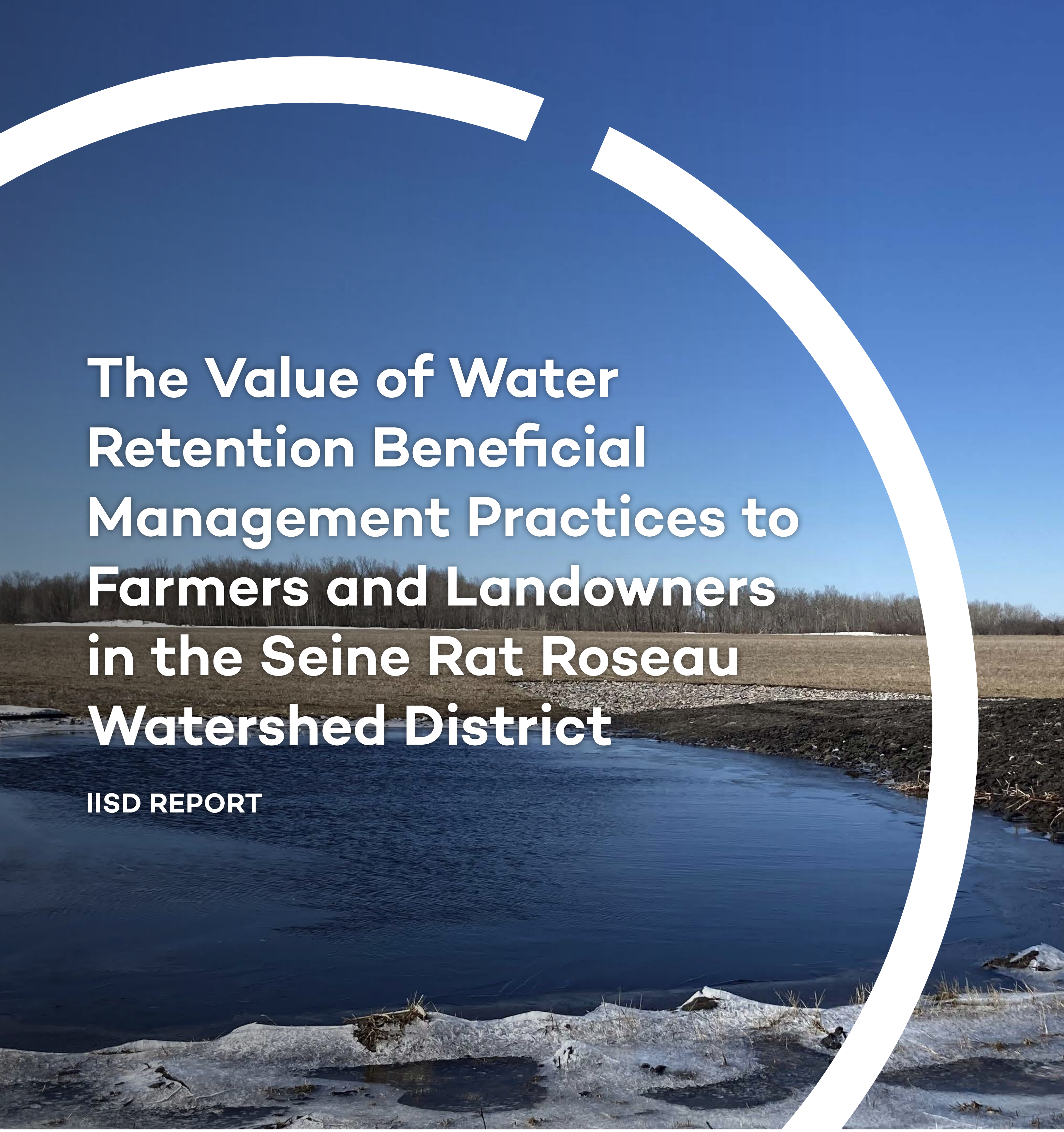

The Value of Water Retention Beneficial Management Practices to Farmers and Landowners in the Seine Rat Roseau Watershed District

IISD REPORT

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Seine Rat Roseau Watershed District (SRRWD)

The SRRWD plans and undertakes projects within the Watershed District aimed at the long-term sustainable use and management of land and water resources. The district is made up of three (3) watersheds, including the Seine River, Rat River, and Roseau River.

