water bodies that have surface water >2m in depth. May include lacustrine wetlands.
Wetlands	Water bodies that have surface water (<2m in depth) that is at or immediately below the ground surface. Soils are saturated for long enough to have hydrologic indicators. Includes wetlands with both mineral (e.g., swamps, marshes, shallow open water) and peat (e.g., bogs and fens) soils.
GREEN	
Soil	The natural, unconsolidated, mineral and organic material occurring on the surface of the Earth; it is a medium for the growth of plants.
Forest	A plant formation that is composed of trees the crowns of which touch, so forming a continuous canopy, or areas dominated by vegetation >2m in height with woody stems.
Grassland	Ground covered by vegetation that is dominated by grasses (*Poaceae*) that are native to the region.

Step 3: Gather the Required Data

The first step in quantifying the contribution of NI to flood mitigation is to carry out hydrologic and hydraulic modelling. This modelling produces flood maps that show the extent of inundation reach, and this information can be used to determine flood depths and inundation periods under each flood event, for each scenario. The data from the hydrologic/hydraulic modelling is then used to create an AAD curve for each flood event, under each scenario. In order to create the AAD curve, data that allows for the estimation of market and non-market damages is required, which includes consideration of the land uses/properties that are impacted, damages to infrastructure and content, disrupted activities, public costs, and affected households/individuals. The biophysical data that are required to complete the hydrologic/hydraulic modelling, as well as the economic data required to create AAD curves is listed and described in Table 3.

Table 3: Data required to undertake the NI assessment in the Elbow River watershed, including commentary on the use, availability, and source for each dataset.

Data Type	Data Use & Description	Data Availability/Source
BIOPHYSICAL DATA		
Natural Regions and Subregions	Provides a macro assessment of the larger project area in order to characterize the watershed into hydrologically distinct areas based on biophysical data.	Freely available through Government of Alberta Open Data Catalogue
Watershed Boundaries	HUC 2,4,6,8,10 watersheds	Freely available through Government of Alberta Open Data Catalogue
Terrain/Topography	The rate and volume of stormwater entering a receiving stream is impacted by the topography in the catchment. Slopes and depression storage within a catchment influence the rate of runoff generation. Areas of higher slopes contribute to an elevated peak runoff rate due to the reduction of time of concentration and a reduced potential for infiltration. Areas with significant depression storage allow for additional stormwater detention and infiltration potential, thereby reducing the amount of runoff produced in a catchment. • LiDAR 7.5 or 15 m DEM: Partial coverage of the Elbow River Watershed • Provincial 25 m DEM: Full coverage of the Elbow River Watershed • ABMI Alberta-wide ALOS 15 m DSM (resampled from 30 m original data): Full coverage of the Elbow River Watershed	• LiDAR 7.5 or 15 m DEM: Available through GoA with Memorandum of Agreement or can be purchased through AltaLIS for $400/TWP for 7.5m and $100/TWP for 15m • Provincial 25 m DEM: Freely available through Altalis under the Government of Alberta Open Data Licence • ABMI 15 m DSM: Freely available through the ABMI FTP Server
Land Cover	Vegetation and various natural land cover types influence the runoff produced within a catchment through interception, infiltration, and evapotranspiration. At a	• Annual Crop Inventory (AAFC land cover): Freely available through the Government of Canada Open Government Data Catalog • Bow River Basin Land Cover: Miistakis Institute (in development)

