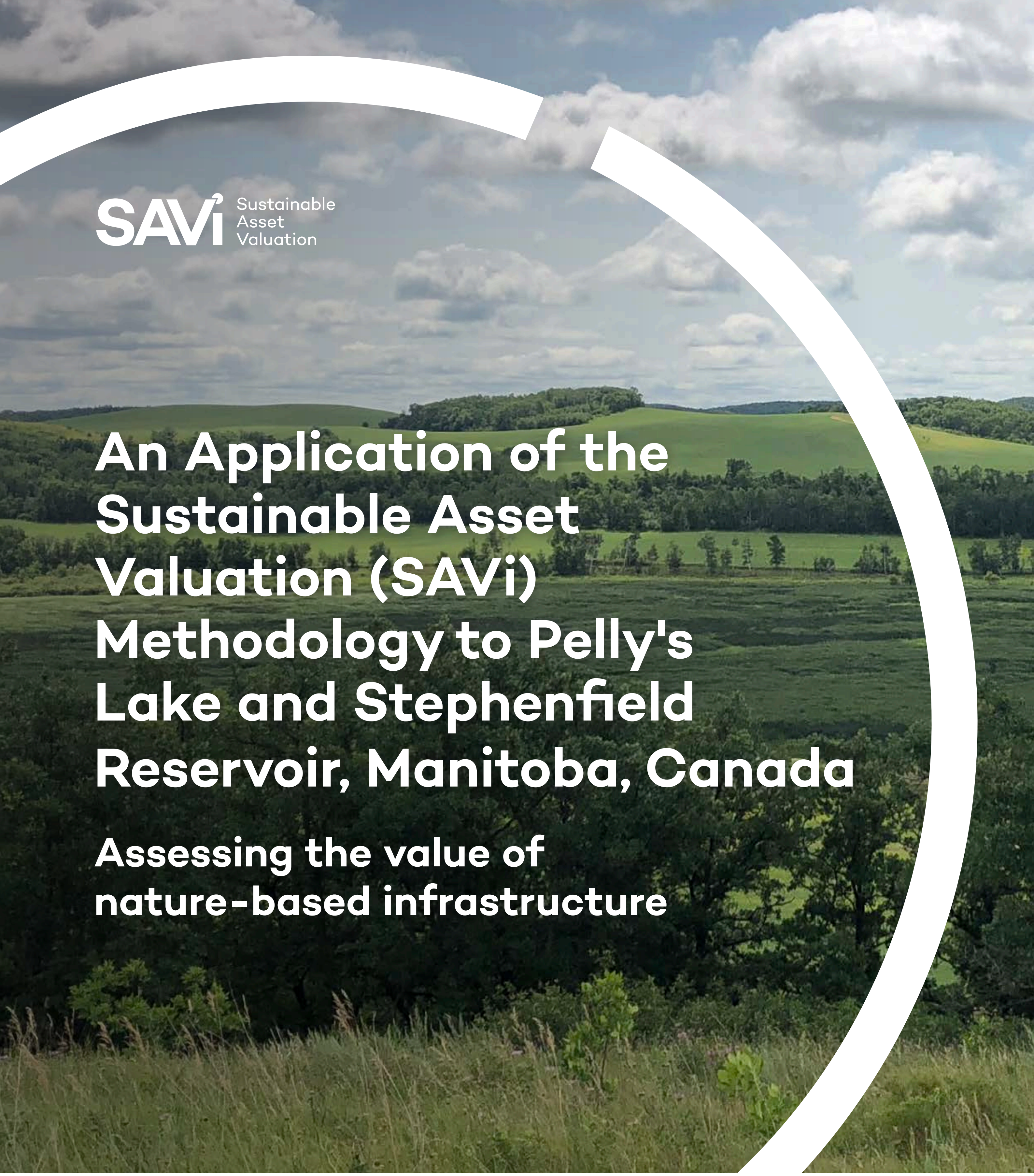

SAVi Sustainable Asset Valuation

An Application of the Sustainable Asset Valuation (SAVi) Methodology to Pelly's Lake and Stephenfield Reservoir, Manitoba, Canada

Assessing the value of nature-based infrastructure

IISD International Institute for Sustainable Development

MAVA Fondation pour la Nature

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June 2019

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The MAVA Foundation was established in 1994 and is a family-led, Swiss-based philanthropic foundation with offices in Switzerland and Senegal.

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An Application of the Sustainable Asset Valuation (SAVi) Methodology to Pelly's Lake and Stephenfield Reservoir, Manitoba, Canada

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June 2019

About SAVi

SAVi is an assessment methodology that helps governments and investors steer capital towards sustainable infrastructure. SAVi's features are:

Simulation

SAVi combines the outputs of systems thinking and system dynamics simulation (built using Vensim) with project financing modelling (built with Corality Smart).

Valuation

Cost of Risk: SAVi places a financial value on economic, social and environmental risks. It then shows how these risks affect the financial performance of infrastructure projects and portfolios, across their life cycles. These types of risks are often overlooked in traditional financial valuations.

Cost of Externalities: SAVi identifies and values in financial terms the externalities that arise as a direct consequence of infrastructure projects. This analysis enables policy-makers and investors to appreciate the second-order gains and trade-offs of infrastructure investments, which may otherwise not be apparent under a traditional valuation.

Costs of Emerging Risks: SAVi shows how externalities today can transform into direct project risks tomorrow. Such valuations help stakeholders make decisions in favour of sustainable infrastructure.

Customization

SAVi is customized to individual investment projects and portfolios. SAVi can therefore value the cost of risks along with a range of wider externalities that are directly material to each asset.

www.iisd.org/savi

Acknowledgements

The authors of this report would like to thank Justin Reid from LaSalle Redboine Conservation District for providing data and insights into Pelly’s Lake, and Mark Lee from Surface Water Management at Manitoba Sustainable Development and Christian Propp from Hydrologic Forecasting and Water Management at Manitoba Infrastructure for providing data and insights into Stephenfield Reservoir. Their engagement and expertise were essential for the success of this research.

Executive Summary

This report presents the results of the Sustainable Asset Valuation (SAVi), as applied to Stephenfield Reservoir and Pelly's Lake, in Manitoba, Canada.

The MAVA Foundation and the International Institute for Sustainable Development (IISD) built SAVi to identify and value the costs of risks, as well as the costs of externalities, of infrastructure projects, portfolios and policies. SAVi is a simulation methodology that combines the outputs of systems dynamics simulation with project finance modelling. It is customized to each asset, portfolio or policy. Because it can provide exact intelligence on the costs of risks and externalities, it can explore if sustainable and resilient infrastructure can also bring the most attractive financial returns. See https://savi.iisd.org for further details.

In Manitoba, Canada, and indeed all over the world, policy-makers grapple with the costs of maintaining natural ecosystems, including wetlands, forests, protected areas, etc. As public budgets diminish, decision makers are often viewing such spending as a luxury that can be ill afforded, especially in light of other seemingly more urgent upgrades in mobility, healthcare, education, transport, social housing and the like. However, natural ecosystems provide a range of "services"—that is, ecosystem services—such as storing water, supplying water, protecting against floods, preventing erosion, reducing the impacts of heat and drought, reducing air pollution, reducing noise pollution and improving aesthetics. With the advent of climate change, natural ecosystems are also critical, as they serve as buffers against catastrophic weather and the resulting floods, droughts, landslides and forest fires. However, what is the financial value of these "services"? Also, if policy-makers, investors and citizens were better informed on these services and their values, would it support the conservation and regeneration of natural habitats? Alternatively, to put it another way, would citizens, businesses, industries, investors and governments be ready to spend on maintaining natural ecosystems if there were more predictability and certainty about the services natural ecosystems can provide?

This SAVi assessment responds to these questions. It gives a valuation of the ecosystem services provided by examples of built and natural infrastructure: (i) Stephenfield Reservoir is a civil engineered reservoir that was built for irrigation and domestic water supply; and (2) Pelly's Lake is a natural wetland that is being actively managed for flood control. Their added benefits are related to improved habitat and biodiversity, groundwater recharge, nutrient and sediment sequestration, carbon offsets and various economic uses of the biomass (plant material). From there, the assessment values the cost of the grey infrastructure that would be needed to provide the same level of service. The results are discussed in some detail below and in Section 5 of this report.

This assessment was conducted in close collaboration with LaSalle Redboine Conservation District, Manitoba Sustainable Development and Manitoba Infrastructure. We sourced data from public sources as well as from these organizations.

Scenario Assumptions

The SAVi assessment estimates the value of ecosystem and infrastructure services provided by Pelly's Lake and Stephenfield Reservoir, and assesses the required costs of providing these services with built or updated infrastructure. A baseline scenario and a climate change scenario were simulated for both assets. The table below provides a description of the baseline and climate change scenarios, and the additional sensitivity scenarios simulated for Stephenfield Reservoir and Pelly's Lake.

Table ES1. Overview of assumptions by scenario

Scenario	Description
Baseline	A business-as-usual (BAU) scenario that assumes the continuation of historical trends such as water extraction and population growth. There are no climate change impacts assumed in the baseline.
Climate change (CC)	The climate change scenario assumes an increase in precipitation variability and a shift in precipitation patterns.
Sensitivity scenarios	Stephenfield Reservoir: • O&M irrigation: two assumptions on the cost of operations of irrigation infrastructure, low (CAD 24/ha/year) and high (CAD 150/ha/year). • Conventional (5 per cent/year) and low (2.5 per cent/year) discount rates for the value of asset services. A low discount rate results in a higher medium- to long-term value for the ecosystem services provided by the asset. Pelly's Lake: • Ecosystem services: high case and low case for the provision of ecosystem services (i.e., cattail production) from wetland and lake. The assumptions used are: - Cattail yield, low (15 tonnes/ha/year) and high (18 tonnes/ha/year) (based on Grosshans et al., 2011). - Nitrogen (N) removal from wetland, low (350 kg N/ha/year) and high (32,000 kg N/ha/year) (based on Berry et al., 2017; Olewiler, 2004; Wilson, 2008). - Phosphorus (P) removal from wetland, low (80 kg P/ha/year) and high (770 kg P/ha/year) (based on Berry et al., 2017; Olewiler, 2004). - P removal from cattail, low (20 kg P/ha/year) and high (60 kg P/ha/year) (based on Berry et al., 2017; Grosshans et al., 2014). • Conventional (5 per cent/year) and low (2.5 per cent/year) discount rates for the value of asset services. A low discount rate results in a higher medium- to long-term value for the ecosystem services provided by the asset.

Note: O&M = operation and management

SAVi Results: Stephenfield Reservoir

The SAVi tool analysis indicates that the real value of Stephenfield Reservoir is that it provides extremely cost-effective irrigation and water storage services. The operating and management costs of the reservoir are CAD 256,000, while the irrigation and water storage services it provides enable economic activity that adds up to a cumulative discounted value of CAD 6.07 billion by 2050. Details are provided in Table ES2.

The SAVi analysis also highlights that, if the Province of Manitoba were to build grey infrastructure to provide the same water storage and irrigation services that are currently being provided by Stephenfield Reservoir, the capital cost required would be CAD 5.3 million. The cost of maintaining the reservoir by way of comparison is CAD 256,000. Moreover, should grey infrastructure be built, the cost of maintaining this built asset would be approximately CAD 300,000, which is also higher than the current reservoir maintenance costs.

In light of this analysis, Manitoba would do well to maintain Stephenfield Reservoir and consider the related expenditure as one that optimizes value for money across the asset life cycle.

Table ES2. Summary of the SAVi analysis of Stephenfield Reservoir (cumulative from 2019 to 2050)

		Discounted results			Undiscounted results		
Category	**Unit**	**(1) Baseline**	**(2) Climate change**	*(2) vs (1)*	**(1) Baseline**	**(2) Climate change**	*(2) vs (1)*
Direct revenues and cost							
Revenues from water licences and tourism (see Table 5)	CAD_{2019}	678,413	678,413	*0.00%*	1,356,793	1,356,793	*0.00%*
O&M cost of the reservoir (see Table 5)	CAD_{2019}	256,005	256,005	*0.00%*	160,001	160,001	*0.00%*
Value of agriculture-related services							
Value of agriculture-related services which in turn are linked to irrigation and water storage (see Table 6)	CAD_{2019}	315,419,939	306,590,138	*(5.52%)*	625,205,933	607,812,652	*(2.78%)*
Capital and O&M costs required to build new grey infrastructure to provide the same services currently delivered by Stephenfield Reservoir							
Irrigation services (see Table 7)	CAD_{2019}	5,417,056	5,432,542	*0.28%*	5,718,888	5,734,962	*0.28%*
Water storage (see Table 7)	CAD_{2019}	208,820	232,765	*11.47%*	208,820	232,765	*11.47%*

Note: O&M = operation and maintenance

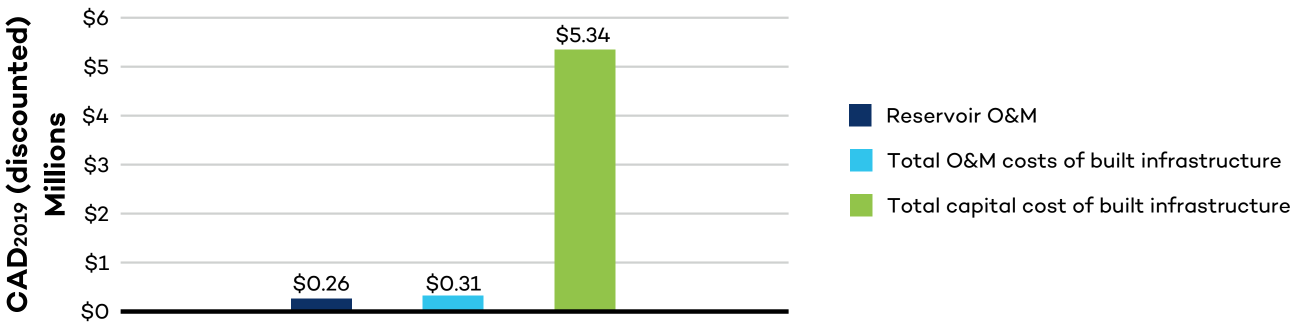

Figure ES1. Comparing the cost of Stephenfield Reservoir with new grey infrastructure that would provide the same volume of services, 2019 and 2050 (all costs are cumulative)

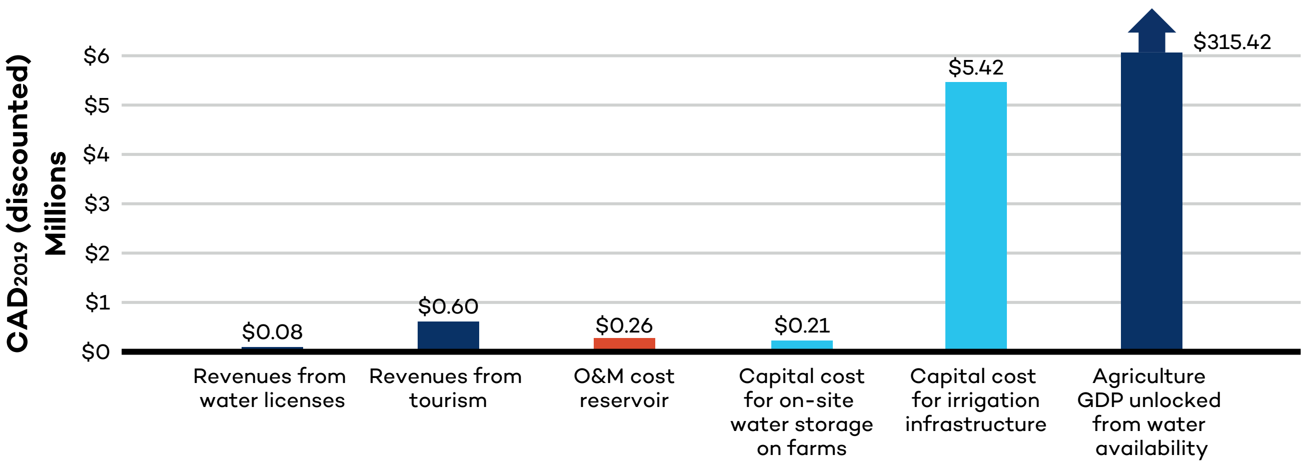

Figure ES2. SAVi valuation on the costs, benefits and avoided costs of Stephenfield Reservoir, 2019 to 2050

SAVi Results: Pelly's Lake

The real benefits of Pelly's Lake are in the ecosystems and infrastructure services that it provides: representing cumulative discounted valuation of approximately CAD 60 million between 2019 and 2050. The breakdown is provided in Table ES3.