The SRRWD operates under the authority of the Watershed Districts Act and Regulations and correspondingly follows the WD Program Mandate to support and promote the sustainable management of the land, water and related resources in Manitoba.

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November 2022

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For the Seine Rat Roseau Watershed District

Photo: SRRWD

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1.0 Project Background

Considering the increasing frequency and length of droughts as well as a greater potential for flash floods in Manitoba, water retention projects are an important option to help agricultural producers maintain productivity on their farms while also providing benefits to the local watershed. The preliminary results from the Living Lab – Eastern Prairies (LLEP) socio-economic survey suggest that the main barriers to general adoption of Beneficial Management Practices (BMPs) in Manitoba are high upfront and longer-term maintenance costs, lack of financial assistance, lack of time, and uncertainty about economic benefits (Puzyreva et al., 2022). Based on these findings, there is a need to examine the costs and benefits of water retention more closely—specifically by assessing the upfront and maintenance costs of BMPs in Manitoba, reviewing available financial assistance, and estimating economic benefits of water retention to producers and the watershed.

Figure 1. Example of an on-farm water retention project in the SRRWD

Source: SRRWD.

In 2022, the International Institute for Sustainable Development (IISD), Seine Rat Roseau Watershed District (SRRWD), and Agriculture and Agri-Food Canada (AAFC) LLEP economic team collected cost, benefit, and other related information for **10 water retention projects** constructed in the Seine, Rat, and Roseau watersheds in Manitoba to **better understand their costs and benefits** and communicate these findings to producers.

2.0 Context

2.1 Climate Risks and Water Retention in Manitoba

Climate change is a significant risk to agricultural producers across the Prairies. In Canada, the Prairies are warming more quickly than many other regions outside of the Arctic (Bush & Lemmen, 2019), and if unaddressed, the predicted increases in heat waves, droughts, floods, and severe storms threaten the productivity and livelihood of Canadian producers (Laforge et al., 2021). The severe drought conditions of 2021, with record temperatures and wildfires, caused widespread crop failure and feed shortages for livestock (Nickel, 2021; Rosen, 2021). Although prairie drought historically occurs every 20–30 years, climate scientists warn that drought events similar to that of 2021 will become increasingly frequent (Laforge et al., 2021). Sauchyn et al. (2020) predict that annual precipitation will increase, although it is expected to accumulate in the winter and spring; wetter springs will transition to drier summers and falls. Increased extreme rainfall events, along with the likelihood of high spring runoff, will put agricultural land at greater risk of flooding (Sauchyn et al., 2020). Ironically, climate change will increase the risk of both flooding and drought (Sauchyn et al., 2020).

The province of Manitoba recognizes the growing threat of climate change to the environment, economy, and its residents. In response, Manitoba released its 2017 *Made-In-Manitoba Green Plan*, which aims to make Manitoba Canada's cleanest, greenest, and most climate-resilient province, with a focus on four pillars: Climate, Jobs, Water, and Nature (Manitoba Sustainable Development, 2017). The plan provides a framework to support climate change adaptation and specifically commits to no net loss of water retention, by keeping water on the landscape for improved water quality and resilience to flood and drought. Water retention projects are suggested to enhance resilience and provide benefit to agricultural producers and local communities. Manitoba supports the development of "multi-purpose, multi-scale retention systems that allow water to be stored on the landscape, thereby reducing local flooding, and also providing extra water that can be distributed during times of drought" (Manitoba Sustainable Development, 2017, p. 37). An updated Provincial Water Management Strategy, currently under development via the *Made-In-Manitoba Green Plan*, is anticipated for release in 2022. Based on the public engagement completed in 2021, water retention projects were listed as an important consideration in building climate change resilience (Government of Manitoba, 2021).