Data Type	Data Use & Description	Data Availability/Source
	minimum, the land cover dataset used for this assessment must include classes for Forest and Grassland. • Annual Crop Inventory (AAFC land cover): Full coverage of the study area. Released yearly since 2009, with most recent year 2020. Maps 42 classes at 30 m resolution derived from Landsat imagery. Overall accuracy for crop classes is 91% and 66% for non-agriculture classes. • Bow River Basin Land Cover: In progress, partial coverage, not available until end of 2022. • ESRI 2020 Land Cover: Full coverage of the study area. 10 class global land use/land cover map at 10 m resolution derived from Sentinel-2 imagery. Overall accuracy is 86%, with class accuracies ranging from 38% to 99%.	• ESRI 2020 Land Cover: Freely available through ESRI/arcgis.com
Human Footprint	Identifies the extent and types of development within the catchment. Identification of extent is required to determine overall imperviousness, which impacts the amount of runoff generated within a catchment. Can be used in combination with land cover data to identify areas of disturbed vegetation, or areas of vegetation that have been modified (e.g., forestry, agriculture). • ABMI Human Footprint: Full coverage of the study area. A province-wide human footprint map that consolidates 21 human footprint categories based on more than 115 anthropogenic disturbance types. Compiled using existing data (Alberta Base Features, Inventories, etc.) and manual thematic mapping of SPOT6 satellite imagery.	• Freely available through the ABMI website of FTP Server. Complete datasets available for 2014, 2016, 2018, with partial datasets also available for 2010, 2015, and 2017 (individual feature layers only, not a composite footprint layer).
Watercourses	Rivers, streams, creeks are conveyance features that also increase infiltration and provide additional storage flexibility	Freely available through Government of Alberta Open Data Catalogue

Data Type	Data Use & Description	Data Availability/Source
	and resiliency in larger rainfall events through banked or flood plain storage. • Provincial hydrography: (recently updated)	
Waterbodies	Lakes and wetlands are detention features that provide peak flow attenuation by collecting water from a catchment, infiltrating and evaporating it, and allowing it to discharge at a slower rate. • Provincial hydrography: (recently updated) • Provincial merged wetland inventory: Lacking full coverage of the study area; coverage is good in the east half of the watershed, but only covers a small portion of the western part of the watershed where it transitions to the Rocky Mountain natural region. Existing coverage includes the area derived for Rocky View County where accuracy is generally within 5 m and wetland mapping is very detailed and accurate capturing wetlands down to a size of 220 m^2, and the area within Tsuu T'ina Nation, which was derived from SPOT imagery and is generally accurate within 20 to 50 m, but only maps larger, obvious wetlands, and many wetlands are missing throughout this area. • ABMI Wetland Inventory – released in March 2021 and based on Sentinel-1 and Sentinel-2 10 m resolution imagery. Fully covers the study area, and the minimum mapping unit varies from 400 m^2 in the Prairie region to 1,000 m^2 in Boreal/Foothills and Rocky Mountain areas. Overall accuracies for this merged data product range from 84.5% to 90.1%, although wetland class accuracies are substantially lower (range from 20% to 83%, depending on wetland class and region).	• Provincial hydrography & merged wetland inventory: Freely available through Government of Alberta Open Data Catalogue • ABMI Wetland Inventory: Freely available through the ABMI website or FTP Server • Bow River Basin current and restorable wetland inventory: Miistakis Institute (in development)

Data Type	Data Use & Description	Data Availability/Source
	• Bow River Basin current and restorable wetland inventory: In progress, partial coverage, not available until end of 2022	
Floodplain	Land areas adjacent to waterbodies and watercourses that are subject to recurring inundation • Inundation data/flood extents (City of Calgary) • Alberta Flood plain mapping (last updated October, 2021)	• Inundation data/flood extents (City of Calgary): Freely available through the City of Calgary Open Data site • Alberta Flood plain mapping: Freely available through Government of Alberta Open Data Catalogue
Climate (temperature & precipitation)	Climate data to use for configuring the hydrological model • Alberta Climate Information Service (ACIS): Provides access to data on precipitation, temperature, and potential evaporation from over 350 meteorological stations within the province, as well interpolated weather data at the township scale since 1961. • ClimateAB: Historical and projected climate data for Alberta that can be used to estimate more than 50 monthly, seasonal, and annual climate variables	• ACIS: Freely available through the Government of Alberta ACIS website • ClimateAB: Freely available through https://sites.ualberta.ca/~ahamann/data/climateab.html
Soil	Various soil conditions are present within Alberta. Specific soil types should be determined within the catchment of interest as they impact the amount of runoff generated within a catchment through differing hydraulic conductivities, suction heads, porosity, and field capacities. Infiltration rates, as determined by the soil conditions present within the catchment, will influence the quantity and rate of water received by the receiving watercourse. Sands and loams will generally result in a lower runoff rate within a catchment due to increased infiltration rates, whereas low-conductivity soils such as silts and clays will result in elevated runoff rates • AGRISID 4.1: Lacking full coverage of study area (restricted to White Zone). Provides information on soils for Alberta's Agricultural area.	• AGRISID 4.1: Freely available through the geodiscover.alberta.ca website and the Government of Alberta Open Data Catalogue • SLC V3.2: Freely available through the Government of Canada Agriculture and Agri-Food Canada Geospatial Products website