When reviewing the climate change scenarios, we remind readers that the volume of rainfall has little effect on the performance of the wetland in terms of cattail harvesting, nutrient removal, carbon sequestration, etc.

Table ES3. Valuation of the ecosystem services provided by Pelly's Lake

Benefits and ecosystem valuation	Unit	Discounted results			Undiscounted results		
		(1) Baseline	(2) Climate change	*(2) vs (1)*	(1.1) Baseline	(2.1) Climate change	*(2.1) vs (1.1)*
Direct revenues and cost							
Cattail value added	CAD_{2019}	97,546	97,546	*0.00%*	879,534	879,534	*0.00%*
O&M cost	CAD_{2019}	176,416	176,416	*0.00%*	342,717	342,717	*0.00%*
Added benefits							
Nutrient removal	CAD_{2019}	47,497,559	47,497,559	*0.00%*	92,271,379	92,271,379	*0.00%*
Carbon sequestration	CAD_{2019}	11,925,298	11,925,298	*0.00%*	23,167,064	23,167,064	*0.00%*
Flood protection	CAD_{2019}	743,279	1,064,505	*43.22%*	1,386,960	2,157,886	*55.58%*
Capital costs of building grey infrastructure providing the same services as Pelly's Lake							
Waste water	CAD_{2019}	13,884,979	13,807,278	*(0.56%)*	25,519,747	25,323,302	*(0.77%)*
Carbon sequestration	CAD_{2019}	23,104,923	23,104,923	*0.00%*	23,104,923	23,104,923	*0.00%*

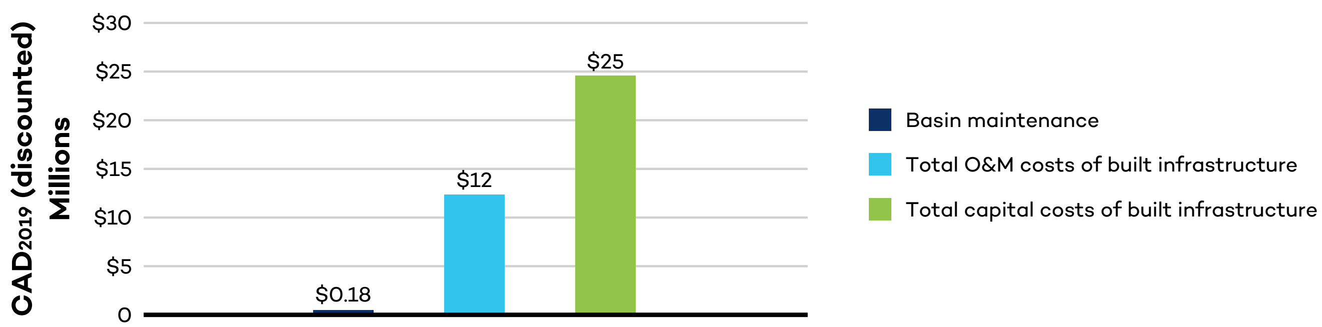

Figure ES3. Comparing the capital and operating costs of built or grey infrastructure to provide the services currently provided by Pelly's Lake (cumulative values from 2019 to 2050)

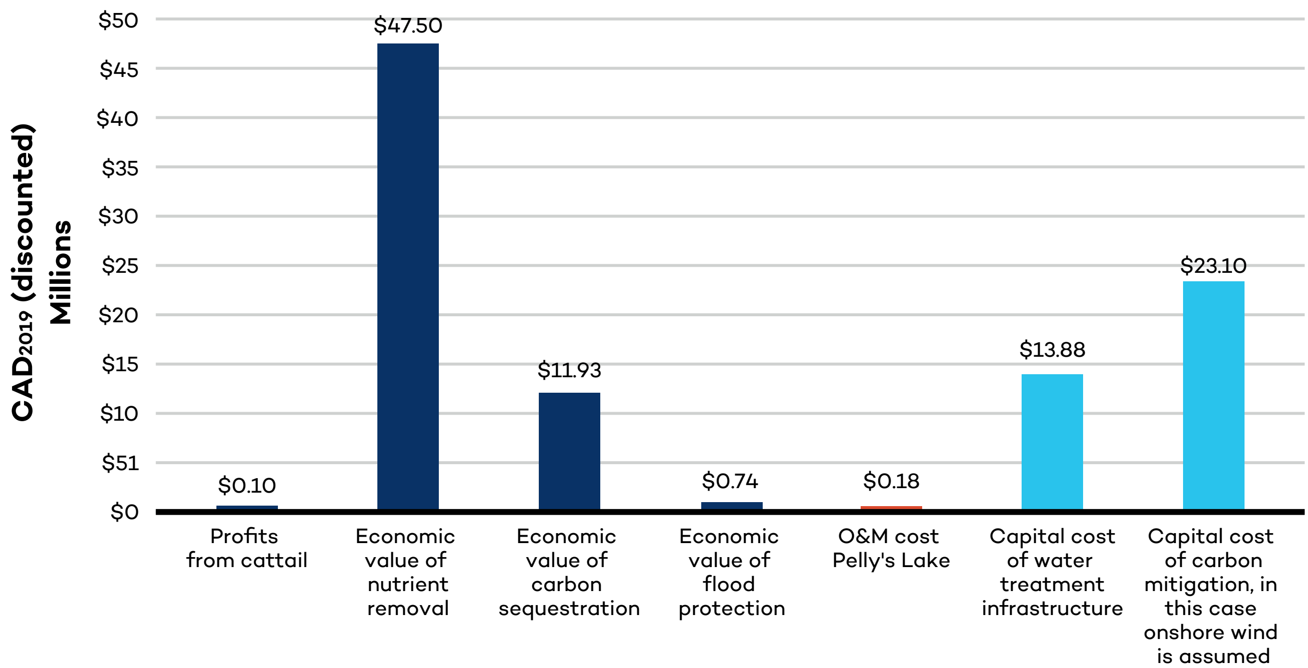

Figure ES4. SAVi valuation on the current costs and benefits of Pelly's Lake (cumulative values from 2019 to 2050)

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Abbreviations

BAU	business as usual
CC	climate change
CLD	causal loop diagram
GDP	Gross Domestic Product
LSRCD	LaSalle Redboine Conservation District
N	nitrogen
NI	natural infrastructure
O&M	operation and maintenance
P	phosphorous
PFRA	Prairie Farm Rehabilitation Administration
PVWC	Pembina Valley Water Cooperative
SAVi	Sustainable Asset Valuation

1.0 Introduction

Natural and bio-engineered ecosystems provide us with a range of infrastructure techniques that are often financially undervalued. Research and literature now can quantify the environmental and social benefits, especially of nature-based infrastructure.

IISD used the Sustainable Asset Valuation (SAVi) methodology on two infrastructure assets in Manitoba, Canada, to understand the value of both assets and to assess how they meet provincial priorities. SAVi uses a bottom-up integrated and technology-rich model.

This SAVi assessment focuses on Pelly's Lake, a natural wetland, and Stephenfield Reservoir, a built reservoir that has become naturalized over time. This study focuses on the quantification and economic valuation of services provided by the two assets without performing a direct comparison between the two. In this report, we present both the discounted and undiscounted results of the SAVi analyses. While SAVi analyses are usually conducted using only discounted values, in this case, stakeholders expressly asked us to include both.

Conventional assessments account for revenues from ecosystem services such as carbon offsets, commercialization of biofuel by-products and others. The conventional investment case for nature-based assets remains a challenge, particularly with services that do not generate marketable revenues. However, natural assets often provide market revenues; enable us to reduce spending on the financing, building and maintenance of built assets; and generate a range of additional positive environmental, social and economic externalities. When financially valued, these can strengthen the broader case for the conservation of natural ecosystems at large.

The contribution of natural infrastructure (NI) as part of a system requires an integrated assessment to fully capture the range of services provided and account for the cost of alternatives. Maintaining water supply for communities and agriculture would likely require installing pumping stations, water storage reservoirs and additional pipelines, while nutrient removal would require installing wastewater treatment plants, nutrient buffers or other mitigation strategies. Built infrastructure typically comes at a significant cost, both in terms of investment and operations and maintenance (O&M) expenditure, and creates additional technology-related risks compared to nature-based assets.

To fully understand the implications of both built and natural infrastructure assets, the financial analysis carried out with SAVi considers the investment and O&M expenditure of the asset, the avoided investments and O&M expenditure from providing the same level of service with built infrastructure, and the monetized added benefits generated by ecosystem and infrastructure service streams provided by the asset.

Several components of SAVi were combined for the systemic assessment of built and natural infrastructure in Canada:

- SAVi Water Balance Model: used for biophysical dynamics, water supply and nutrient uptake, as well as agriculture production; can be applied to both natural and built infrastructure.
- SAVi Irrigation: used to assess the impacts of using irrigation infrastructure for agriculture.
- SAVi Wastewater: used to evaluate options to treat nutrients.
- SAVi Energy: for emission reduction

BOX 1. DEFINITIONS

Anoxia	An absence of oxygen
Built infrastructure asset	Infrastructure constructed by humans, including dams, culverts or wastewater facilities
Boreal forests	A type of forest that grows in the Northern Hemisphere and is resilient to cold temperatures
Carbon offsets	A financial instrument used to compensate for the emission of carbon dioxide from industrial or other human activity
Cattail	A tall, reedy wetland plant with long leaf blades
Discounting	A finance process to determine the present value of a future cash value
Grey infrastructure	Structures that use primarily concrete and steel
Natural infrastructure	Natural systems that are actively managed to provide infrastructure outcomes such as managed wetlands, riparian buffers or green roofs
Riparian buffers	A forested area near a stream or river that is used to protect the waterway from the impact of surrounding land use, such as farming

2.0 The Context of Manitoba

2.1 Manitoba Infrastructure Priorities

Manitoba, a province in central Canada, comprises a large agricultural sector, a population concentrated in the southern part of the province and diverse landscapes. Provincial ecosystems include vast tracts of prairie grasslands, wetlands, boreal forests and thousands of small lakes. Historically, much of the land-use change has been attributed to agricultural development. A unique feature of this province is its hydrology. The province receives significant amounts of water from neighbouring provinces and agricultural land, increasing flood risks and ultimately resulting in significant nutrient loads and contaminants to the major waterways, such as Lake Winnipeg. These factors cause challenges with eutrophication and nutrient management (Environment Canada and Manitoba Water Stewardship, 2011).

Provincial infrastructure priorities, therefore, include a focus on built and natural infrastructure that can manage climate change impacts (floods/droughts), water supply, drainage and storage, agriculture and irrigation, water quality and habitat enhancement.

Manitoba has developed the Climate and Green Plan (Manitoba Sustainable Development, 2017) with goals to reduce carbon emissions and improve provincial resilience to floods and drought. **Climate change** has significant implications for Manitoba's infrastructure priorities, particularly related water management. Climate change is increasing global catastrophic events, and flood events are exponentially growing in Canada (Stewart, 2018). Moudrak and Stewart stress that the current infrastructure is not designed to withstand the severity or frequency of these events, putting our communities and ecosystems at risk (Stanley, Puzyreva, & Roy, 2019).

Due to its topography, Manitoba experiences frequent flooding across the land and downstream in many major lakes and rivers. The province relies on local infrastructure, both built and natural, for **water storage**, for local water supply and to reduce flood-related damage downstream. Water storage creates a local **water supply** for domestic consumption and agricultural use. Many infrastructure projects, including Stephenfield Reservoir, were built for water supply and irrigation. The Pembina Valley Water Cooperative (PVWC) relies on local water storage to supply 14 municipalities in southern Manitoba with clean drinking water. With the acceleration of climate change, the impact of drought events on water supply is a concern that led to the development of a drought plan by the PVWC and their municipalities (Penner, 2018).

Agriculture is a large driver of the Manitoba economy. Because it is largely rainfed, it depends heavily on rainfall and temperature. With climate change resulting in unpredictable and variable temperature and water availability, there may be a decline in crop yield and available pastureland and an increase in pests or diseases (Agriculture and Agri-Food Canada, 2015). During periods of drought, built and natural infrastructure designed to store and recharge groundwater is essential to supply local communities with water for various purposes. While irrigation is not a widely used practice in Manitoba, some farmers rely on local water supplies/reservoirs for irrigating their crops. Under drought conditions, reservoirs may restrict water allocation licences to reduce water consumption, eliminating access for irrigation practices. This may reduce annual crop production and can have significant economic and societal impacts. The large agricultural sector and high-water flows have also led to high nutrient loads in regional waterways, which is attributed to fertilizer application and land-use change (Donahue, 2013; Liu et al., 2008).

Reducing nutrient runoff, preventing eutrophication and improving **water quality** are policy priorities in Manitoba with implications for water management infrastructure, especially NI. Eutrophication in Manitoba has been attributed to high nutrient loads from nonpoint sources (e.g., watershed runoff), point sources (e.g., wastewater facilities) and climate change (Kling, Watson, McCullough, & Stainton, 2011; Schindler, Hecky, & McCullough, 2012). Eutrophication has significant implications for aquatic ecosystems and the fisheries industry—through excessive aquatic vegetation and algae growth, anoxia, fish kills and the spread of invasive species—deteriorating aquatic ecosystem health (Ansari & Gill, 2014). Algal blooms due to eutrophication also plug up pipes and boat motors, causing inconvenience and additional expense for local water supply and reliant economic sectors.

Due to land-use change, declining water quality, invasive species, expansion of urban developments and climate change, there has been significant loss and fragmentation of wildlife **habitat** across Manitoba. A lot of plant and animal life is at risk due to the continued threat. In fact, the Nature Conservancy of Canada (Kraus, 2018) expressed that temperate grasslands located in southern Manitoba, which are home to more than 60 at risk species, are the world's most endangered ecosystem.

2.1.1 BUILT AND NATURAL INFRASTRUCTURE TO ADDRESS PRIORITY NEEDS

Manitoba relies on both built and natural infrastructure to meet provincial service needs. Built infrastructure refers to infrastructure constructed by humans, including dams, culverts or wastewater facilities. NI, a subset of green infrastructure, refers to natural systems that are actively managed to provide infrastructure outcomes, including managed wetlands, riparian buffers or green roofs (ICF, 2018). This report highlights the contributions of NI, especially with regards to mitigating flood- and drought-related impacts. A recent report published for the Canadian Council of Ministers of the Environment (ICF, 2018) discusses the role of NI for improving resiliency.

In Manitoba and Canada, NI is emerging as a cost-effective means to meet service requirements while providing additional outcomes such as climate resiliency and environmental, economic and social benefits (ICF, 2018; Moudrak, Feltmate, Venema, & Osman, 2018).

Built infrastructure, such as wastewater facilities, are designed to treat and manage nutrient and contaminant loads downstream. However, several Manitoba wastewater treatment plants, such as the largest one in the City of Winnipeg, require upgrades to meet Manitoba's water quality regulations of 1 mg/L of total phosphorus and 15 mg/L of total nitrogen (Government of Manitoba, 2011). NI options might, in some cases, provide cost-effective complements or even alternatives for wastewater treatment, while also providing other priority benefits locally and beyond.