2.2 Funding Support for Producers

The Growing Outcomes for Watershed (GROW) program, established under the *Made-In-Manitoba Green Plan*, partners with the Watershed Districts to compensate producers for projects on their land that provide ecological goods and services. The SRRWD, for example, currently funds 80% to 100% of the cost of a water retention structure and pays CAD 15 to CAD 30 per year per acre of land that is back flooded after installation (SRRWD, 2021).

3.0 Methods

To collect data for the purpose of this project, the SRRWD, IISD, and AAFC LLEP economic team developed two questionnaires:

1. **Questionnaire for producers who had water retention projects installed on their farms:** This questionnaire collected data on farm operation along with costs and benefits of water retention and other details such as the year a water retention project was built and its primary purpose.
2. **Questionnaire for the SRRWD staff:** This questionnaire collected technical information such as storage capacity of the site, surface area, drainage area, and flood protection benefits.

The SRRWD distributed the questionnaire to select producers who previously had water retention projects installed through the SRRWD Water Retention program. Responses were collected from nine producers regarding 10 water retention projects installed between 2014 and 2020.[1] The responses were analyzed and a cost-benefit analysis performed for all 10 water retention projects (see Section 4.4 Cost-benefit analysis).

[1] One producer installed two water retention projects on their farm.

4.0 Results

4.1 General Description of Farms and Water Retention Projects Surveyed

4.1.1 Farm Types

Out of a total of nine producers, **seven operate livestock farms**, specifically:

- five beef cattle ranching and farming
- one buffalo ranching and farming
- one dairy cattle and milk production

The remaining **two producers** out of nine are **exclusively engaged in crop farming**. As for the livestock producers in the sample, six of the seven livestock producers also grow forage crops for hay, silage, or seed, and two indicated that they also grow field crops and, therefore, have a combination of pasture and cropland on their farms. Farming is the primary source of household income for most producers interviewed (seven out of nine).

4.1.2 Farm Size

Our sample includes both small and large farms. **The average farm size in our sample is 1,338 acres**. For producers with pastureland, the areas of pastureland vary from 279 acres to 2,142 acres, with an average size of 772 acres.[2] For producers with cropland, the areas of cropland vary from 125 acres to 2,600 acres, with an average size of 900 acres.

4.1.3 Water Retention Type

Out of 10 projects, six projects are in-channel, and four projects are overland flow. In-channel projects are constructed within the existing banks of a waterway, while overland water retention captures overland/non-channelized flow. Retention types are further described in Appendix A, including licence class, storage type, and control structure.

4.1.4 Year Built

The majority of water retention projects (six) were **installed in 2020**. In addition, one was installed in 2014, one in 2017, one in 2018, and one in 2019. This has some implications for the benefits observed to date—for some projects, producers might not yet have experienced a full range of benefits, which has implications for the return on investment presented later in the cost and benefit analysis.

[2] The average farm size in Manitoba in 2016 was 1,192 acres (Government of Manitoba, n.d.).

4.1.5 Purpose of Water Retention Projects

The **main motivation for producers** to construct these water retention projects was to **help reduce downstream flooding** (9 projects out of 10), followed by creating wildlife habitat (five projects), protecting farms from drought, ensuring enough water for livestock, and increasing farm productivity (four projects). Only one producer (the one who implemented two projects) indicated that improving water quality downstream was one of the reasons to install water retention on their farm, stating that "[the]Main reason for the project was to ensure sufficient water supply for livestock and to improve soil drainage/water management in that area."

From the perspective of the SRRWD, which helped implement the projects, **all the projects were built primarily to slow the flow of water for the purpose of reducing the potential for downstream flooding**. Some of the projects were also implemented to capture nutrients, create habitat, protect against drought, and prevent degradation of local infrastructure, such as reduced road maintenance costs or costs to other infrastructure or farmlands.

Therefore, the primary goal of the projects was flood mitigation, which influenced the design of the sites—that is, individual sites are generally composed more significantly of temporary (rather than extended or permanent) storage to prioritize flood mitigation benefits—each site can have components of each storage type depending on its outlet configuration.