Data Type	Data Use & Description	Data Availability/Source
	• Soil Landscapes of Canada (SLC) V3.2: Full coverage of study area. Compiled at a scale of 1:1 million, shows the major characteristics of soil and land.	
• ECONOMIC DATA		
Direct Market Damages	Data required to estimate direct content and structural damages include: • Spatial data inventory that provides the location and area of inundated residential and non-residential structures in the study area and classifies them by type (i.e., single-family, low-rise apartment, general office, grocery store, etc.) and describes the physical characteristics of each structure (e.g., basement) • Hydrologic data that describes the height of flooding for each residential and non-residential structure in the spatial inventory • Residential and non-residential content and structure damage curves (i.e., average damage estimates for various flood water levels)	• Spatial data on built structures may be obtained from individual municipalities in the study area to create a general dataset of residential and non-residential building structure typologies. Attributing built structures with more detail (e.g., building age, renovations and improvements) may require additional data or data from third parties • Flood height data across inundated structures: compiled from hydrologic modelling outputs derived from the biophysical data • Residential and non-residential content and structure damage curves: Freely available through the Alberta Flood Damage Assessment Study (2015).
Indirect Market Damages	Data required to estimate indirect damages include: • Hydrologic data that describes extent and duration of flooding across the study area. • Spatial data inventory that classifies inundated non-residential structures in the study area and describes their physical characteristics • Spatial data inventory of major inundated roadways • Information pertaining to potentially disrupted waste disposal and other municipal services • Information pertaining to potential public health impacts	• Hydrologic data that describes the extent and duration of flooding across the study area will be compiled from hydrologic modelling outputs and spatial layers identified above • Inundated roadways: Derived layer intersecting road data (available from municipalities or the Alberta Open Data Catalogue) and flooding data • Disrupted services: Some data and information may be acquired through engagement with municipal staff within the study area • Public health impacts: Some data and information may be acquired through engagement with public health officials or via surveys

Data Type	Data Use & Description	Data Availability/Source
Non-market Damages	Estimating non-market damages such as mental health impacts (e.g., anxiety, worry, post-traumatic stress) would require a thorough review of the available literature of the non-market damages associated with flooding and an appropriate application of those damages to the flood scenarios.	• Freely available data and information from academic and non-academic literature.

Step 4: Hydrologic/Hydraulic & Economic Modelling

Once the data has been assembled, hydrologic/hydraulic modelling must be completed to map the inundation areas associated with each defined flood event and scenario. The individual contribution of different NI types can be examined based on the topography and cover type on a per hectare basis. This may be conducted in HEC (HEC-RAS / SWMM), PCSWMM (2D PCSWMM for conveyance) or other hydrologic/hydraulic models (i.e. XPSWMM, InfoWorks, etc.). It is recommended that a review of the recommended software be carried out to assess the best model to weigh out the differing NI characteristics, as this is of highest importance in the analysis. This data is then used to calculate inundations depths and periods, which is required for the economic evaluation.

Step 4a) Hydrologic/Hydraulic Modelling

1) Background Base Model: The spatial area should be confirmed to determine the relevant boundary conditions for the starting base model. Considerations for the base model include:
    - Catchment areas
    - Major drainage conveyance
    - Topography
    - Any offsite input locations and associated inflow hydrographs
2) Divide into subcatchments: Assign regional zones associated with:
    - Soils
    - Landcover
    - Land-Use
    - Roughness coefficient
3) Build in distinct NI elements: Add each NI element (Table 2) and their specific attributes related to runoff flow, volume, and storage.
4) Input local climate data: Input rainfall and temperature data into model.
5) Run Model Scenarios
    - Scenario 1: Current day NI for 1:20, 1:50, and 1:100-yr flood occurrences
    - Scenario 2: Removal of NI for 1:20, 1:50, and 1:100-yr flood occurrences
6) Map inundation areas and estimate flood height: In order to determine the flood damage to structures in the study area, the outputs from the flood modelling need to be linked to a spatial data inventory of structures that are located within the inundation area. Because the height of the flood modelling influences the calculation of flood damages, both the area of inundation and the height of the flood waters must be used to identify the extent of the flooding impact for each scenario. The spatial inventory of affected structures must include information on the type of structure (e.g., residential/commercial), and the characteristics of each structure (e.g., building typologies), such that the number of structures of various types/typologies impacted by each flood event can be estimated.