NI options, such as managed wetlands, can provide infrastructure outcomes plus significant ecological and economic benefits. Wetlands can store a significant volume of water, with potential to prevent and mitigate flood impacts (ICF, 2018). In addition to water storage, they filter water of contaminants and excessive nutrients, create habitat, recharge groundwater and can store carbon, reducing carbon emissions to the atmosphere. Managed wetlands meet local priorities of water storage/supply, water quality improvement, climate resiliency and habitat enhancement. An estimated 70 per cent of Canada's wetlands have been lost to economic sector pressures and land-use change. This loss has resulted in significant nutrient loads downstream, impacting water quality, flooding and the economy (Ducks Unlimited Canada. n.d.). The province is currently updating drainage regulations under the Water Rights Act to ensure no net loss of wetland benefits in Manitoba (Manitoba Sustainable Development, 2018).

Positive environmental, societal and economic outcomes and benefits of NI are generally understood; however, these benefits remain difficult to quantify and value such that policy mechanisms such as incentives can be developed to manage these natural assets.

2.1.2 SITE DESCRIPTIONS

Figure 1. Pelly's Lake

Pelly's Lake is in south-central Manitoba, in the Pembina Valley, within the area of the local watershed management group called the LaSalle Redboine Conservation District (LSRCD). The Pelly's Lake Ecological Management Area developed a water retention project to manage flood water with a controlled water storage habitat of 1,200 acre-feet (Roy & Grosshans, 2017). This natural asset also provides added benefits of wetland health, biodiversity, habitat availability, groundwater recharge, nutrient and sediment sequestration, carbon offsets and a biomass economy (Grosshans et al., 2014; Berry, 2016; Berry, Yassin, Belcher, & Lindenschmidt, 2017). IISD has worked directly with the LSRCD in designing the ecological management area and quantifying Pelly's Lake's added benefits. The cattail management and harvesting efforts have removed nutrients from the water while creating localized commercial use for the biomass for energy production and paid carbon offsets.

Figure 2. Stephenfield Reservoir

Stephenfield Reservoir was built in 1963 by the Prairie Farm Rehabilitation Administration (PFRA) and is located east of Pelly's Lake, in south-central Manitoba. The reservoir, now owned by Manitoba, was originally built to store water for supply, irrigation and domestic use, with a storage capacity of 3,690 acre-feet (PFRA, 2007). Today, the reservoir is an essential water supply source for the PVWC: Stephenfield Reservoir provides full and partial water supply to nine towns and rural municipalities from Stephenfield water treatment plant. The Stephenfield water treatment plant is one of three operating plants in the PVWC, which together service over 50,000 people (PVWC, 2019). The reservoir is also used for recreation, including camping, beach use, hiking trails, boating and fishing, and provides habitat for fish, waterfowl and wildlife.

3.0 SAVi Analysis

3.1 The Need for a Systemic Approach

Assessing the value of an infrastructure asset, be it natural or built, is a complex task. In particular, NI often provides ecosystem services that may enable economic activity, strengthen social empowerment and well-being, and further support ecological integrity. As a result, any analysis of NI has to assess impacts across: (i) dimensions of development (i.e., social, economic and environmental), (ii) economic sectors, (iii) economic actors (e.g., households, public and private sectors), (iv) over time and (v) in space.

Specifically, the analysis performed with SAVi builds on four main pillars (Figure 3):

1. Assess and quantify the ecosystem and infrastructure services provided by the infrastructure assets.
2. Determine the current investments and O&M expenditure required by these assets.
3. Estimate the revenues generated by the provision of the current ecosystem and infrastructure services.
4. Quantify the required investment and O&M expenditure for delivering the same level of services with built infrastructure. In the case of Pelly's Lake, this refers to replacing services provided by the lake with built infrastructure. For Stephenfield, it means reinvestment in new/updated built infrastructure.

The SAVi model was developed using the system dynamics methodology (Sterman, 2000). Its core pillars are feedback loops, delays and non-linearity. These are explicitly represented in the model using stocks and flows, which are solved with differential equations. The SAVi model has been developed based on global literature, customized with local stakeholder input and parametrized with local, accessible data. The model simulates from 2000 to 2050. There are two main reasons for using this specific time frame: (i) being causal–descriptive, SAVi needs to be validated against historical data (hence the simulation of the model between 2000 and 2018); and (ii) being focused on infrastructure, its costs and outcomes, SAVi needs to forecast the impacts of infrastructure throughout its lifetime (hence the simulation of the model between 2019 and 2050, assuming a 30-year lifetime of infrastructure investments). In order to capture seasonal variability in water demand and precipitation, the model is simulated using a monthly time step (dt = 0.083). Two main scenarios are presented to better assess and interpret the outcomes of infrastructure investments (baseline and climate change scenarios), but many more can be tested with the model.

This assessment in Manitoba examined two infrastructure assets, one built (Stephenfield Reservoir) and one natural (Pelly's Lake), to understand their costs (capital and O&M) and benefits (valued in markets) to create a better case for support based on the real, cumulative value of benefits produced by these assets.

The information generated from these four assessments is then packaged in an integrated analysis that compares the economic viability of both assets with built or replacement infrastructure projects. This addresses a variety of questions:

- For governments, a SAVi analysis can assess value for money for public investments and determine changes in government revenues and expenditure:
  - Do natural and built infrastructure assets trigger positive externalities, enabling growth in other areas and sectors?

- Can natural and built infrastructure increase fiscal sustainability, lowering medium- to long-term costs?
- Does natural and built infrastructure increase the effectiveness of spending and value for money for taxpayers?

• For investors and asset operators, a SAVi analysis can assess the impacts of improved sustainability on future cash flows and financial returns:
  - Is my asset contributing to emission reduction, and by how much (disclosure statements)?
  - What are the environmental, social and economic co-benefits generated by the asset?
  - How can current O&M costs be justified in light of the costs of replacing key services?
  - What is the internal rate of return of my investment when considering a broader set of indicators? Is this asset relevant to impact investors?

The analysis makes use of local data and research, allowing for the models to be tailored to the asset—in this case, Stephenfield Reservoir and Pelly's Lake. This report outlines the model, scenarios and simulation outputs, which were discussed with local researchers and asset operators. The results of the analysis are presented in Part 5.

The model was run based on available and local reports/data to show how SAVi can be applied and to assess investment, revenue and economic viability of asset services. Technical documentation of both models, including data sources and references, are provided in the Annex of this report.

Scope of the analysis

Stephenfield Reservoir and Pelly's Lake

1 What are the services provided?

1. Water supply
2. Scenic beauty
3. Nitrogen and phosphorus uptake
4. Carbon sequestration
5. Economic activity

2 What is the cost of providing these services?

1. Maintenance
2. Water provisioning
3. Cattail production

3 What are the revenues generated from provision of these services

1. Water provisioning
2. Tourism

4 What is the cost of building alternative (built) infrastructure to provide the same services

1. Water Supply
2. Irrigation
3. Water (nutrient) treatment
4. Carbon sequestration

Figure 3. Scope of the SAVi analysis in Canada

3.2 Method: Systems thinking

The key variables and main drivers for the assessment of natural and built infrastructure were analyzed and summarized in a causal loop diagram (CLD) (see Figure 4). The CLD includes the main indicators analyzed; their interconnections with other relevant aspects related to the use of infrastructure, such as total area and ecosystem/infrastructure services provided; and the feedback loops they form when human use of the asset is considered. The CLD was developed and customized to the local context in collaboration with local stakeholders, which also provided the necessary information for the assessment. The CLD is the starting point for the development of the mathematical stock and flow model. The model results are presented in Section 4.

CLDs include variables and arrows (called causal links), with the latter linking the variables together with a sign (either + or −) on each link, indicating a positive or negative causal relation (see Table 1):

- A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction.
- A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction.

Table 1. Causal relations and polarity

Variable A	Variable B	Sign
↑	↑	+
↓	↓	+
↑	↓	-
↓	↑	-

Circular causal relations between variables form causal, or feedback, loops. These can be positive or negative. A negative feedback loop tends toward a goal or equilibrium, balancing the forces in the system (Forrester, 1961). A positive feedback loop can be found when an intervention triggers other changes that amplify the effect of that initial intervention, thus reinforcing it (Forrester, 1961). CLDs also capture delays and non-linearity.

The creation of a CLD has several purposes: first, it combines the team's ideas, knowledge and opinions; second, it highlights the boundaries of the analysis; third, it allows all stakeholders to achieve basic-to-advanced knowledge of the analyzed issues and their systemic properties. Having a shared understanding is crucial for solving problems that influence several sectors or areas of influence, which are common in complex systems. Since the creation of a CLD touches upon and relies on cross-dimensional knowledge, it supports developing a shared understanding of the factors that generate the problem and those that could lead to a solution among all the parties involved in the decision-making process and implementation. It can also lead to effective implementation of successful private–public partnerships. As such, the solution should not be imposed on the system but should emerge from it. In other words, interventions should be designed to make the system start working in our favour (i.e., decision makers and relevant stakeholders) to solve the problem, rather than generating it.

In this context, the role of feedbacks is crucial. It is often the very system we have created that generates the problem, due to external interference or to a faulty design. Its limitations emerge as the system grows in size and complexity. In other words, the causes of a problem are often found within the feedback structures of the system. The indicators are not sufficient to identify these causes and explain the events that led to the creation of the problem. We are too often prone to analyzing the current state of the system or to extend our investigation to a linear chain of causes and effects, which does not link back to itself, thus limiting our understanding of open loops and linear thinking.

3.3 Model: SAVi

We have applied the SAVi model to Stephenfield Reservoir and Pelly's Lake because there are growing concerns over irregular rainfall patterns and floods, water quality, irrigation and water needs in Manitoba. As a result, we customized SAVi to, first, identify, quantify and carry out an economic valuation of the assets and the services provided by natural and built infrastructure and, second, to estimate the potential cost of generating these same services with new/updated built infrastructure. Ultimately, the model should answer the following questions

a) What is the value of the economic, environmental and social benefits generated by the asset?

b) Is the asset demonstrating value for money that can inform investments in the future?

c) What are the wider implications for infrastructure investment in Manitoba if economic, environmental and social benefits generated by natural and built assets ought to be considered in the feasibility analysis?

In the Stephenfield Reservoir and Pelly's Lake context, water is a critical aspect to consider. This is the starting point for the development of the CLD (Figure 4), which is also the blueprint for the creation of the mathematical stock and flow model.

Specifically, Figure 4 shows a generalized CLD that highlights the most important contributions of NI that are captured by the models developed for Stephenfield Reservoir and Pelly's Lake. For water specifically, the CLD indicates that the higher the rainfall, the faster the water bodies replenish and the more water can be extracted, and vice versa. The CLD also shows that balancing recharge and extraction rates is critical for maintaining a higher water stock. This in turn improves the water storage and water supply potential of both the reservoir and the lake.

With higher water availability, there is (i) a higher potential for water extraction and use, and hence a reduction of the stock of water (creating a balancing loop, B1) and (ii) a reduced need for expanding efficient irrigation infrastructure, which in turn reduces the amount of water that has to be sourced from irrigation and lowers water extraction, which is also affected by population and other municipal uses, all else equal. These dynamics form a reinforcing loop, R1. This reinforcing loop represents the potential to increase efficiency by increasing the use of water-saving irrigation infrastructure but also ultimately leads to growing depletion of the stock of water. When this happens, an additional balancing loop increases in strength, B2. Specifically, when the water stock declines, the risk of droughts increases, leading to stranded agriculture land (or land left to rainfed agriculture), characterized by reduced productivity or no production. This is a natural balancing loop that stresses limits to water availability.

The water stock has other impacts besides the direct ones to agriculture production and municipal water use. In fact, when the water stock is high, water levels rise and the number of overflows increases, possibly leading to flooding damage. Conversely, if the stock is low, the flood risk declines since the lake and reservoir will serve as a buffer.

Further, the water stock, as well as floods and droughts, affect ecological integrity, which in turn impacts wetland flora and fauna. These influence tourism as well as two critical ecosystem services: nutrient removal and carbon sequestration. The former affect nutrient concentration, which is also driven by waste water, fertilizer use, atmospheric deposition and precipitation (which determines runoff, for instance), and ultimately water quality. The latter influences the concentration of emissions in the atmosphere and health impacts.

In addition to these baseline dynamics, which highlight the services provided by Stephenfield Reservoir and/or Pelly's Lake (highlighted in green) as well as the emerging costs (highlighted in red), the CLD shows what investments would be required to provide the same services with built or new infrastructure (highlighted in orange). These investments include water supply, storage capacity, irrigation, flood mitigation, climate mitigation and wastewater treatment (for nutrient removal). When linking these three elements together, the CLD shows how infrastructure is creating important synergies in the provision of services (e.g., with the water stock being a central, gateway variable for unlocking such synergies on water supply, climate mitigation and nutrient removal), which otherwise would need to be tackled by several individual investments.

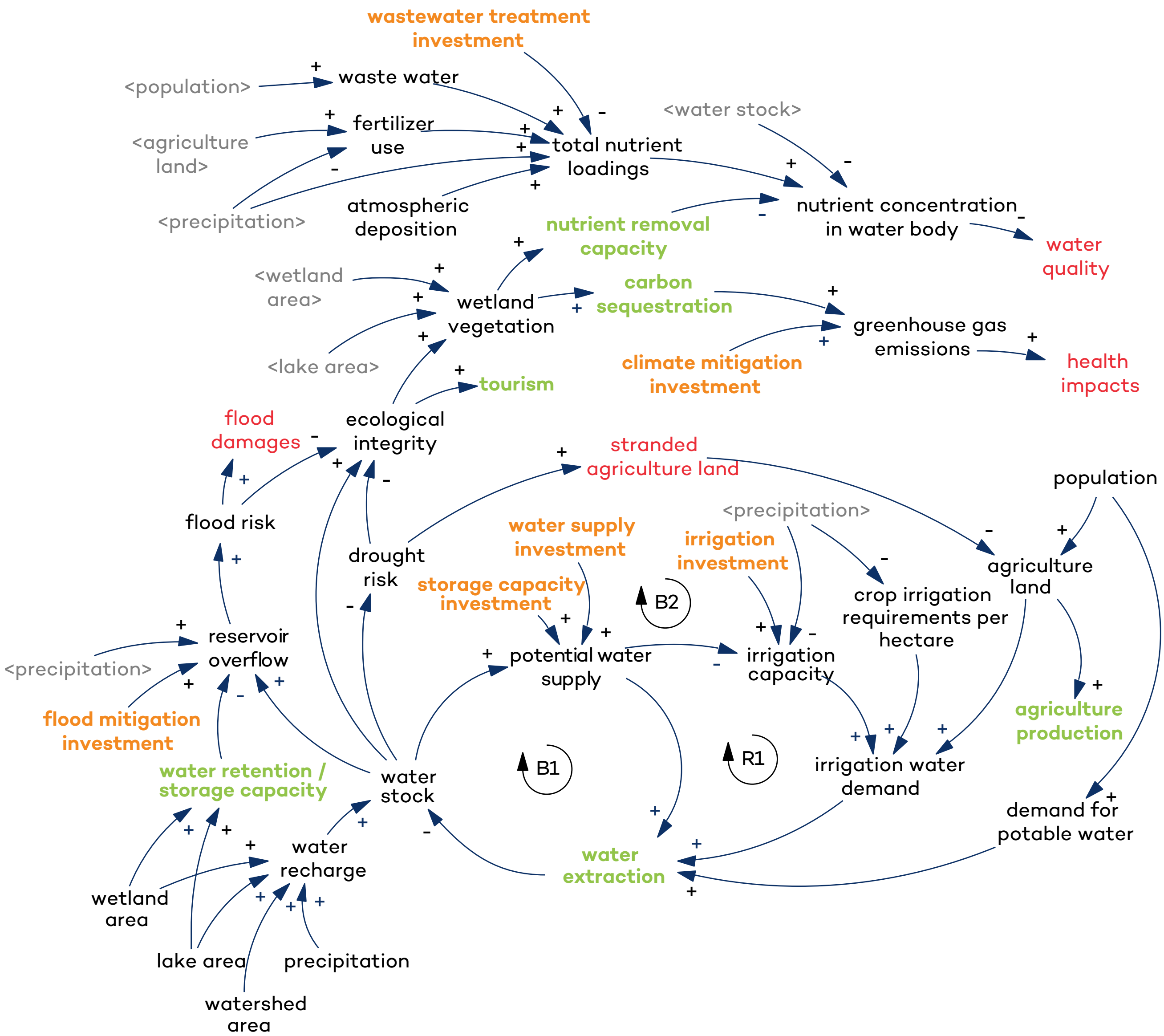


Figure 4. CLD of the SAVi model applied to Stephenfield Reservoir and Pelly's Lake

Legend:

- *A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction; a causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction.*
- *Feedback loops, represented in the diagram with R or B surrounded by a circular arrow, can be classified as positive or negative. Positive (or reinforcing) feedback loops amplify change and are typically identified by an R notation, while negative (or balancing) feedback loops counter and reduce change and are identified by a B notation.*
- ***Green variables** represent the ecosystem and infrastructure services provided by the asset; **red variables** represent current emerging negative impacts and costs originating from environmental degradation; and **orange variables** represent investments required to replace services provided by the infrastructure.*

BOX 2. MODEL BOUNDARIES

The SAVi model for Stephenfield Reservoir and Pelly's Lake includes the following sectors, selected variables and technologies. More details are provided in Annex I.