4.2 Costs

4.2.1 Types and Magnitude of Costs

The total costs of water retention projects vary based on the farm's topography, project size, project design, required annual maintenance, and whether the producer needs to take the land out of production for the construction of the project, otherwise known as opportunity costs. Total project costs per acre-foot[3] of water storage in our sample range from CAD 287.74/acre-foot to CAD 12,837.70/acre-foot over the project's lifespan, with an **average total cost of CAD 2,748.30/acre-foot of water storage**.

Upfront costs are necessary to design and construct the project and involve putting in place the berm, spillway, and control structures. For the 10 projects analyzed in this study, upfront costs vary from CAD 7,025.00 to CAD 87,050.44 in 2020 dollars. In general, upfront project costs increase with project size; however, there is a significant range in project cost-efficiency based on required earthworks. The cost of projects can be much smaller if the existing topography minimizes the earthwork required. Also, larger projects may require licensing, which involves more rigorous engineering design and can add to the cost.

[3] An acre-foot equals 1,233 cubic metres. An acre-foot of water covers the area of a football field 1 foot (30 centimetres) deep.

Some annual maintenance of the water retention project is usually required. Regular checking and fence maintenance takes on average 7.25 hours per year based on four projects. Landscaping, which includes seeding and mowing the berm, takes on average 23 hours per year based on three projects. Another common maintenance activity is culvert washout repair (which is covered by SRRWD). Annual maintenance costs tend to be higher for projects that experience heavy flow volumes during spring runoff prior to having time to settle, have higher vehicle and livestock traffic due to the berm forming a major access route, and having a wetland area capable of supporting beavers since beavers can block the culvert (which can later cause a culvert washout). Annual maintenance costs tend to be lower for projects that are designed to capture overland flow versus in-channel projects (where water levels rise more rapidly should the culvert become blocked) and for projects with little traffic and low-density livestock. To monetize the value of time spent on maintenance activities in the cost-benefit analysis (see Section 4.4, Cost-benefit Analysis), we used the Manitoba labour rate of CAD 24/hour from Government of Manitoba (2021b).

The opportunity cost (lost revenue) of the projects depended on how much (if any) land needed to be taken out of production/pasture in order to build the project or costs for ecosystem goods and services resulting from the new management. Where the projects involved the loss of productive acreage, the opportunity costs were valued at a maximum of CAD 30/acre per year based on a rate established by the SRRWD Alternative Land Use Services program for the back flooded areas (SRRWD, 2021).

The upfront, maintenance, opportunity, and total costs for the 10 projects are summarized in Appendix A.

4.2.2 Funding Programs

One producer indicated that the construction costs would have been prohibitive if it were not for the participation in the SRRWD Water Retention program, which covers from 80% to 100% of total project cost (SRRWD, n.d.). High upfront costs can be covered by funding programs. Funding for water retention projects is made available through the GROW program.[4] The East Interlake Watershed District, Inter-Mountain Watershed District, Pembina Valley Watershed District, and Redboine Watershed District offer GROW funding. Souris River Watershed District[5] and Whitemud Watershed District have specific Water Retention Programs.

When the land is taken out from production to accommodate the water retention projects, SRRWD offers annual compensation to producers under the Alternative Land Use Services program at a rate of CAD 15 to CAD 30 per acre of land that is back flooded after installation (SRRWD, 2021).

[4] https://www.gov.mb.ca/water/watershed/grow/

[5] https://srwd.ca/programs/water-retention-program/

4.3 Benefits

Based on the evidence collected, the installation of water retention projects changes farm management, allowing for more efficiency and multiple benefits in wet and dry years. In the SRRWD, water retention projects improved surrounding pastures and ensured there is enough water for cattle. One producer mentioned that it took 2 to 3 years after the installation of a water retention project to realize how big of an impact it would have on the management of his farm. The design of the water retention project is key and can provide a win–win option for both farm owners and their neighbours.

Even though 6 out of 10 projects were less than 2 years old at the time of the survey (having been installed in 2020), many of the producers indicated that they already experienced various benefits of their water retention projects in terms of decreased costs and increased revenue as the result of the following:

Flood protection: Flood control was the main motivation for building all 10 retention projects. For five projects, producers indicated that they already observed this benefit in terms of avoided flood damages; for another five, it is still too early to tell whether their water retention project provides flood protection benefits.