Step 4b) Economic Modelling

Using the information resulting from the above-described flood modelling, market (direct and indirect) and non-market damages can be estimated as follows:

1) Direct Damages: Under both scenarios, direct damages (including residential and non-residential content and structural damages) can be calculated using the Alberta Provincial Flood Damage Assessment Study (IBI Group and Golder Associates 2015). To estimate direct damages using the 2015 study, the number of inundated buildings (e.g., agricultural, residential, commercial, industrial, and institutional) is required. Furthermore, the structure type of residential buildings (e.g., single-family, low-rise apartment, etc.) and the general content of commercial buildings (e.g., general office, clothing, groceries, general retail, etc.) are needed to estimate direct damages.

2) Indirect Damages: Under both scenarios, indirect damages can be calculated either from first principles, or as a percentage of total direct damages as suggested by the Alberta Provincial Flood Damage Assessment Study (IBI Group and Golder Associates 2015). Calculating indirect damages from first principles would require a thorough analysis and valuation of individual indirect damage categories including, but not limited to:

- business disruption,
- residential disruption,
- traffic disruption,
- waste disposal, and
- public health costs.

This method can be highly resource intensive. As such, an alternative methodology for estimating indirect damages is to calculate these damages as a percentage of direct damages. Ideally, analysts would conduct a thorough review of the flood modelling scenarios to understand the potential for flood events to impact indirect market costs associated with. This analysis would require an understanding of the number and type of businesses/industries impacted by flooding, what transportation routes may be affected by flooding, the duration of the flood, etc. With this information the appropriate percentage of direct damages can be used to estimate total indirect damages under each scenario as recommended by the Alberta Provincial Flood Damage Assessment Study (IBI Group and Golder Associates 2015).

3) Non-market Damages: Non-market damages associated with flooding are arguably the most difficult to estimate. Estimating non-market damages such as anxiety, worry, and post-traumatic stress associated with flooding would require a thorough review of the available literature of the non-market damages associated with flooding and an appropriate application of those damages to the flood scenarios.

The extent of data and information required to estimate market and non-market damages associated with the flooding scenarios will depend on the selected Study Area. Ideally, the entire area that hosts end-users impacted by the flood mitigation services offered by NI would be included in the study. However, depending on the available budget and scope of work, economic valuation may be focused on specific municipalities (e.g., the City of Calgary).

After the total damages associated with both scenarios are estimated, the value of damages avoided as a result of existing NI can be calculated and the value of this infrastructure in mitigating floods in the study area can be estimated. A similar exercise can be conducted for other flood modelling scenarios to estimate the value of additional mitigation infrastructure, such as the restoration (i.e., addition) of flood mitigating natural infrastructure, the construction of grey infrastructure, or some combination of the two.

Modelling Limitations and Considerations:

We have outlined a relatively simple approach to assessing the contribution of NI to flood mitigation in the Elbow River watershed because we feel that starting simple, and building in complexity as needed and required, is the best approach to advancing discussions about integrating NI into flood mitigation planning. As such, there are several important limitations of this modelling that should be considered:

- Generally, habitats need to be in good condition to provide ecosystem services, and drivers of ecosystem change can have both positive and negative impacts on condition (Maes et al. 2018; Vihervaara et al. 2019). Consequently, pressure, condition, and the supply of ecosystem services are linked, as condition is likely to be good - with correspondingly high function and supply of services - if pressures are absent. In the assessment scenarios that we have laid out above, the estimates of flood mitigation values are based on an assumption that the underlying function of the NI has not been substantially impaired, and that each NI feature has sufficient function to deliver the flood mitigation service being valued. Notably, land development or land use that causes change to ecosystem function can lead to a decrease in the supply and flow of flood mitigation services (e.g., wetland drainage, forestry). The estimates of NI value that would be derived from the approach outlined in this report would not account for the influence of condition on the current supply of flood mitigation services.