- Water demand: residential, irrigation
- Water supply: precipitation, water balance for the reservoir/lake
- Water use:
    - Three irrigation technologies: flood, centre pivot, drip
    - Five types of water pumps: electric, natural gas, propane, diesel, gasoline
- Nitrogen and phosphorus loading:
    - Five sources: waste water, agriculture fertilizer, manure, atmospheric deposition, stormwater runoff
- Wastewater treatment: (three technologies): physical removal, ultrafiltration, reverse osmosis
- Land cover: agriculture, urban and forest (plus wetland)
- Economic activity:
    - Agriculture production and employment
    - Cattail bioeconomy
    - Tourism revenues

4.0 Scenarios

The SAVi assessment estimates the value of ecosystem and infrastructure services provided by Pelly’s Lake and Stephenfield Reservoir, and assesses the required costs of providing these services with built or updated infrastructure. A baseline scenario and a climate change (CC) scenario were simulated for both assets. Table 2 provides a description of the baseline and CC scenarios, and the additional sensitivity scenarios simulated for Stephenfield Reservoir and Pelly’s Lake.

Table 2. Overview of assumptions by scenario

Scenario	Description
Baseline	A business-as-usual (BAU) scenario that assumes the continuation of historical trends such as water extraction and population growth. There are no climate change impacts assumed in the baseline.
CC	The CC scenario assumes an increase in precipitation variability and a shift in precipitation patterns.
Sensitivity scenarios	Stephenfield Reservoir: • O&M irrigation: two assumptions on the cost of operations of irrigation infrastructure, low (CAD 24/ha/year) and high (CAD 150/ha/year). • Conventional (5 per cent/year) and low (2.5 per cent/year) discount rates for the value of asset services. A low discount rate results in a higher medium- to long-term value for the ecosystem services provided by the asset. Pelly’s Lake: • Ecosystem services: high case and low case for the provision of ecosystem services (i.e., cattail production) from wetland and lake. The assumptions used are: - Cattail yield, low (15 tonnes/ha/year) and high (18 tonnes/ha/year) (based on Grosshans et al., 2011). - Nitrogen (N) removal from wetland, low (350 kg N/ha/year) and high (32,000 kg N/ha/year) (based on Berry et al., 2017; Olewiler, 2004; Wilson, 2008). - Phosphorus (P) removal from wetland, low (80 kg P/ha/year) and high (770 kg P/ha/year) (based on Berry et al., 2017; Olewiler, 2004). - P removal from cattail, low (20 kg P/ha/year) and high (60 kg P/ha/year) (based on Berry et al., 2017; Grosshans et al., 2014). • Conventional (5 per cent/year) and low (2.5 per cent/year) discount rates for the value of asset services. A low discount rate results in a higher medium- to long-term value for the ecosystem services provided by the asset. **The low discount rate scenario is referred to as Low DR ES; see Section 5 of this report.**

Monetary results are presented in two forms: discounted (or net present value) or undiscounted. Discounting is applied to consider the value of future investments, today. In fact, the net present value represents how much the investment is worth in today's money, considering the potential cost of financing, inflation and more. A higher discount rate assumes that money will be worth less in the future. A low discount rate assumes instead that the value of the investment will be higher in the future. In the context of ecosystem services, there is a long-lasting debate on whether the discount factor should be large or small, or even negative.

Climate assumptions

The model includes precipitation (long-term trend and short-term variability) by month (North American Regional Reanalysis, n.d.) (Annex I), to capture impacts of changing seasonality on asset costs and benefits between 2019 and 2050. The CC scenario assumes for both assets an annual increase of 0.5 per cent in precipitation variability and a change in precipitation patterns. According to the Prairie Climate Centre (2018), precipitation in Manitoba is projected to increase during spring, autumn and winter months, and decrease during the summer months. This change in precipitation patterns is captured by applying a multiplier that increases the share of precipitation during the winter months by 10 per cent and decreases it by 10 per cent during the summer months. The change in precipitation is assumed to occur linearly between 2019 and 2050. The seasonal distribution of precipitation for the years 2045 to 2050 is illustrated in Figure 5. The CC scenario (blue line) shows an increase in the share of precipitation at the beginning and end of the year and a reduction during the summer (peak precipitation) months. Changes in precipitation could result in changes in required water supply from irrigation and flood risk (reservoir overflow), as well as fertilizer use.

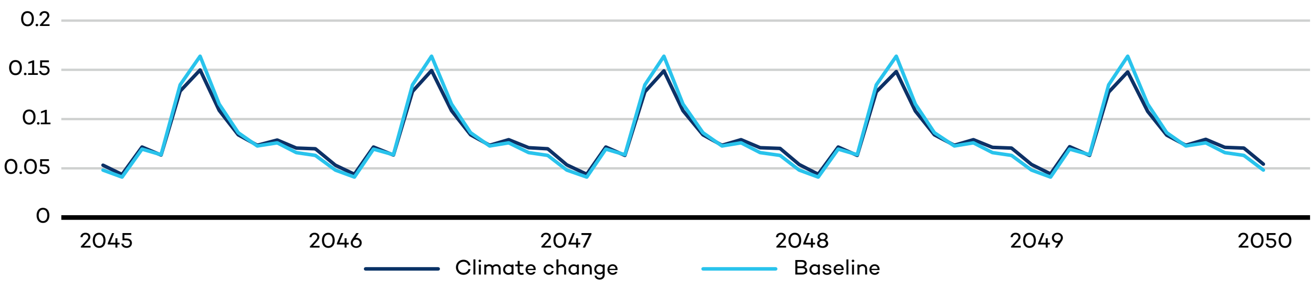


Figure 5. Distribution of seasonal precipitation by scenario (2045–2050)

Assumptions on infrastructure costs and valuation of asset services

The replacement cost of asset services is based on the current level of service(s) provided (e.g., nutrient removal) and the corresponding required capacity of built infrastructure (e.g., water treatment plants) to provide the same level of service. The cost of built infrastructure is discounted at a 5 per cent rate (or 2.5 per cent in the low discount rate scenario) starting from 2019.

Table 3 presents the cost assumptions for each of the infrastructure components.

Table 3. Data sources for the built infrastructure SAVi water balance assessment

Asset type	Variable	Parameter value	Source
Water treatment[1]	Capital cost N removal	CAD 25/kg N	Tetra Tech, 2011 Berry, 2016
	O&M cost N removal	CAD 12.5/kg N	
	Cost of P removal	CAD 60/kg P	Berry, 2016
Irrigation	Capital cost	CAD 80/ha	O'Brien, Dumler, & Rogers, 2011
	Marginal O&M cost [2]	CAD 0.3/ha	Based on Samarawickrema & Kulshreshtha, 2009
	Irrigation efficiency	25%	Sauer, et al., 2010
Water supply	Establishing additional reservoir storage on site	CAD 2,000/ acre-foot	Personal communication, Oshani Perera, May 2017
Carbon sequestration[3]	Cost per tonne of carbon dioxide abated	CAD 25/tonne	International Energy Agency (IEA), 2014, 2017

[1] For this assessment, the cost per kilogram of N removed was calibrated based on reports from Tetra Tech (2011) and Berry (2016) and corresponds to the use of physical removal. The SAVi Wastewater model is, on the other hand, equipped with three different wastewater treatment technologies (physical removal, ultrafiltration and reverse osmosis) and is parametrized based on Iglesias, Ortega, Batanero and Quintas (2010). The standard values used in the SAVi Wastewater model are consistent with cost assumptions used in the SAVi Canada assessment. The N removal efficiency of the different treatment methods is assumed to be 70 per cent for physical removal, 80 per cent for ultrafiltration and 95 per cent for reverse osmosis, respectively.

[2] This assessment considers the marginal cost of irrigation per hectare. The model is calibrated to match the values reported by Samarawickrema and Kulshreshtha (2009), and have been determined by dividing the cumulative O&M cost of irrigation by the total cumulative water use per hectare.

[3] The carbon sequestration cost is estimated based on the cost of reducing emissions (carbon mitigation) using wind power. This is a technology-based comparator, but the carbon tax could also be used. In the case of wind, we have considered an average emission rate of 1 tonne of carbon dioxide per MWh for coal and zero for wind (IEA, 2017). We then considered a cost of CAD 1 million per MW of capacity (IEA, 2014), and 23 per cent use factor. The cost per tonne of carbon dioxide avoided is, as a result, CAD 25 per tonne.

5.0 Results From the SAVi Assessments

The results of the SAVi assessments on Stephenfield Reservoir and Pelly's Lake are presented below. The assessment does not compare or contrast the two assets. Each valuation should be viewed separately.

The assets demonstrate that nature-based infrastructure can deliver a range of services in a much more cost-effective manner than built grey infrastructure. The SAVi assessments also calculate the capital and operating costs that taxpayers would need to face if governments were to build grey infrastructure to provide the same services provided by Stephenfield Reservoir and Pelly's Lake. The results certainly speak for themselves and make the point that governments should not view the O&M of natural assets as "cost centres" that could otherwise be deployed on more urgent needs.

The assumptions for the scenarios are presented in Table 2 in the previous section.

5.1 SAVi Assessment on Stephenfield Reservoir

5.1.1 BIOPHYSICAL PARAMETERS

Figure 6 illustrates the development of the water stock and the N concentration of Stephenfield Reservoir for the baseline (light blue line) and the CC (dark blue line) scenarios. Compared to the baseline, the water level in the CC scenario decreases, starting from 2035, as a consequence of higher precipitation variability and shifts in precipitation patterns toward the winter months, as indicated by the Prairie Climate Centre (2018). The N concentration of the reservoir, estimated based on provincial data on N loading (Environment Canada, 2016) and validated with local data on N concentration for 2002 and 2003 (Water Science and Watershed Management Branch, n.d.), increases by approximately 1.2 per cent as a consequence of slightly lower water levels, as indicated in Figure 6.

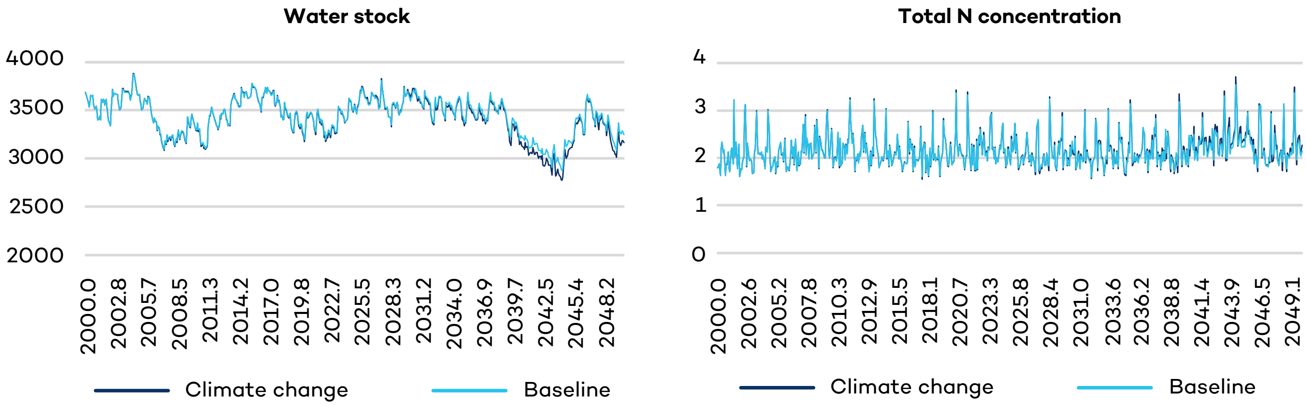


Figure 6. Water stock and total N concentration in Stephenfield Reservoir

Table 4 provides an overview of selected biophysical parameters of Stephenfield Reservoir, presenting cumulative values between 2019 and 2050. For the SAVi assessment, N loading and water demand are presented. In the baseline scenario, the cumulative N loading entering the reservoir between 2019 and 2050 totals 28,420 tonnes, which is equivalent to average annual loading of approximately 916.7 tonnes per year. In the CC scenario, the amount is 2.5 tonnes, or 0.27 per cent lower than in the baseline. Cumulative water demand in the baseline and CC scenarios total 61,905 and 67,188 acre-feet, respectively, indicating an increase of 5,284 acre-feet in total water demand or 170.4 acre-feet per year on average.

Table 4. Biophysical contribution of Stephenfield Reservoir (cumulative from 2019 to 2050)

Biophysical parameters	Unit	(1) Baseline	(2) Climate change	CC vs BAU
N loading	Kg N	28,417,021	28,339,926	*(0.27%)*
N concentration	*Mg/L*	*2.227*	*2.252*	*1.15%*
Water demand	acre-ft	61,905	67,188	*8.53%*

It is important to note that P has been identified as the leading cause of algal blooms and driver of eutrophication (Schindler, 2012). We, however, were not able to include an analysis on P in this assessment due to data constraints. N data was estimated based on provincial data from the National Greenhouse Gas Inventory of Canada (Environment Canada, 2016), and is used to show the impacts that water levels and climate change have on nutrient loading and concentrations in the reservoir. The model determines monthly nutrient loading from different sources (e.g., waste water, fertilizer, manure) based on quantity and delivery coefficients.

N loading and concentration are estimated for different scenarios, including changing climate conditions, and other types of nutrients could be accommodated if data were available. For example, if data on P loading and concentration were available for selected months or years, we could forecast the problem (e.g., algal blooms) and its causes (i.e., loading) and assess the cost of reducing the loading and/or increasing uptake with built and/or natural infrastructure. The biophysical analysis of nutrients was not actively used for the estimation/valuation of direct revenues, services or the replacement cost of infrastructure for Stephenfield Reservoir because there was no service (i.e., reduction in loading or increase in uptake/filtration) associated with nutrients assessed in the scope of this analysis.

5.1.2 ANALYSIS OF REVENUES AND COSTS

Direct revenues and costs from Stephenfield Reservoir are summarized in Table 5.

The reservoir generates approximately CAD 678,400 in discounted revenues, CAD 598,400 from water licensing and CAD 80,000 from tourism. Cumulative O&M expenditure totals approximately CAD 256,000.