Drought protection: Drought protection as the result of retaining water on farms allows for more water security for livestock and an extended grazing period:

- **Extended grazing:** The dams allow water to back up on farmland during spring snow melt and rain showers, reducing flooding. And while water levels recede over the summer, the vegetation in the previously back flooded areas stays green and allows for extended grazing. As one farmer noted: “The retention area provides an area for late season grazing after most of our other pasture dried up.”
- **Reduced need to haul water:** Especially during drought, when paired with alternative watering systems and fencing, water retention reduces costs for hauling water for livestock, including hours spent by farmers and fuel costs. Farmers emphasized that hauling water for livestock is costly in both time and money. Four projects installed on livestock farms received the benefit of water security: for another four on livestock farms it was too early to tell. As one farmer pointed out, “It would be very expensive to haul water in on a daily basis. So instead of having to move the cattle they were actually able to stay on pasture an additional 2 months. Also, less fuel is used to haul cattle or water.”

Improved water quality: This benefit is also expected; however, farmers had no way to measure whether this benefit occurred. We estimated the water quality improvements based on prior studies of water retention and included this benefit in the cost-benefit analysis described later (see Appendix B). The water retention projects can also be paired with fencing to keep cattle out of the drain and therefore improve water quality. One farmer observed, “By retaining water and releasing it slowly there is less soil or river/ditch bank erosion resulting in better water quantity downstream.”

Improved livestock, machinery crossing: 7 out of 10 projects reported receiving this benefit. The berm, when designed to double as a livestock and/or machinery crossing, allows for better access to different parts of the farm. This reduces time and fuel costs to move livestock and machinery and helps better utilize the land.

Increased farm productivity: 6 out of 10 projects received the benefit: for another three it is too early to tell. Overall, this benefit also captures the improvements in farm management described above that led to increased farm productivity overall, such as increase in moisture, better access to different parts of the farm through berm crossing, increased herd health, and better productivity in dry years. One farmer noticed "Increased grazing in 2021 due to this area having a bit more soil moisture in a dry year."

Enhanced wildlife habitat: Water retention projects also often create favourable conditions for wildlife. Producers observed more wildlife around their farm, such as ducks and geese nesting and blackbirds in the cattails. Five out of 10 projects already provided this benefit; for another five, it is too early to tell whether their water retention provides this benefit. One comment received was that "The bird population increased (especially ducks) with the greater availability of water."

Improved relationships with farm neighbours: There is potential to improve relationships with downstream neighbours, especially in wet years, if neighbours realize that the flooding on their land is reduced as a result of the water retention project. Two projects observed the benefit: for another six, it was still too early to tell, and the remaining two projects did not observe this benefit.

Reduced farm stress: Five out of 10 projects observed this benefit, for another three it was too early to tell. The farm management change provides peace of mind by dealing with some on-farm issues. In one case, the project reduced worries that cattle would need to walk far for water: "Peace of mind that cattle have better pastures, more access to water and fences that remain in good condition. Pleased to be able to participate in a project that alleviated flooding concerns downstream."

Other benefits: Six projects reported other benefits such as:

- Recreation – pond used for skating in winter
- "Sense of pride in being able to help provide a benefit for our neighbours and those downstream"
- Retention of water for emergencies.

4.4 Cost-Benefit Analysis

As highlighted above, producers identified a range of benefits from installing water retention projects. Monetizing these benefits allows us to estimate the economic return to communities and landowners from implementing water retention using a common monetary unit. Benefit-cost ratio (BCR) is an important indicator that evaluates value for money from investing in water retention.

It equals the present value of the project's benefits divided by the present value of the costs. The methodology for the cost-benefit analysis used in this study and the main assumptions and the BCR for our water retention projects are presented below.

4.4.1 Methodology for the Cost-Benefit Analysis

To conduct a cost-benefit analysis, for each water retention project we added up the total costs of the project (comprised of the upfront costs in the year it is built, annual maintenance, and opportunity costs) over the lifetime of the project, which in our analysis has been assumed to be 20 years. Then we added up the total value of benefits over 20 years.