- Flooding events are expected to increase in both frequency and duration due to climate change. Because the approach we have outlined does not include a “future” scenario, the contribution of NI to mitigating these future climate events is not explicitly considered. However, as mentioned previously, more complex scenarios and modelling could be undertaken, including modelling that considers future climate projections for the region. Other more complex scenarios could also include assessing the contribution of individual types of NI to flood mitigation separately, rather than in combination. Further, more complex scenarios could be chosen as a comparison to the “existing” scenario; for example, land use projections could be used to model change in land cover through time, or restoration scenarios could be employed to better understand how best to target NI restoration in the watershed. Notably, the more complex the scenario becomes, the more difficult it is to find reliable data that can be used for the modelling; thus, there may be a trade-off between scenario complexity (realism) and reliability of the results.
- This approach limits the valuation of NI to flood mitigation services alone, and other ecosystem services are not considered or evaluated. Indeed, the total economic value of ecosystem services provided by NI in the Elbow River watershed is greater than what would be estimated in the approach outlined in this feasibility study. Natural infrastructure offers a wide variety of ecosystem services beyond flood mitigation including, but not limited to, carbon storage and sequestration, wildlife habitat, recreation services, etc. As such, the flood mitigation service values that can be estimated using the methodological approach described in this study should be considered a conservative, lower end estimate of the total economic value of natural infrastructure in the Elbow River watershed. This is important to consider when contemplating the trade-offs associated with NI conservation, restoration, or development.

Policy and Management for Natural Infrastructure in Alberta

In order to create a comprehensive flood mitigation strategy that includes both natural and grey infrastructure, opportunities for conservation and restoration of natural features must be identified, along with regulatory and non-regulatory tools at all levels of government, that promote an ecosystem-based approach to flood mitigation. Simply put, flood mitigation strategies can more effectively utilize natural infrastructure by 1) retaining what exists; 2) restoring what has been lost; and 3) building only what is necessary (Moudrak et al. 2018).

With regards to “retaining what exists” and “restoring what has been lost”, there are a number of strategies that could mitigate damages in watersheds where flooding poses a current and/or future threat to private and public property (ICF 2018; AI-EES 2014). This includes focusing conservation and restoration efforts on the primary blue and green NI elements that contribute most significantly to flood mitigation within watersheds:

- **Floodplains:** The most efficient strategy for natural riverine flood protection is conserving the natural floodplain. This option involves preserving existing natural ecosystems that are already serving to absorb and otherwise attenuate floods. From a restoration perspective, removal of infrastructure from the floodplain and restoration of the channel to its historical configuration allows the watercourse to freely meander and flood its overbanks, when required.
- **Wetlands:** Inland wetlands are an important resource in flood mitigation because they collect and hold floodwaters, gradually releasing them over time, thereby regulating water flows and reducing peak flow events (Kumar 2017). In watersheds that are experiencing severe flooding, or where flooding is expected to increase as a result of climate change, wetlands offer highly valuable flood protection services, as well as a suite of other important ecosystem services. Given the benefits that wetlands provide, strategically investing in the conservation and/or restoration of wetland habitats, alongside hard infrastructure solutions, should be considered.
- **Forests:** Forests play an important role in stormwater management and are often considered the ‘first line of defence’ as they intercept rainfall, delay runoff, increase infiltration of stormwater into soils, and transpire captured stormwater, with conifer forest contributing more greatly than deciduous forest (Kuehler et al. 2017). The loss of forest cover amplifies the effects of flooding by increasing peak discharge, flood volumes, and flood extents (Bradshaw et. al 2007; Lallemant et. al 2021). Consequently, the conservation of forests and/or the reforestation of areas where forest cover has been lost are important land management considerations in watersheds where flooding is a current and/or future risk to human communities.
- **Native Grasslands**: Much like forests, grasslands contribute to flood mitigation by intercepting rainfall, increasing infiltration, and using water for photosynthesis. Additionally, when compared to non-native grass species, native grasses offer a larger suite of ecosystem services (Stein et al. 2014; Bengtsson et al. 2019). Despite this, native prairie grasslands in Alberta are considered an endangered ecosystem; thus, targeted conservation or restoration of native grasslands has the potential to not only improve flood mitigation services, but to also increase the flow of other important ecosystem services associated with grasslands, such as pollination, biological control, and fodder for livestock.
- **Riparian Areas**: Riparian areas play a unique role as the buffer between water bodies (blue infrastructure) and floodplains (green infrastructure). Riparian vegetation also contributes to flood regulation through increasing surface roughness, which slows down water runoff and reduces the rate of conveyance (Gunnel et al. 2019). Notably, land development often encroaches into riparian areas within urban environments, including the placement of structures (e.g., homes) and other infrastructure (e.g., trails, roads), thereby impairing riparian habitat function. Further, within agricultural landscapes, riparian vegetation is often lost entirely in favour of land conversion to pasture or cropland. Given the high rates of riparian habitat loss and impairment in many watersheds across Alberta, the conservation and restoration of riparian areas has become