Table 5. Direct revenues and costs of Stephenfield Reservoir (cumulative value from 2019 to 2050)

Direct benefits and cost	Unit	Discounted	Undiscounted
Total revenues	CAD2019	**678,413**	**1,356,793**
Revenues from water licences *(licences are issued for water extraction; they are priced at CAD 25 per licence and are valid for 10 years)*	CAD2019	80,001	160,001
Revenues from tourism *Most of these revenues are not spent on maintaining the reservoir but on maintaining the tourism infrastructure, such a parking lots and cabins.*	CAD2019	598,411	1,196,792
Reservoir O&M costs	**CAD2019**	**256,005**	**511,998**

5.1.3 VALUATION OF AGRICULTURE-RELATED SERVICES PROVIDED BY STEPHENFIELD RESERVOIR

Stephenfield Reservoir provides many services to the surrounding community, including irrigation, water supply for municipal use and water storage. The SAVi valuation is limited to agriculture-related services, mainly related to irrigation services for water directly supplied from the reservoir to farms in the surrounding areas. Due to many data gaps, we were unable to produce a valuation for water supply and water storage. Stephenfield Reservoir provides drinking water to approximately, 5,000 people from local municipalities as managed by the Pembina Valley Water Cooperative (personal communication, Tiffany Bell, PVWC, March 2019).

The value of the agriculture-related services provided by Stephenfield Reservoir is presented in Table 6. The assessment assumes:

- Potato production with a yield of 7.06 tonnes per hectare (PotatoPro, 2018)
- A total irrigated area of 60,250 hectares around the reservoir.

Table 6. Valuation of agriculture-related services provided by the Stephenfield Reservoir

		Discounted results		Undiscounted results	
	Unit	**(1) Baseline**	**(2) Climate change**	**(1.1) Baseline**	**(2.1) Climate change**
Agriculture GDP (enabled by irrigation)	mn CAD2019	80.2	78.0	152.1	147.8
Tax revenues from agriculture that is enabled by irrigation	mn CAD2019	10.0	9.8	19.0	18.5
Discretionary spending from agriculture that is enabled by irrigation	mn CAD2020	235.2	228.6	473.1	460.0

Note: mn = million

In the baseline scenario, Stephenfield Reservoir contributes CAD 80.2 million to GDP, CAD 10 million to provincial tax revenues and CAD 235.2 million to discretionary spending. The latter value on discretionary spending represents approximately 1,250 additional jobs.

The CC scenario, on the other hand, shows that changes in precipitation reduces the agricultural contribution to GDP by 2.68 per cent and total discretionary spending from agriculture-related labour by 2.84 per cent.

5.1.4 HOW MUCH WOULD IT COST TO REPLACE IRRIGATION AND WATER STORAGE SERVICES PROVIDED BY STEPHENFIELD RESERVOIR BY NEW GREY INFRASTRUCTURE?

The real value of Stephenfield Reservoir lies in the infrastructure services that it provides to farmers, municipalities and the wider community at large. These infrastructure services include irrigation and water storage. To appreciate the value of these services, SAVi was used to simulate what it would cost to build grey infrastructure that would provide the same volume of irrigation and water storage that is currently being delivered by Stephenfield Reservoir. The results are presented in Table 7; the discount rate is 5 per cent per year.

Table 7. Capital and operating costs of building grey infrastructure that will provide the same irrigation and water storage services as Stephenfield Reservoir (cumulative from 2019 to 2050)

		Discounted results			Undiscounted results		
Costs to build grey infrastructure	**Unit**	**(1) Baseline**	**(2) Climate change**	*(2) vs (1)*	**(1) Baseline**	**(2) Climate change**	*(2) vs (1)*
Total costs of grey irrigation infrastructure	**mn CAD2019**	**5.42**	**5.43**	***0.29%***	**5.72**	**5.73**	***0.28%***
Capital costs	mn CAD2019	*5.12*	*5.12*	*0.00%*	*5.12*	*5.12*	*0.00%*
O&M costs	mn CAD2019	*0.30*	*0.31*	*5.17%*	*0.60*	*0.62*	*2.67%*
Total costs of grey water storage infrastructure	**mn CAD2019**	**0.21**	**0.23**	***11.47%***	**0.21**	**0.23**	***11.47%***
Capital	mn CAD2019	*0.21*	*0.23*	*11.47%*	*0.21*	*0.23*	*11.47%*
O&M	mn CAD2019	*0.00*	*0.00*	*N/A*	*0.00*	*0.00*	*N/A*
Total capital costs of grey irrigation and water storage infrastructure	**mn CAD2019**	**5.33**	**5.35**	**0.45%**	*5.33*	**5.35**	*0.45%*
Total O&M costs of grey irrigation and water storage infrastructure	**mn CAD2019**	**0.30**	**0.31**	**5.17%**	*0.60*	**0.62**	*2.67%*
Total costs to replace Stephenfield Reservoir with new grey infrastructure	**mn CAD2019**	**5.63**	**5.67**	***0.70%***	**5.93**	**5.97**	***0.68%***
Total cost CC versus Baseline	*%*	*0.70%*			*0.68%*		

Note: mn = million

Providing irrigation through new grey infrastructure for approximately 62,000 hectares that are currently irrigated by Stephenfield Reservoir would require CAD 5.12 million in capital costs and approximately CAD 299,400 in O&M costs. The O&M costs under the CC scenario are higher, reaching CAD 314,900. The CC scenario implies lowered rainfall, which in turn would require higher investment in irrigation efficiency.

The total costs of building new grey infrastructure to provide the same volume of water storage as Stephenfield Reservoir would require total capital and operating costs of CAD 208,820. In the case of climate change and less rainfall, additional spending would be required to ensure continuous water supply to maintain agriculture production through the growing period. The total capital and operating costs of new grey infrastructure would then increase to CAD 232,800.

5.1.5 SUMMARY OF THE SAVI ANALYSIS ON STEPHENFIELD RESERVOIR

Table 8. Summary of SAVi analysis on Stephenfield Reservoir (cumulative from 2019 to 2050)

Category	Unit	Discounted results			Undiscounted results		
		(1) Baseline	**(2) Climate change**	*(2) vs (1)*	**(1) Baseline**	**(2) Climate change**	*(2) vs (1)*
Direct revenues and cost							
Revenues from water licences and tourism (see Table 5)	CAD_{2019}	678,413	678,413	*0.00%*	1,356,793	1,356,793	*0.00%*
O&M cost of the reser-voir (see Table 5)	CAD_{2019}	256,005	256,005	*0.00%*	160,001	160,001	*0.00%*
Value of agriculture-related services							
Value of agriculture-related services which in turn are linked to irrigation and water storage (see Table 6)	CAD_{2019}	315,419,939	306,590,138	*(5.52%)*	625,205,933	607,812,652	*(2.78%)*
Capital and O&M costs required to build new grey infrastructure to provide the same services currently delivered by Stephenfield Reservoir							
Irrigation services (see Table 7)	CAD_{2019}	5,417,056	5,432,542	*0.28%*	5,718,888	5,734,962	*0.28%*
Water storage (see Table 7)	CAD_{2019}	208,820	232,765	*11.47%*	208,820	232,765	*11.47%*

Note: O&M = operation and maintenance

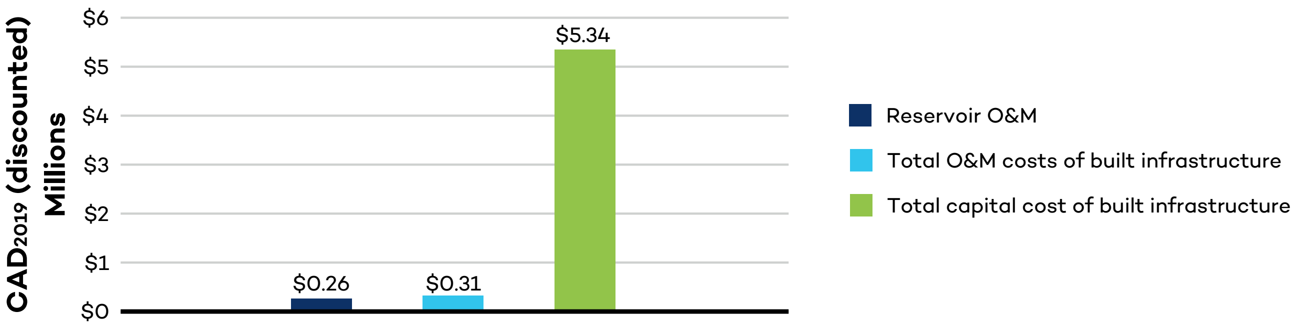


Figure 7. Comparing the cost of Stephenfield Reservoir with new grey infrastructure that would provide the same volume of services, 2019 and 2050 (all costs are cumulative)

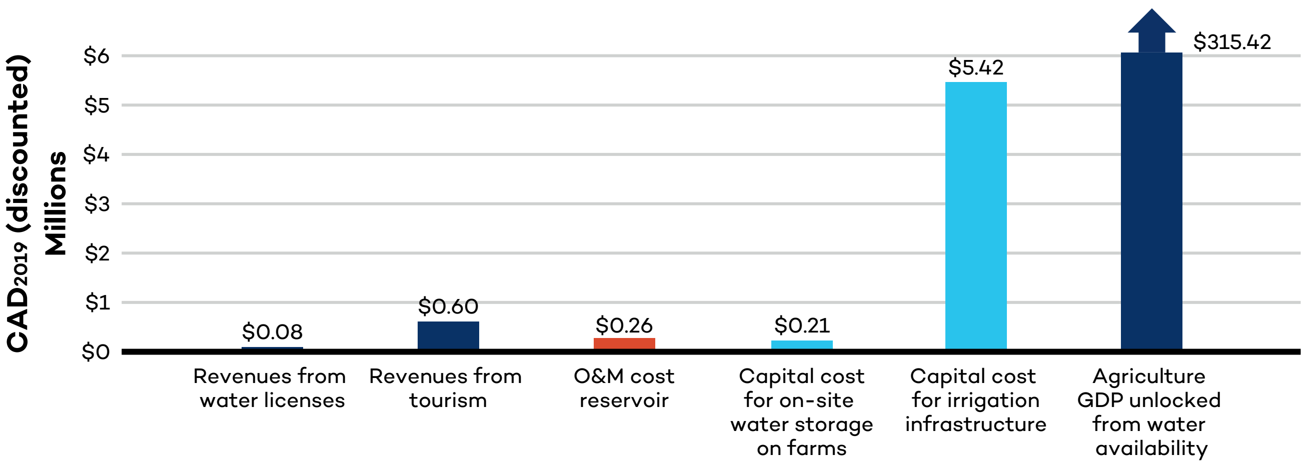


Figure 8. SAVi valuation on the costs, benefits and avoided costs of Stephenfield Reservoir, 2019 to 2050

The SAVI analysis indicates that the real value of Stephenfield Reservoir is that it provides extremely cost- effective irrigation and water storage services. Those services in turn increase the O&M costs of the reservoir to CAD 256,000, while the irrigation and water storage services it provides enables economic activity that adds up to a cumulative discounted value of CAD 6.07 billion by 2050.

The SAVi analysis also points out that, if Manitoba were to build grey infrastructure to provide the same water storage and irrigation services that are currently being provided by Stephenfield Reservoir, the capital costs required would be CAD 5.33 million. The costs of maintaining the reservoir by way of comparison is CAD 256,000. Moreover, should grey infrastructure be built, the costs of maintaining this built asset would be approximately CAD 300,000, which is also higher than the current reservoir maintenance costs.

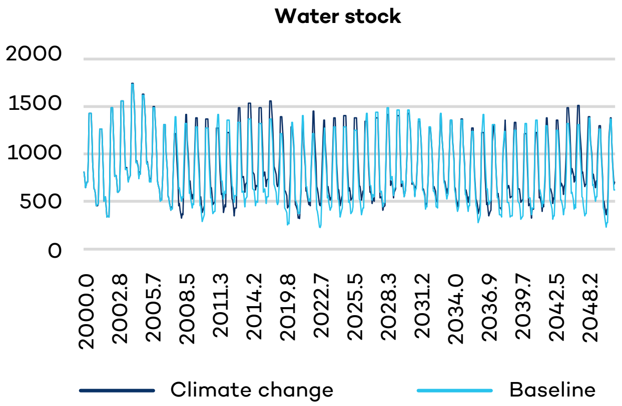
In light of this analysis, Manitoba would do well to maintain Stephenfield Reservoir and consider the related expenditure as one that optimizes value for money across the asset life cycle.

5.2 SAVi Assessment on Pelly's Lake[4]

5.2.1 THE BIOPHYSICAL PARAMETERS OF PELLY'S LAKE

Pelly's Lake provides a range of ecosystem services (water storage, carbon sequestration, nutrient filtration, cattail bioeconomy, etc.) that contribute to the well-being of the population and economic development of the surrounding area. The 121-hectare lake has a storage capacity of approximately 1,200 acre-feet (Berry, 2016) and serves as a buffer. It was established to mitigate flooding and to filter excess nutrients from runoff to improve downstream water quality.

Figure 9 provides an overview of the water stock in Pelly's lake (left) and the potential water shortage during the summer months, both for the baseline (light blue line) and the climate change (dark blue line) scenario. In this assessment, the impact of climate change on precipitation contributes to higher rainfall variability, which shows higher accumulation in the stock (under the assumption that, even in the climate change scenario, only seasonal distribution changes, not total rainfall) (Figure 9).



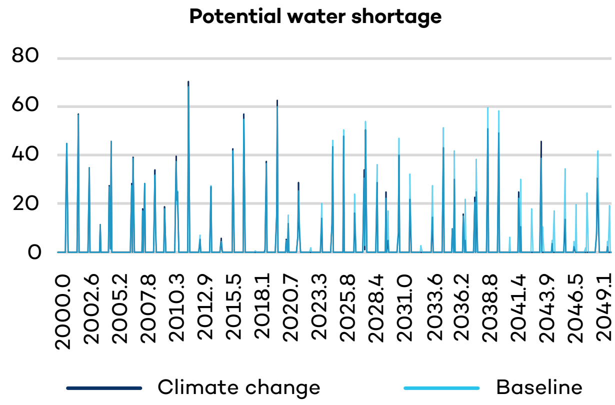


Figure 9. Pelly's Lake water stock and potential water shortage

However, as a consequence of more stable (higher) water levels, the buffering capacity of the lake and wetland in the CC scenario is potentially reduced under the most extreme events. The combination of higher water levels and increased precipitation during winter months increases the flood risk. Figure 10 illustrates the flood indicator that is determined based on precipitation relative to the baseline. The higher the value of the flood indicator, the higher the flood risk.

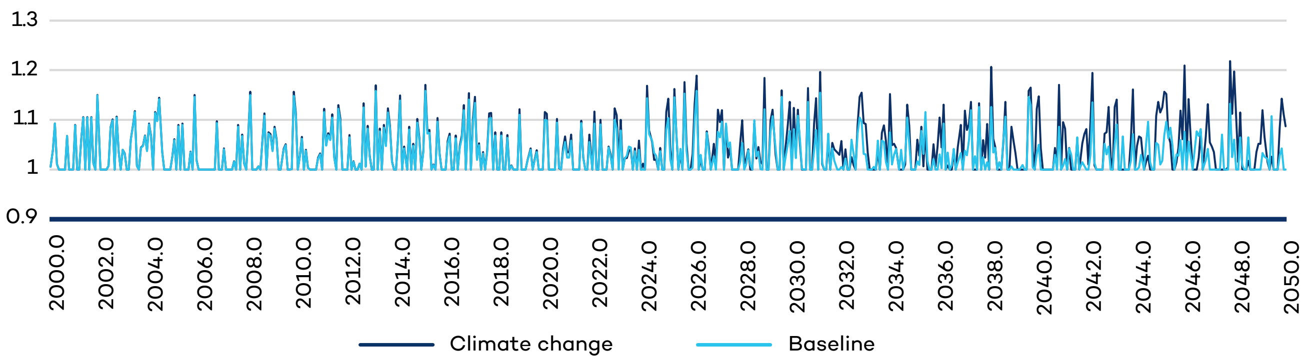


Figure 10. Flood indicator: Pelly's Lake

[4] Many of the assumptions in the Pelly's Lake assessment stem from research conducted by Berry (2016). Data sources and references are listed in Annex I.