In doing so, we "discounted" the value of costs and benefits that occur in the future years using a 3% discount rate[6] to reflect the lower impact of costs and benefits that occur in the future. The reason for discounting costs and benefits can be explained by the following examples: a CAD 2,000 bill that comes due 3 years from now is generally preferred to a CAD 2,000 bill that comes due tomorrow. Similarly, it is better to receive CAD 500 today than to receive CAD 500 next year, or, worse, 10 years from now. In our methodology, the cost or benefit one year in the future is reduced by 3% to calculate its "present value." A cost or benefit that occurs, for example, 5 years into the future is discounted by 3% five times or by about 15%.[7]

This methodology can also be expressed by the following formula where the total present value of costs over a 20-year period is subtracted from the total present value of benefits over 20-year period to arrive at the net present value (NPV). NPV, therefore, compares discounted benefits and costs and is an indication of whether the project produces gains or losses from the investment.

$$NPV = \sum_{t=0}^{n} \left[\frac{Benefits_t}{(1+r)^t} - \frac{Costs_t}{(1+r)^t} \right]$$

Where monetized benefits include:

- Nutrient runoff reductions (e.g., total phosphorus (TP), total nitrogen (TN) and total suspended sediment (TSS) runoff reductions)
- Expanded grazing
- Saved time for hauling water for livestock
- Saved time for crossing the drain
- Money savings on fertilizer purchase
- Prevention of fencing damage

[6] As recommended by the Treasury Board in the case of projects that have significant social and environmental benefits (ECCC, 2016; Treasury Board of Canada Secretariat, 2007).

[7] Mathematically, it is actually closer to 14%. Mathematically, discounting a number by 3%, and doing that five times means multiplying by 0.97 × 0.97 × 0.97 × 0.97 × 0.97 = 0.8587, which is 14.2% lower than the original number.

- Saved costs of removing manure
- Increased land value

Costs include

- Upfront costs of water retention project
- Annual maintenance costs[8]
- Opportunity costs estimated as the forgone net revenue from pasture and/or crop production

t is time (year), n is the lifespan of water retention project, and r is discount rate. In our baseline model, n=20 years, r=3%. Inflation rate is assumed to be 2%. The base year is 2020 (where t=0 in the equation), which also means that the costs and benefits are expressed in 2020 prices.

We also examined costs and benefits using steeper discount rates of 5%, 7%, and 9% (Appendix D). These higher discount rates may be more aligned with a reasonable rate of return on capital investments and may therefore better reflect the present value of project costs and benefits at a farm financial level.

Water Quality Benefits

Based on the assumptions detailed in Appendix B, the 10 water retention projects installed by the farmers in the SRRWD remove 74.37 kg of TP, 689.93 kg of TN, and 12.46 tonnes of total suspended sediments on average every year. The following dollar values per kg of pollutant removed were used in our water quality benefit calculations:

- TP removal: CAD 60/kg (Bassi et al., 2019; Berry, 2017)
- N removal: CAD 38/kg (Bassi et al., 2019; Berry, 2017; Tetra Tech, 2011)
- TSS reduction: CAD 0.025/kg (Yang et al., 2016).

The total present value of water quality benefits for all 10 projects over the lifespan of water retention projects (20 years) is CAD 560,378.

Other Benefits

In addition to water quality benefits, we were able to monetize some additional co-benefits[9] mentioned by producers, such as expanded grazing, saved time on hauling water for livestock, cost saving on fertilizer purchase. These benefits, which totalled CAD 598,744 across the 10 project sites, are described in the Appendix C.

[8] To monetize the value of time spent on maintenance activities, we used the Manitoba labour rate of CAD 24/hour from Government of Manitoba (2021b).

[9] Since the primary purpose of the examined water retention projects was flood mitigation, we refer to benefits other than prevention of flood damages as co-benefits.