the focus of many organizations and programs (e.g., Watershed Resiliency and Restoration Program).

When giving consideration to "building only what is necessary", a full cost-benefit analysis (CBA) or cost-effectiveness analysis (CEA) should be considered to evaluate individual scenarios and the trade-offs between NI conservation and/or restoration. A CBA is the generally accepted methodology for establishing the net social benefit of a particular activity by assigning a dollar value to all social costs and benefits associated with an activity and subtracting the former from the later to estimate net social benefit. The estimated value of flood mitigation services provided by NI in the Elbow River watershed could be used, in part, to inform a CBA of NI restoration or land use development that results in the loss of NI. Additional information, including the total economic value of other ecosystem services offered by NI, would also be required. Under a CBA framework, decision-makers would have more robust information from which to base land use management and development decisions.

Application of Conservation & Restoration Tools

As there are very few examples of maintaining NI as a flood mitigation strategy, it is important to identify the existing policy and management levers that can support the conservation and/or restoration of NI for flood mitigation, as well as identify barriers that may limit the use or effectiveness of existing policy and management levers. In this section, we identify key considerations and steps that are required to identify existing management and implementation tools.

Step 1: Identify the NI Asset Type

In some cases, a single NI asset (i.e. a wetland) may be the focus of management efforts, while in other cases, an entire region (i.e. municipality or region of public lands) that includes several different NI asset types may be under consideration. In either case, it is important to determine what type of NI asset is being managed, as the type of asset will influence the policies and legislation that may be triggered in the management of those assets, as well as the types of voluntary programs that might exist for the conservation or restoration of those assets.

Step 2: Identify Private/Public Lands, Managing Jurisdiction(s) & Conservation Status

The management of NI assets is complex, and the policies, regulations, legislation, and programs that are in place to secure or manage NI vary depending upon whether the asset is located on private or public land, in addition to whether the land has any legally assigned conservation or protection status. Because of this, it is important to identify whether the NI of interest are located on indigenous, private, or public land; the type of public land that is involved (i.e., municipal, provincial, or federal), and; the legal protection status (if any) of the land (e.g., park or protected area, conservation easement, etc.).

Understanding land ownership, the jurisdiction(s) that are involved, and whether there are any legal protections afforded to those lands, will allow for the identification of existing management levers and opportunities that are available to enhance, conserve, or restore NI on the lands of interest. Further, the type of asset, in combination with where the asset is located, influences the suite of legislative and policy tools that are available for their management. For example, all permanent and naturally occurring water bodies in Alberta are owned by the Crown under the *Public Lands Act*, regardless of whether those features are located on private or public land. Further, wetlands located on federal lands are managed under the federal wetland policy, while wetlands on private and municipal/provincial lands are managed under the provincial wetland policy and any impacts to these assets must be authorized under the provincial *Water Act*. Thus, identifying the type of NI asset, in combination with the understanding the land ownership and managing jurisdiction, is critical to identifying the suite of conservation and restoration tools that may be available.

A list of the types of data that would be required to identify land ownership status, managing jurisdiction, and the conservation or protection status of those lands is provided in Table 4.

Table 4: Data required to evaluate ownership and conservation/protection status of lands within the Elbow River watershed, including commentary on the use, availability, and source for each dataset.