5.2.2. ECOSYSTEM SERVICES PROVIDED BY PELLY'S LAKE

Table 9 provides an overview of selected ecosystem services from Pelly's Lake, including water storage, nutrient removal, carbon sequestration and cattail production. The simulation uses two sets of assumptions for the provision of ecosystem services (low and the high); details are provided in Section 3.

Table 9. Ecosystem services provided by Pelly's Lake (cumulative value from 2019 to 2050)

		(1) Baseline		(2) Climate change		(2) vs (1)	
Biophysical indicators	**Unit**	**Low**	**High**	**Low**	**High**	*Low*	*High*
Water storage	acre-feet	1,210	1,210	1,210	1,210	1,210	1,210
Nutrient removal*							
N removal	tonne N	1,913	120,753	1,913	120,753	*0.0%*	*0.0%*
P removal	tonne P	375	3,158	375	3,158	*0.0%*	*0.0%*
Carbon sequestration	tonne CO^2	924	936	924	936	*0.0%*	*0.0%*
Production							
*Cattail production***	tonne	56,416	67,700	56,416	67,700	*0.0%*	*0.0%*
Potential N fertilizer	tonne N	600	720	600	720	*0.0%*	*0.0%*
Potential P fertilizer	tonne P	75	225	75	225	*0.0%*	*0.0%*
Potential energy generation	GJ	959	1,354	959	1,354	*0.0%*	*0.0%*

** Carbon sequestration and nutrient removal consider the 121 ha of lake area (cattail) and 8,587 ha of watershed area (wetland).*

***Cattail production assumes that the entire surface area of cattail (lake area) is harvested.*

5.2.3 REVENUES AND COSTS OF PELLY'S LAKE

Table 9 indicates the direct revenues generated from cattail production and the maintenance costs of the Pelly's Lake basin. The simulation assumes that the entire 121 hectares of lake area is used for cattail cultivation and harvesting. The simulation also assumes that there is no difference in cattail harvesting due to climate change. As indicated in Table 10, the revenues from cattail do not cover the O&M costs of maintaining the basin.

Table 10. Direct revenues and costs Pelly's Lake (cumulative value from 2019 to 2050)

Direct benefits and costs	Unit	Discounted results		Undiscounted results	
		Low production	High production	Low production	High production
Profits from cattail production	CAD2019	97,546	117,060	879,534	1,055,441
Basin maintenance	CAD2019	176,416	176,416	342,717	342,717

5.2.4 VALUATION OF ECOSYSTEM SERVICES PROVIDED BY PELLY'S LAKE

Table 11. Valuation of ecosystem services provided by Pelly's Lake (cumulative value from 2019 to 2050)

Valuation of ecosystem services	Unit	(1) Baseline	(2) Climate change	(2) vs (1)	(3) CC + Low DR ES	(3) vs (1)
Total ecosystem services provided	**CAD2019**	**60,166,136**	**60,487,362**	*0.53%*	**81,975,765**	**36.2%**
N removal	**CAD2019**	**35,881,335**	**35,881,335**	*0.00%*	**48,608,384**	**35.5%**
Cattail	CAD2019	*11,256,883*	*11,256,883*	0.00%	15,249,688	35.5%
Other biomass	CAD2019	*24,624,452*	*24,624,452*	0.00%	33,358,696	35.5%
P removal	**CAD2019**	**11,616,224**	**11,616,224**	**0.00%**	**15,736,468**	**35.5%**
Cattail	CAD2019	*2,323,245*	*2,323,245*	0.00%	3,147,294	35.5%
Wetland	CAD2019	*9,292,979*	*9,292,979*	0.00%	12,589,174	35.5%
Carbon sequestration	**CAD2019**	**11,925,298**	**11,925,298**	**0.00%**	**16,155,181**	**35.5%**
Cattail	CAD2019	*762,314*	*762,314*	0.00%	1,032,706	35.5%
Wetland	CAD2019	*11,162,984*	*11,162,984*	0.00%	15,122,475	35.5%
Flood protection	**CAD2019**	**743,279**	**1,064,505**	**43.22%**	**1,475,732**	**98.5%**

** Carbon sequestration and nutrient removal consider 121 ha of lake area (cattail) and 8,587 ha of watershed area (wetland)*

As presented in Table 11, the cumulative value of ecosystem services provided by the lake totals CAD 60.17 million and CAD 60.49 million in the baseline and CC scenarios, respectively.

The difference between the baseline and the CC scenarios stems from increased flood protection provided by Pelly's Lake. This indicates that approximately CAD 320,200 in flood damages are mitigated in the CC scenario. This is equivalent to avoided flood damages of CAD 10,360 per year on average between 2019 and 2050. Note that the volume of rainfall does not affect the performance of the lake in terms of nutrient removal and carbon sequestration.

The third scenario provides an overview of the valuation of ecosystem services if a 2.5 per cent discount rate is applied, instead of 5 per cent (which was used in baseline and the CC scenarios). The results indicate that discounting ecosystem services at a lower rate increases their economic value by 36.25 per cent compared to the baseline scenario.

What Table 11 also shows is that there are many ecosystems services provided by Pelly's Lake, and the value of these services is significant. In the case of the CC scenario, the value of ecosystem services is higher; wetlands are indeed valuable assets to counter the impacts of extreme weather events. The food protection value comes out as the lowest because there are no residential and commercial developments around Pelly's Lake. There are also no insured assets around Pelly's Lake. Therefore, losses that are incurred in the case of flooding are lower.

5.2.5 HOW MUCH WOULD IT COST TO BUILD AND MANAGE GREY INFRASTRUCTURE THAT WILL PROVIDE THE SAME ECOSYSTEM SERVICES PROVIDED BY PELLY'S LAKE?

Table 12. Capital and O&M costs to build and operate grey infrastructure to provide the same ecosystem services as Pelly's Lake (cumulative from 2019 to 2050)

		Discounted results			Undiscounted results		
Ecosystems services	**Unit**	**(1) Baseline**	**(2) Climate change**	**(2) vs (1)**	**(1) Baseline**	**(2) Climate change**	**(2) vs (1)**
Water treatment to reduce nutrients further downstream	**mn CAD2019**	**13.88**	**13.81**	**(0.56%)**	**25.52**	**25.32**	**(0.77%)**
Capital costs	mn CAD2019	1.54	1.54	*0.00%*	1.54	1.54	*0.00%*
O&M costs	mn CAD2019	12.34	12.26	*(0.63%)*	23.98	23.78	*(0.82%)*
Carbon sequestration	**mn CAD2019**	**23.10**	**23.10**	***0.00%***	**23.10**	**23.10**	***0.00%***
Total capital costs of grey infrastructure	**mn CAD2019**	**24.65**	**24.65**	*0.00%*	**24.65**	**24.65**	*0.00%*
Total O&M costs of grey infrastructure	**mn CAD2019**	**12.34**	**12.26**	*(0.63%)*	**23.98**	**23.78**	*(0.82%)*
Total cost by scenario	**mn CAD2019**	36.99	36.91	***(0.21%)***	48.62	48.43	***(0.40%)***
Total cost CC versus Baseline	%	-0.21%			-0.40%		

Note: mn = million

Table 12 provides the capital and O&M costs required to build and operate an array of grey infrastructure that would provide the same ecosystem services as Pelly's Lake.

The total cumulative cost of this grey infrastructure is CAD 36.99 million in the baseline and CAD 36.91 million in the CC scenario. In both scenarios, capital investments represent 66.6 per cent of the total costs.

Reducing nutrients to safeguard downstream water quality requires a capital investment of CAD 1.54 million in both scenarios. The operation of these facilities requires a further CAD 12.34 million and CAD 12.26 million in O&M expenditure in the baseline and CC scenarios, respectively.

The replacement of wetland and lake as carbon sink is the highest cost item; it requires investments in the range of CAD 23.1 million in the baseline and in the CC scenario.[5]

5.2.6 CAN WE USE PELLY'S LAKE TO PROVIDE IRRIGATION SERVICES IN THE FUTURE? WHAT WOULD BE THE VALUE OF SUCH A SERVICE? TO WHAT EXTENT WILL IT CONTRIBUTE TO HIGHER AGRICULTURE OUTPUT?

Infrastructure needs in Manitoba are often related to water, including water quality management, water supply and water storage. In the region, the impacts of climate change are expected to increase risks related to floods and droughts. Agriculture is a large driver of the Manitoba economy and is largely rainfed. Climate models predict an increase in variable precipitation and a decline during the summer growing season months. Water storage across the province and watershed are emerging as essential infrastructure assets for water supply and groundwater recharge.

There are ongoing discussions around expanding agricultural irrigation in Manitoba to improve productivity and to cope with the increasing variability of water availability due to a changing climate. In light of the above, SAVi was used to simulate the value of Pelly's Lake as a provider of irrigation services in the years to come.

Table 13. Irrigation-related services that could be provided by Pelly's Lake (cumulative values from 2019 to 2050)

		(1) Baseline		(2) Climate change		(2) vs (1)	
	Unit	**Low**	**High**	**Low**	**High**	*Low*	*High*
Water demand for irrigation	acre-feet	37,200	37,200	36,786	36,786	*(1.1%)*	*(1.1%)*
Agriculture production	tonne	182,264	182,264	182,526	182,526	*0.1%*	*0.1%*

5 The installation of onshore wind is used as a comparator for the reduction of carbon dioxide emissions and for the estimation of capital and O&M costs.

Table 13 presents the volume of irrigated area that can be provided by Pelly's Lake. Table 13 also shows the tonnage of agriculture output that can be provided by the lands irrigated by Pelly's Lake.

The assumptions made for this analysis include:

- The annual water supply that could be provided by Pelly's Lake is equal to the lake's total storage volume of 1,200 acre-feet.
- Between 2019 and 2050, the cumulative water supply that could be obtained from the lake totals 37,200 acre-feet until 2050, and the corresponding enabled agriculture production totals 182,264 tonnes.

Table 14. Valuation of irrigation-derived benefits that could be provided by Pelly's Lake in the future (cumulative values from 2019 to 2050)

Irrigation-derived benefits	Unit	(1) Baseline	(2) Climate change	(2) vs (1)	(3) CC + Low DR ES	(3) vs (1)
Total benefits	**CAD2019**	**15,705,636**	**15,738,302**	***0.21%***	**15,738,302**	**0.21%**
Agriculture GDP	CAD2019	9,548,979	9,575,221	*0.27%*	9,575,221	0.27%
Tax revenues	CAD2019	1,193,622	1,196,903	*0.27%*	1,196,903	0.27%
Discretionary income[6]	CAD2019	6,156,658	6,163,082	*0.10%*	6,163,082	0.10%

Table 14 indicates the future irrigation-derived benefits that can be realized if Pelly's Lake were used for water storage and irrigation purposes in the years to come. The total value of the benefits, including agriculture GDP, tax revenues and discretionary income, reach CAD 15.7 million. In the CC scenario, the net financial benefits are 0.21 per cent, or CAD 32,666 higher compared to the baseline.

[6] Discretionary income represents the share of labour income that flows back into the economy in the form of increasing consumption. The model assumes 30 per cent of labour income as discretionary income.

Table 15. What would it cost to build grey infrastructure to provide the same irrigation and water storage services that Pelly's Lake can deliver in the years to come? (cumulative from 2019 to 2050)

		Discounted results			Undiscounted results		
Establishment cost	**Unit**	**(1) Baseline**	**(2) Climate change**	**(2) vs (1)**	**(1) Baseline**	**(2) Climate change**	**(2) vs (1)**
Irrigation	**mn CAD2019**	**0.57**	**0.57**	***(0.04%)***	**0.60**	**0.60**	***(0.09%)***
Capital	mn CAD2019	0.54	0.54	*0.00%*	0.54	0.54	*0.00%*
O&M	mn CAD2019	0.03	0.03	*(0.63%)*	0.06	0.06	*(0.82%)*
Water storage	mn CAD2019	**0.06**	**0.06**	*0.00%*	**0.06**	**0.06**	*0.00%*
Capital	mn CAD2019	0.06	0.06	*0.00%*	0.06	0.06	*0.00%*
O&M	mn CAD2019	0.00	0.00	*N/A*	0.00	0.00	*N/A*
Total capital costs of replacement	mn CAD2019	**0.60**	**0.60**	*0.00%*	**0.60**	**0.60**	*0.00%*
Total O&M costs of replacement	mn CAD2019	**0.03**	**0.03**	*(0.63%)*	**0.06**	**0.06**	*(0.82%)*
Total cost by scenario	**mn CAD2019**	0.63	**0.63**	***(0.03%)***	0.66	**0.66**	***(0.08%)***
Total cost CC versus Baseline	%	(0.03%)			(0.08%)		

In addition, Pelly's Lake could serve as a buffer for storing and provisioning water for irrigation in years to come. Pelly's Lake hence provides irrigation-related services in addition to the ones listed and assessed in Table 16.

Table 16. Valuation of the ecosystem services provided by Pelly's Lake

Benefits and ecosystem services valuation	Unit	Discounted results (1) Baseline	(2) Climate change	(2) vs (1)	Undiscounted results (1.1) Baseline	(2.1) Climate change	(2.1) vs (1.1)
Direct revenues and cost							
Cattail value added	CAD2019	97,546	97,546	0.00%	879,534	879,534	0.00%
O&M costs	CAD2019	176,416	176,416	0.00%	342,717	342,717	0.00%
Added benefits							
Nutrient removal	CAD2019	47,497,559	47,497,559	0.00%	92,271,379	92,271,379	0.00%
Carbon sequestration	CAD2019	11,925,298	11,925,298	0.00%	23,167,064	23,167,064	0.00%
Flood protection	CAD2019	743,279	1,064,505	43.22%	1,386,960	2,157,886	55.58%
Costs of building grey: Replacement cost with built infrastructure							
Waste water	CAD2019	13,884,979	13,807,278	(0.56%)	25,519,747	25,323,302	(0.77%)
Carbon sequestration	CAD2019	23,104,923	23,104,923	0.00%	23,104,923	23,104,923	0.00%

Using the lake as a water storage and irrigation asset provides benefits in the range of CAD 18.5 million, for both agriculture production and income creation (see Table 17). The provision of water storage and irrigation with built infrastructure would require investments of around CAD 0.8 million and CAD 63,854 in irrigation and water storage infrastructure, respectively.

Table 17. Value of untapped future irrigation-related services that could be derived from Pelly's Lake (cumulative from 2019 to 2050)

Benefits and ecosystem services valuation	Unit	(1) Baseline	(2) Climate change	(2) vs (1)	(1.1) Baseline	(2.1) Climate change	(2.1) vs (1.1)
Added benefits							
Agriculture	CAD2019	15,705,636	15,738,302	0.21%	18,549,218	18,619,478	0.38%
Replacement cost							
Irrigation	CAD2019	567,962	567,760	(0.04%)	598,269	597,757	(0.09%)
Water storage	CAD2019	63,854	63,854	0.00%	63,854	63,854	0.00%

This analysis estimates the ecosystem and infrastructure benefits of Pelly's Lake; however, it should be noted that the economic value generated by these ecosystem services require other types of industrial and economic inputs, which have not been included in their entirety.

We also need to point out that not all economic benefits are entirely enabled by Pelly's Lake and that not all the ecosystem services provided by the lake would need to be replaced with built infrastructure. Nevertheless, the differential between the costs of maintaining the lake and the value it brings remains considerable.

This is most evident when considering the cost of building new infrastructure to provide the same services as currently provided by Pelly's Lake: CAD 0.63 million. And if we want to build infrastructure to provide the same volume of untapped irrigation services that could be provided by Pelly's Lake in years to come, it would cost CAD 15.7 million.

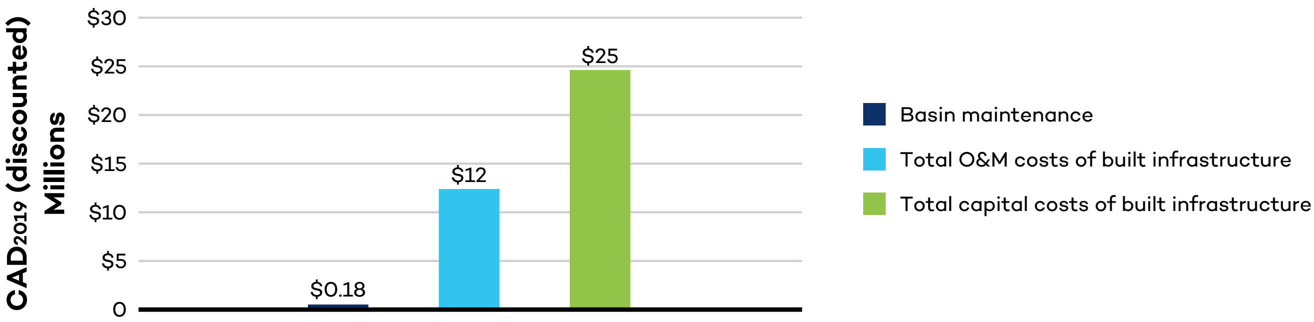


Figure 11. Comparing the capital and operating costs of built or grey infrastructure to provide the same services provided by Pelly's Lake (cumulative values from 2019 to 2050)

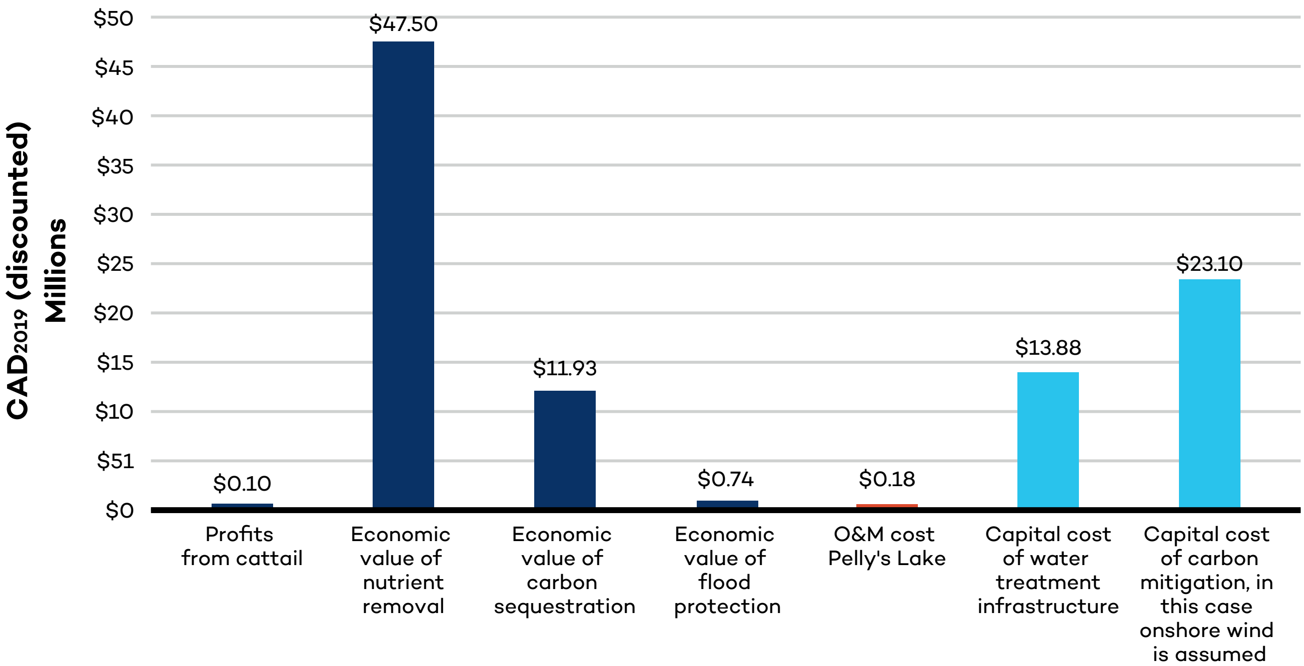


Figure 12. Breakdown of costs and benefits derived from Pelly's Lake (cumulative values from 2019 to 2050)

6.0 Final Remarks

"Retain what you have, restore what you've lost, and build what you must" —Moudrak et al. (2018)

This assessment used the SAVi to understand the costs and benefits of two Manitoba infrastructure assets—Stephenfield Reservoir (built) and Pelly's Lake (natural)—to develop a case for support for maintaining water storage assets based on the value of benefits and services from them. The assessment demonstrates the value of protecting natural assets and investing in NI more broadly, to provide infrastructure services with valuable environmental benefits. In addition, this SAVi assessment shows the costs and benefits of NI in climate adaptation, mitigating impacts of extreme weather events and providing additional benefits (ICF, 2018; Moudrak et al., 2018). Both of these aspects are critically important as policy-makers grapple with the rising costs of extreme weather events and the resulting rising insurance premiums, increased spending on the maintenance of public assets and much more.

In the case of Stephenfield Reservoir, which is a built asset and where the surroundings have become naturalized over time, the SAVI analysis confirms its value-add on water storage and supply. The focus should not exclusively be on revenues and costs, but include economic benefits enabled by the reservoir through the storage and provision of water. When comparing the costs of building grey infrastructure to provide the same volume of services that are currently provided by Stephenfield Reservoir, the story is even more compelling. The reservoir costs CAD 0.256 million to operate and maintain, while grey infrastructure would cost CAD 5.33 million to build and CAD 0.3 million to maintain. Manitoba and all its stakeholders are thus well served by spending CAD 16,000 per year to maintain Stephenfield Reservoir today and in the years to come.[7]

Pelly's Lake, on the other hand, is a natural wetland that is actively managed to provide water storage, nutrient filtration, carbon sequestration, wildlife habitat and biodiversity, and cattail as a raw material for various uses. Based on the SAVi analysis, Pelly's Lake currently operates at higher costs than the revenues from marketable benefits (such as those created by the use of cattail). However, the value of additional benefits from ecosystem services, including nutrient removal, carbon sequestration and flood protection, are significant, far outweighing its O&M costs. The value of Pelly's Lake is even more compelling if we compare it to the cost of building and operating grey infrastructure to provide the same services. The lake costs CAD 0.18 million to operate and maintain, while grey infrastructure would cost CAD 25 million to build and CAD 12 million to maintain. LSRCD and its many stakeholders are thus well served by spending 0.18 million on maintaining the lake today and in years to come. This is especially true given the high valuations of the lake as a water storage and irrigation asset in the future. Irrigation is a key adaptation measure in response to variability in water for agriculture. In a time of changing climates, the value of water storage across the landscape is certainly set to increase.

Both of these SAVi assessments demonstrate an incentive to retain and manage existing built infrastructure and retain and restore NI to meet infrastructure demands today and in the future.

[7] Annual O&M costs of Stephenfield Reservoir are CAD 16,000 (see Annex I for more details). Discounted at 5 per cent, the cumulative total cost between 2019 and 2050 is equal to CAD_{2019} 256,005.

References

Agriculture and Agri-Food Canada. (2015). Impact of climate change on Canadian agriculture. Retrieved from http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/climate-change-and-agriculture/future-outlook/impact-of-climate-change-on-canadian-agriculture/?id=1329321987305

AgriLIFE Extension. (2011). *Economics of irrigation systems*. Texas A&M AgriLife Communications.

Ansari, A.A., & Gill, S.S. (2014). *Eutrophication: Causes, consequences and control (Volume 2)*. Spring Science + Business Media Dordrecht.

Badiou, P., McDougal, R., Pennock, D., & Clark, B. (2011). Greenhouse gas emissions and carbon sequestration potential in restored wetlands of the Canadian prairie pothole region. *Wetlands Ecology and Management, 19*(3): 237-257. doi: 10.1007/s11273-011-9214-6

Berry, P. (2016). *An economic assessment of on-farm surface water retention systems*. Saskatoon: School of Environment and Sustainability, University of Saskatchewan.

Berry, P., Yassin, F., Belcher, K., & Lindenschmidt, K-E. (2017). An economic assessment of local farm multi-purpose surface water retention systems under future climate uncertainty. *Sustainability*. 9(456). doi: 10.3390/su9030456

Clarkson, R. & Deyes, K. (2002). *Estimating the social cost of carbon emissions, economic service*. Retrieved from http://www.civil.uwaterloo.ca/maknight/courses/CIVE240-05/week3/carbon%20social%20cost.pdf

Dion, J., & McCandless, M. (2013). *Cost-benefit analysis of three proposed distributed water storage options for Manitoba*. Retrieved from https://www.iisd.org/sites/default/files/publications/mb_water_storage_options.pdf

Donahue, W. F. (2013). *Determining appropriate nutrient and sediment loading coefficients for modeling effects of changes in landuse and landcover in Alberta watersheds*. Canmore: Water Matters. Retrieved from https://www.alces.ca/reports/download/383/Determining-Appropriate-Nutrient-and-Sediment-Loading-Coefficients-for-Modeling-Effects-of-Changes-in-Landuse-and-Landcover-in-Alberta-Watersheds--Donahue-2013-.pdf

Ducks Unlimited Canada. (n.d.). *The impacts of wetland loss in Manitoba*. Retrieved from https://www.gov.mb.ca/waterstewardship/iwmp/willow_creek/documentation/ducks.pdf

Environment Canada & Manitoba Water Stewardship. (2011). *State of Lake Winnipeg: 1999 to 2007*. Retrieved from https://www.gov.mb.ca/waterstewardship/water_quality/state_lk_winnipeg_report/pdf/state_of_lake_winnipeg_rpt_technical_high_resolution.pdf

Environment Canada. (2016). *National inventory report 1990–2014: Greenhouse gas sources and sinks in Canada*. Retrieved from http://publications.gc.ca/collections/collection_2016/eccc/En81-4-1-2014-eng.pdf

Forrester, J.W. (1961). *Industrial dynamics*. Cambridge, MA: MIT Press.

Government of Manitoba. (2005). *The camper's guide*. Retrieved from https://www.gov.mb.ca/sd/parks/pdf/brochures/campers_guide.pdf

Government of Manitoba. (2011). The Save Lake Winnipeg Act Ch. 36. Retrieved from http://web2.gov.mb.ca/laws/statutes/2011/c03611e.php.

Government of Manitoba. (2015). *Guidelines for estimating crop production costs 2015*. Retrieved from https://digitalcollection.gov.mb.ca/awweb/pdfopener?smd=1&did=23977&md=1

Grosshans, R. E., Venema, H. D., Cicek, N., & Goldsborough, G. (2011). *Cattail farming for water quality: Harvesting cattails for nutrient removal and phosphorus recovery in the watershed*. Paper presented at WEF-IWA Nutrient Recovery and Management, Miami, Florida.

Grosshans, R.E., Gass, P., Dohan, R., Roy, D., Venema, H.D., & McCandless, M. (2013). *Cattail harvesting for carbon offsets and nutrient capture: A "lake friendly" greenhouse gas project*. Retrieved from https://www.iisd.org/sites/default/files/publications/cattail_harvesting_carbon_offsets.pdf

Grosshans, R.E., Grieger, L., Ackerman, J., Gauthier, S., Swystun, K., Gass, P., & Roy, D. (2014). *Cattail biomass in a watershed-based bioeconomy: Commercial-scale harvesting and processing for nutrient capture, biocarbon and high-value bioproducts*. Retrieved from https://www.iisd.org/sites/default/files/publications/cattail-biomass-watershed-based-bioeconomy-commerical-scale-harvesting.pdf

Grosshans, R.E., & Roy, D. (2017). *How to best manage water retention sites to protect Manitoba's environment*. Retrieved from https://www.iisd.org/sites/default/files/publications/best-manage-water-retention-manitoba.pdf

ICF. (2018). *Best practices and resources on climate resilient natural infrastructure*. Prepared for Canadian Council of Ministers of the Environment. Retrieved from https://www.ccme.ca/files/Resources/climate_change/Natural_Infrastructure_Report_EN.pdf

International Energy Agency (IEA). (2014). World energy investment outlook 2014: Cost assumptions. In *World Energy Investment Outlook 2014*. Paris: IEA.

International Energy Agency. (2017, 11). Energy Snapshot: Marginal abatement cost curve for oil & gas related methane emissions, 2015. Retrieved from https://www.iea.org/newsroom/energysnapshots/marginal-abatement-cost-curve-for-oil-and-gas-methane-related-emissions.html

Iglesias, R., Ortega, E., Batanero, G., & Quintas, L. (2010). Water reuse in Spain: Data overview and costs estimation of suitable treatment trains. *Desaliniation*, *263*(1–3), 110. doi: 10.1016/j.desal.2010.06.038

Informa Economics. (2014). *The economic contributions of the Manitoba Potato Complex*. Retrieved from https://www.potatopro.com/sites/default/files/pictures/the-economic-contribution-of-manitoba-potato-production-november-26-2014.pdf

Intergovernmental Panel on Climate Change. (2007). Summary for policymakers. In: Solomon, S., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), *Climate change 2007: The physical science basis*. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY. doi:10.1038/446727a

Karras Spangelo, P. (1991). Memorandum: Stephenfield Reservoir, Development of the Current Stephenfield Rule Curve.

Kling, H.J., Watson, S.B., McCullough, G.K., & Stainton, M.P. (2011). Bloom development and phytoplankton succession in Lake Winnipeg: A comparison of historical records with recent data. *Aquatic Ecosystem Health and Management, 14*(2), 219–224.

Kraus, D. (2016, Updated 2018). Why Canada's prairies are the world's most endangered ecosystem. Nature Conservancy of Canada. Retrieved from http://www.natureconservancy.ca/en/blog/archive/grasslands-the-most.html#.XDUfzvZFyM8

La Salle Redboine Conservation Distric.t (LSRCD). (2013). *Pelly's Lake Watershed Management Area*. Manitoba: LSRCD.

Liu, M., Tian, H., Chen, G., Ren, W., Zhang, C., & Liu, J. (2008). Effects of land-use and land-cover change on evapotranspiration and water yield in China during 1900-2000. *Journal of American Water Resources Association, 44*(5), 1193–1207.

Manitoba Sustainable Development. (2017). *A Made-in-Manitoba Climate and Green Plan*. Retrieved from https://www.gov.mb.ca/asset_library/en/climatechange/climategreenplandiscussionpaper.pdf

Manitoba Sustainable Development. (2018). *Towards 'no net loss' of wetland benefits in Manitoba*. Presentation by Andrea McLean. Retrieved from https://www.phjv.ca/wp-content/uploads/2018/09/McLean-Towards-No-Net-Loss-of-Wetland-Benefits-in-MB.pdf

Martin, D., Dorn, T., Melvin, S., Corr, A., & Kranz, W. (2011). Evaluating energy use for pumping irrigation water. *Proceedings of the 23rd Annual Central Plains Irrigation Conference*. Retrieved from https://www.ksre.k-state.edu/irrigate/oow/p11/Kranz11a.pdf

Moudrak, N., Feltmate, B., Venema, H., & Osman, H. (2018). *Combating Canada's rising flood costs: Natural infrastructure is an underutilized option*. Prepared for Insurance Bureau of Canada. Waterloo: Intact Centre on Climate Adaptation, University of Waterloo.