Data Type	Data Use & Description	Data Availability/Source
LAND OWNERSHIP, JURISDICTION & STATUS		
Land Ownership Status	Determination of private versus public land ownership, including determination of which jurisdiction (municipal, provincial, federal) controls the public land. • Title Mapping: Data ownership type can be estimated via type of LINC number, but for accurate information it needs to be combined with SPIN2 data	• Title Mapping: Available through AltaLis for $150/TWP. • SPIN2 data: Available from the GoA at a cost of $150 per 100,000 parcels • This data may also be available through partnerships with municipalities as cleaned tax roll data (all personal information removed)
Conservation & Protection Status – Public Land	Determination of the conservation and protection status of public lands. • Provincial Parks and Protected Areas • National Parks • Municipal Environmental Reserves	• Provincial & federal parks and protected areas: Freely available through Government of Alberta Open Data Catalogue • Municipal Environmental Reserves: May be freely available through municipal open data catalogues or municipal partnerships
Conservation & Protection Status – Private Land	Determination of conservation protected private land ownership within the study area. • Spatial Data from individual land trusts	• Spatial data can be made available at the discretion of individual land trusts operating in the area
Indigenous Lands	Identification of First Nations and Métis lands. • Municipal Districts of Alberta	• Freely available through Government of Alberta Open Data Catalogue

Step 3: Identify Regulatory & Non-Regulatory Tools

In Alberta there are many existing regulatory tools that directly support the conservation, maintenance, and/or restoration of NI. Examples of these include the *Water Act*, *Alberta Land Stewardship Act*, *Public Lands Act*, *Municipal Government Act*, and statutory plans and policies that are approved by municipal councils, such as Municipal Development Plans, Area Structure Plans, and Intermunicipal Development Plans. There are various other regulatory tools, that while not focused specifically on NI, may secondarily benefit NI because the asset includes biophysical attributes that may be protected, either provincially or federally, through mechanisms such as the *Species at Risk Act* or the *Wildlife Act*. Similarly, the *Municipal Government Act* provides the authority for Environmental Reserve and Environmental Reserve Easements that not only fulfill legislative mandates, but can also be used in some cases to conserve NI.

Increasingly, statutory municipal plans, such as Municipal Development Plans, are recognizing the important contribution of NI to resiliency, sustainability, and flood mitigation, with some of these plans including reference to the need of integrating NI management into underlying frameworks that guide land development (e.g., City of Calgary Municipal Development Plan 2020). Consequently, these plans can be used to support the development and implementation of policies and bylaws that enable the protection and/or restoration of NI on lands that are under the control of the municipality. Additionally, some municipalities, such as the Town of Okotoks, have completed a natural asset inventory and ecosystem service assessment to identify and value NI located within their jurisdictions (Fiera Biological 2020). These types of inventories are useful in identifying NI that provide essential ecosystem services, thereby allowing for this type of information to be considered alongside other information when making land use decisions. Notably, the development of operations and maintenance plans, alongside plans and policies, are key to the management of NI within municipalities, and should focus on service delivery and include multi-departmental support (Municipal Natural Assets Initiative 2017).

In addition to the statutory requirements for the management of NI in Alberta, there are a wide range of non-statutory policies, guidelines, and strategies that may be used to conserve or restore NI. This includes development setback guidelines, low impact development guidelines, and restoration plans that provide direction for managing NI assets on both private and public land. Additionally, there are a number of voluntary programs and beneficial management practices that can be adopted by private land owners that lead to NI conservation or restoration.

Important Considerations for the Conservation & Restoration of NI

A major challenge in the conservation and restoration of NI for mitigating flooding is the spatial disconnect between the location of the asset that provides the ecosystem service, and the location of the end user that experiences the benefit of the flood mitigation service. Because of the nature of how water flows across the landscape, the flood mitigation services offered by NI disproportionately benefit downstream end users, and in many cases, the downstream end user may be located tens, or even hundreds of kilometers away.