Manitoba Water Stewardship. (2005). *Stephenfield Lake Watershed Management Plan*. Retrieved from https://www.gov.mb.ca/waterstewardship/reports/watershed/stephenfield_wmp_2005-06.pdf

Neuvoo. (2019). Average salary food processing plant Manitoba – State 02/2019. Retrieved from https://neuvoo.ca/salary/?job=food+processing+plant

North American Regional Reanalysis (NARR). (n.d.). Monthly average of daily precipitation for Stephenfield Reservoir and Pelly's Lake from 1979 to 2018. NARR data provided by the NOAA/OAR/ESRL PSD. Retrieved from https://www.esrl.noaa.gov/psd/

O'Brien, D., Dumler, T., & Rogers, D. (2011). *Irrigation capital requirements and energy costs*. Retrieved from http://www.waterandenergyprogress.org/library/irrigationcosts.pdf

Olewiler, N. (2004). *The value of natural capital in settled areas of Canada*. Ducks Unlimited Canada and the Nature Conservancy of Canada. Retrieved from https://www.cmnbc.ca/wp-content/uploads/2018/11/natural20capital_0.pdf

Pembina Valley Water Cooperative (PVWC). (2019). *Pembina Valley Water Cooperative Inc. Annual compliance report 2018*. Retrieved from https://pvwc.ca/wp-content/uploads/2015/02/Annual-Report-2018.pdf

Penner, D. (2018). Water co-op is ready for drought situation. *Pembina Valley Online*. Retrieved from https://pembinavalleyonline.com/local/water-co-op-is-ready-for-drought-situation

Prairie Farm Rehabilitation Administration. (1961). *Boyne River Project, Stephenfield Dam (Site 4)* (Interim Engineering Report No.2). Department of Agriculture, Engineering Branch.

Prairie Farm Rehabilitation Administration. (2007). *Town of Carman – Water supply study*. Winnipeg: Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration.

PotatoPro. (2018). Potato sector statistics. Retrieved from https://www.potatopro.com/manitoba/potato-statistics

Prairie Climate Centre. (2018). *Manitoba and climate change*. Retrieved from https://climateatlas.ca/sites/default/files/Manitoba-Report_FINAL_EN.pdf

Province of Manitoba. (2019). Corporate income taxes. Retrieved from https://www.gov.mb.ca/finance/business/ctaxes.html

Roy, D., & Grosshans, R. (2017). *How to best manage water retention sites to protect Manitoba's environment*. IISD. Retrieved from https://www.iisd.org/sites/default/files/publications/best-manage-water-retention-manitoba.pdf

Samarawickrema, A., & Kulshreshtha, S. (2009). Marginal value of irrigation water use in the South Saskatchewan River Basin, Canada. *Great Plains Research: A Journal of Natural and Social Sciences, 19*(1).

Sauer, T., Havlik, P., Schneider, U., Schmid, E., Kindermann, G., & Obersteiner, M. (2010). Agriculture and resource availability in a changing world: The role of irrigation. *Water Resources Research, 46*(6). doi:10.1029/2009WR007729

Schindler, D.W. (2012). The dilemma of controlling cultural eutrophication of lakes. *Proceedings of the Royal Society B: Biological Sciences*. Retrieved from http://doi.org/10.1098/rspb.2012.1032

Schindler, D.W., Hecky, R.E., & McCullough, G.K. (2012). The rapid eutrophication of Lake Winnipeg: Greening under global change. *Journal of Great Lakes Research, 38*, 6–13.

Stanley, M., Puzyreva, M., & Roy, D. (2019). *Advancing natural infrastructure in Canada: A forum report*. Winnipeg: International Institute for Sustainable Development.

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Boston: Irwin/McGraw-Hill.

Stephenfield Lake Watershed Round Table. (2005). *Stephenfield Lake Watershed Management Plan*. Retrieved from https://www.gov.mb.ca/waterstewardship/reports/watershed/stephenfield_wmp_2005-06.pdf

Stewart, C. (2018, November 14). Elevated climate risks and implication for the insurance sector (PowerPoint). Paper presented at Advancing Natural Infrastructure in Canada Forum, Winnipeg, Manitoba. Retrieved from https://www.iisd.org/sites/default/files/meterial/Craig%20Stewart%2C%20Insurance%20Bureau%20of%20Canada%202018.pdf

Tetra Tech. (2011). *Technical and economic evaluation of nitrogen and phosphorus removal at municipal wastewater treatment facilities*. Retrieved from https://fortress.wa.gov/ecy/publications/publications/1110060.pdf

Water Science and Watershed Management Branch. (n.d.). 2002 to 2003, Stephenfield Reservoir water quality data. Winnipeg: Manitoba Sustainable Development.

Wilson, S. J. (2008). *Lake Simcoe basin's natural capital: The value of the watershed's ecosystem services*. Retrieved from https://davidsuzuki.org/wp-content/uploads/2008/06/lake-simcoe-basin-natural-capital-value-watershed-ecosystem-services.pdf

Annex I: Assumptions and Data Sources

Stephenfield Reservoir

Variable	Unit	Parameter value	Source
Number of licences for water supply	licences	2,000 (year 2,000 assumption made for model calibration)	Assumption based on population. Population data from 2005 indicates 3,885 people (Stephenfield Lake Watershed Round Table, 2005).
Cost per licence	CAD/licence	2.5	Spreadsheet indicates a value of CAD 25 per licence, and a duration of 10 years. A cost of CAD 2.5 per licence is used to reflect the fact that licences are not renewed every year. The revenues from licences are hence annualized.
Number of tourist nights	nights/year	3,400	Manitoba Water Stewardship, 2005
Fee per night	CAD/night	11	Government of Manitoba, 2005
Annual O&M Stephenfield	CAD/year	16,000	2% of initial capital investment according to 1962 construction costs (PFRA, 1961)

Category	Variable	Unit	Value model	Source
Water supply	Average cost of water storage per acre-feet	CAD/acre-feet	2,000	Personal communication, Oshani Perera, May 2017
	Reservoir share of demand	%	20%	Assumption
Irrigation	Capital cost: Flood	CAD/hectare	80	O'Brien, Dumler, & Rogers, 2011
	Marginal O&M cost: Flood	CAD/hectare	0.3	Samarawickrema & Kulshreshtha, 2009

Variable	Unit	Value	Source
Lake area	km^2	3.7	Berry, 2016
Estimated storage capacity at full supply	acre-feet	3,690	PFRA, 1961; Stephenfield Lake Watershed Round Table, 2005
Seasonal precipitation[8]	mm/hectare/month	Initial: 25.42 Minimum: 18.00 Maximum: 98.31	Based on data from North American Regional Reanalysis (NARR, n.d.) (Stephenfield Reservoir 49.525−98.293)

Variable	Unit	Value	Source
Water demand per capita	litre/person/year	140,542	Berry, 2016
Initial population	person	3,885	Stephenfield Lake Watershed Round Table, 2005, based on 2001 census
Distribution of municipal water demand	mm/hectare	See spreadsheet	Karras Spangelo, 1991

Variable	Unit	Value	Source
Irrigation efficiency			
Flood	%	25%	Sauer et al., 2010
Sprinkler*	%	64%	Sauer, et al., 2010
Drip*	%	82%	Sauer, et al., 2010
Average water demand per hectare	acre-feet/month	See spreadsheet	Spreadsheet
Desired share of land irrigated	%	100	Assumption

**blue parameters not used in analysis*

[8] Minimum and maximum values reported in this table consider the projections between 2019 and 2050.

Variable	Unit	Value	Source
Capital expenditure			
Flood	CAD/hectare	80	O'Brien, Dumler, & Rogers, 2011
Sprinkler*	CAD/Hectare	1,500	AgriLIFE Extension, 2011
Drip*	CAD/Hectare	2,885	AgriLIFE Extension, 2011

**blue parameters not used in analysis*

Variable	Unit	Value	Source
Initial forest land	acres	31,527	Stephenfield Lake Watershed Round Table, 2005
Initial agriculture land (agriculture cropland, including annual crops, forages and grasslands)	acres	192,045	Stephenfield Lake Watershed Round Table, 2005
Initial urban land	acres	8,320	Stephenfield Lake Watershed Round Table, 2005

Variable	Unit	Value	Source
Average yield agriculture land	tonne/ hectare/year	7.06	Based on PotatoPro, 2018
Average value added per ton	CAD/tonne/ year	262.211	Based on Informa Economics, 2014; PotatoPro, 2018
Average employment per hectare	person/ hectare	0.111748	Based on Informa Economics, 2014
Manitoba tax rate	%	12.5%	Province of Manitoba, 2019
Average income per person	CAD/person/ year	38,000	neuvoo, 2019

Pelly's Lake

Variable	Unit	Parameter value	Source
Cost per licence	CAD/licence	2.5	A cost of CAD 2.5 per licence is used to reflect the fact that licenses are not renewed every year. The revenues from licences are hence annualized. (personal communication, M. Stanley, August 13, 2018)
Annual O&M Pelly's Lake	CAD/year	11,025.8	2% of initial capital investment according to construction costs (Berry, 2016; LSRCD, 2013)

Category	Variable	Unit	Value	Source
Irrigation	Capital cost: Flood	CAD/hectare	80	O'Brien, Dumler, & Rogers, 2011
	Marginal O&M cost: Flood	CAD/hectare	0.3	Based on Samarawickrema & Kulshreshtha, 2009
Wastewater treatment	Capital cost N removal	CAD/kg	25	Tetra Tech, 2011
	O&M cost N removal	CAD/kg/year	12.5	Tetra Tech, 2011
	Capital cost P removal	CAD/kg	46	Tetra Tech, 2011
	O&M cost P removal	CAD/kg/year	10	Tetra Tech, 2011
Carbon offset	Costs per tonne of CO2 abated	CAD/tonne	25	Based on the carbon offset credit in Berry, 2016

Variable	Unit	Value	Source
Lake area	km^2	1.21	Berry, 2016
Estimated storage capacity at full supply	acre-feet	1,210	Grosshans & Roy, 2017
Seasonal precipitation[9]	mm/hectare/month	Initial: 25.42 Minimum: 18.00 Maximum: 98.31	Based on data from NARR, n.d. (Pelly's Lake 49.581–98.813)

Variable	Unit	Value	Source
Irrigation efficiency			
Flood	%	25%	Sauer, et al., 2010
Sprinkler*	%	64%	Sauer, et al., 2010
Drip*	%	82%	Sauer, et al., 2010
Water supply per year (potential)	acre-feet/year	1,210	Grosshans & Roy, 2017
Desired share of land irrigated	%	100	Assumption

**blue parameters not used in analysis*

Variable	Unit	Value model	Value report	Source
Capital expenditure				
Flood	CAD/hectare	80	-	O'Brien, Dumler, & Rogers, 2011
Sprinkler*	CAD/hectare	1,160	1,155.39	AgriLIFE Extension, 2011
Drip*	CAD/hectare	2,494	2,493.61	

**blue parameters not used in analysis*

[9] Minimum and maximum values reported in this table consider the projections between 2019 and 2050.

Variable	Unit	Value	Source
Lake area	hectare	121	Berry, 2016
Area used for cattail production	hectare	121	Whole lake area assumed (Berry et al. 2017)
N removal per ha of cattail	Kg N/hectare/year	160	Berry, 2016; Grosshans et al. 2014
Average wetland N removal rate per ha low case	Kg N/hectare/year	350	Berry, 2016; Olewiler 2004; Wilson 2008
Average wetland N removal rate per ha high case	Kg N/hectare/year	32,000	
P removal per ha of cattail low case	Kg P/hectare/year	20	Berry, 2016; Grosshans et al. 2014
P removal per ha of cattail high case	Kg P/hectare/year	60	
Average wetland P removal rate per ha low case	Kg P/hectare/year	80	Berry, 2016; Oetwiler 2004
Average wetland P removal rate per ha high case	Kg P/hectare/year	770	

Variable	Unit	Value	Source
CO_2 equivalent (CO_2e) removed per tonne of dry cattail	tonne/hectare/year	1.05	Dion & McCandless 2013; Grosshans et al., 2012
Carbon sequestration per ha of wetland	tonne/hectare/year	3.25	Badiou, McDougal, Pennock, Clark, 2011; Berry et al., 2017)
Social cost of carbon per tonne of CO_2e	CAD/tonne	64	Berry et al., 2017; Clarkson & Deyes, 2002; Intergovernmental Panel on Climate Change, 2007; Wilson 2008
Manitoba carbon offset per tonne of CO_2e	CAD/tonne	25	Berry, 2016

Variable	Unit	Value	Source
Area used for cattail production	hectare	121	Arc GIS, Berry et al., 2017
Cattail yield (dry biomass) low case	tonne/ hectare/year	15	Berry, 2016
Cattail yield (dry biomass) high case	tonne/ hectare/year	18	Berry, 2016
Cattail value per tonne	CAD/tonne	50	Berry, 2016
Costs per tonne of cattail harvested	CAD/tonne	34.41	Dion & McCandless, 2013, Grosshans et al. 2013
N removal per tonne of cattail	Kg N/tonne/ year	160	Berry, 2016; Grosshans et al. 2014
Energy content per tonne of cattail (dry) low	GJ/tonne	17	Berry, 2016; Grosshans et al., 2014
Energy content per tonne of cattail (dry) high	GJ/tonne	20	Berry, 2016; Grosshans et al. 2014

Variable	Unit	Value	Source
Alfalfa			
Land use	hectare	736.74	Based on Berry et al., 2017
Average yield	tonne/ hectare/year	6.72	Berry, 2016
Average sales price	CAD/tonne	132.28	Berry, 2016; Government of Manitoba, 2015
Average production cost	CAD/hectare	534.93	Berry, 2016
Average labour income	CAD/person/ year	38,000	neuvoo, 2019
Average employment per hectare	person/ hectare/year	0.111748	*See Potato section*
Barley			
Land use	hectare	334.88	Based on Berry, Yassin, Belcher, & Lindenschmidt, 2017
Average yield	tonne/ hectare/Year	3.77	Berry, 2016
Average sales price	CAD/tonne	173.23	Berry, 2016; Government of Manitoba, 2015
Average production cost	CAD/hectare	534.93	Berry, 2016
Average labour income	CAD/person/ year	38,000	neuvoo, 2019
Average employment per hectare	person/ hectare/year	0.111748	*See Potato section*
Canola			
Land use	hectare	3,080.93	Based on Berry et al., 2017
Average yield	tonne/ hectare/year	2.24	Berry, 2016
Average sales price	CAD/tonne	418.87	Berry, 2016; Government of Manitoba, 2015
Average production cost	CAD/hectare	534.93	Berry, 2016
Average labour income	CAD/person/ year	38,000	neuvoo, 2019
Average employment per hectare	person/ hectare/year	0.111748	*See Potato section*

Variable	Unit	Value	Source
Potato			
Land use	hectare	0	Based on Berry et al., 2017
Average yield	tonne/hectare/year	17.96	PotatoPro, 2018
Average value added	CAD/tonne	262.21	Informa Economics, 2014
Average labour income	CAD/person/year	38,000	neuvoo, 2019
Average employment per hectare	person/hectare/year	0.111748	Full supply chain employment from potato production assumed based on Informa Economics, 2014
Spring wheat			
Land use	hectare	2,545.11	Based on Berry et al., 2017
Average yield	tonne/hectare/year	3.36	Berry, 2016
Average sales price	CAD/tonne	238.83	Berry, 2016; Government of Manitoba, 2015
Average production cost	CAD/hectare	534.93	Berry, 2016
Average labour income	CAD/person/year	38,000	neuvoo, 2019
Average employment per hectare	person/hectare/year	0.111748	*See Potato section*

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