This spatial disconnect between where the NI is located, and where the benefits of the flood mitigation services are experienced, creates challenges with respect to the management of NI. For example, large urban centres often rely on upstream flood mitigation services offered by NI located outside their jurisdictional boundaries but have little or no control over how those NI elements are managed. This challenge is highlighted by the way in which wetlands are managed in the province of Alberta. While wetlands provide critical flood mitigation services, permits for the removal of wetlands are granted by the provincial government with a primary focus on how wetland removal impacts local hydrologic conditions, with little or no consideration for how the cumulative loss of wetland ecosystem services might influence downstream end users at a regional scale. In addition, while the provincial wetland policy requires the replacement of lost wetland area through compensatory habitat replacement, the restoration of wetland habitat often occurs outside the watershed of impact (Clare and Krogman 2013), thereby relocating ecosystem services from one location to another without any consideration for how this relocation may impact the supply of ecosystem services.

An additional challenge of effective integration of NI into flood mitigation strategies is that many of the ecosystem and hydrologic process that are critical to the supply of ecosystem services operate at spatial extents that are much larger than typical land use planning scales. This leads to a misalignment between the scale required to optimize the benefits of NI, and scale at which we plan and manage landscapes. For example, the common subdivision planning process used by municipalities in Alberta is at a much finer scale than that of a functioning ecosystem, and because of this, municipal planning and development often leads to the impairment of ecosystems that provide services to local, as well as regional, or even global end-users.

This focus on small-scale planning increases the complexity of conserving NI at a landscape-level, potentially leading to what Allred et al. (2021) described as a series of asynchronous or "uncoordinated, local planning decisions." This problem is often exacerbated by the way in which municipal land development is financed through off-site levies (OSL), which incentivizes the use of conventional grey infrastructure and is not well-suited to the inclusion of NI. Moreover, because the upstream NI that provides flood protection to downstream communities typically falls outside of the jurisdiction of the benefitting municipality, the application of the conventional OSL framework to NI is not appropriate. Adjustment to the *Municipal Government Act* to explicitly contemplate NI, as well as the development of cross-jurisdictional cost-sharing frameworks, will likely be necessary to allow for more effective management of NI at appropriate spatial and temporal scales. This mismatch between the scale at which ecosystems function and the scale at which we plan, manage, and finance land use and development highlights the importance of intermunicipal, intramunicipal, and regional planning that includes consideration of the ecosystem service benefits that flow to end users across multiple spatial and temporal scales.

Conclusion

Natural disasters, such as flooding, come with enormous economic, social, and human costs, the severity of which is predicted to increase over the next century due to the effects of climate change. While traditionally, human communities have relied on engineered solutions to mitigate the effects of flooding, there is a growing awareness that natural infrastructure, such as wetlands, forests, and rivers, offer valuable flood mitigation services. As a result, there are calls to conserve, restore, and manage NI as a stand-alone solution, or to integrate NI along with grey infrastructure to create a hybrid approach to flood mitigation. Despite these calls, ecosystem-based adaptation strategies that utilize or improve NI for mitigating or controlling flood risk are relatively uncommon.

One of the key barriers that has been identified in the lack of development and implementation of ecosystem-based adaptation strategies is a general skepticism that this approach can meaningfully reduce disaster risk. This skepticism is due, in part, to a lack of credible technical information that illustrates and quantifies the role and significance of NI in the provision of flood mitigation services. In light of this, a major objective of this report was to outline an approach to undertake the technical work required to quantify the contribution of NI to flood mitigation, and to illustrate the feasibly of implementing this technical work, using the Elbow River watershed as a case example. Additionally, we generally discuss the key management considerations, challenges, and opportunities for conserving and restoring NI in Alberta.

While this report outlines an approach to assessing the gross contribution of NI to flood protection by comparing a “with NI” and “without NI” scenario, this approach can be used to evaluate any number of scenarios in which the objective is to understand how NI contributes to flood mitigation. This could include examining the individual contribution of specific types of NI to flood protection, comparisons of various alternate future management scenarios, as well as scenarios that examine questions related to where and how much NI to conserve or restore to optimize flood mitigation benefits. Regardless of what scenarios are selected, ultimately, the technical tools and data resources are generally available to undertake this type of analysis. But, as is the case with many issues related to land management, “the devil is in the details”, and carefully defining and constructing the modelling scenarios, critically evaluating the available data, and comprehensively documenting any assumptions and limitations of the analysis is essential for creating credible information that can be used to inform ecosystem-based strategies for flood mitigation in Alberta.

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