Net Benefits and BCR

In 7 out of the 10 projects examined, the long-term benefits of the projects outweighed the costs. There were significant differences in the extent to which benefits exceeded the costs. In some cases, benefits were only marginally higher than costs. In one case, benefits outweighed the costs more than nine to one. In that case, total project costs of CAD 38,440.78 resulted in on-farm and environmental benefits value at over CAD 360,000. Net benefits tended to be highest for the projects on livestock farms that were in operation longer than other water retention projects and reported multiple on-farm benefits, specifically related to cost efficiencies, for example, time saved on hauling water for livestock and accessing different parts of the farm with machinery or expanded grazing. Additionally, those sites that improved water quality most were downstream of the highest sources of nutrient and sediment accumulations and have greater permanent and extended storage capacities to provide more efficient removal rates.

Of the three projects for which costs outweighed the benefits, two of them were crop-only operations, and all of them were constructed recently (in 2020). In all three cases, the costs were primarily a result of large upfront construction costs, and the benefits including only modelled water quality benefits that were insufficient to offset the costs over the project lifetime.

In all 10 sites, water quality benefits were dominated by estimated reductions in TN in the downstream waterways, which accounted for 72% to 89% of the water quality benefits.

Based on our analysis of seven livestock producers in the SRRWD in Manitoba, the average BCR for implementation of water retention project is 3.16, which means that for every dollar invested in water retention over the period of 20 years, producers and the watershed receive CAD 3.16 dollars in water quality, extended grazing, and other co-benefits[10] (Appendix D). This suggests that, on average, the co-benefits of these projects more than justify the costs of their implementation.

In all 10 sites, lifetime project costs were dominated by the upfront costs, which accounted for anywhere from 53% to 100% of the lifetime project costs. On the other hand, benefits were generally spread out evenly over the lifetime of the project. Because costs are dominated by upfront costs, while benefits are more spread out over time, the discounting of future costs and benefits significantly impacts the estimated net benefit of each project. The more future benefits are discounted, the lower the lifetime net benefit of the project. When future costs and benefits are discounted at 3%, in our primary analysis, the lifetime benefits outweigh the costs in 7 out of the 10 projects studied, with benefits outweighing costs by more than 2.5 to 1 on average (more than 3 to 1 if the two farms without livestock are excluded). If the higher 9% discount rate is used, then benefits outweigh costs by, on average, only 1.6 to 1 (2 to 1 for livestock farms) (see the sensitivity analysis in Table D2). However, even at a 9% discount rate, lifetime benefits still outweighed costs in 6 out of 10 projects.

10 Excluding primary flood protection benefit.

4.5 Feedback From Producers on Their Water Retention Projects

Eight out of nine producers surveyed in this study indicated that they would recommend water retention to other farmers. One producer indicated that it was too early to tell whether they would recommend water retention to other farmers.

Some farmers expressed that they initially hesitated about installing water retention because they believed that the project would flood their pastures. The back flood projection maps created by SRRWD staff and a better understanding of projects' designs helped alleviate these concerns. They realized that the water retention projects can be designed in a way that both helps neighbours and has little to no negative impact on their operation. One farmer shared that "More people should be doing this because it's a good way to help with keeping water back. The SRRWD staff are so easy to work with," while another noted "My initial concern was about having the pastures flooded for a period of time. But when I understood the design, it became clear that it would actually be a win–win."

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Appendix A. Water Retention Types and Costs

Table A1. Technical and cost summary of water retention projects.

	Technical specifications				Costs, in 2020 CAD			
Site ID	**Licence class**	**Storage type**	**Control**	**Storage capacity[a], acre-feet[b] of water**	**Upfront costs**	**Maintenance cost and opportunity costs per year**	**Present value of total costs from 2021 to 2040, 3% discount rate**	**Present value of total costs per acre-foot of storage, 3% discount rate**
WS	Large	Overland flow	Passive[d]	376.00	$74,738	$1,850	$108,189	$288
HL	Large	Overland flow	No control-breach in lateral dike	60.00	$47,900	$25	$48,352	$806
HO	Large	Overland flow	Passive	45.00	$26,129	$0	$26,129	$581
ST	Large	Overland flow	Passive	45.00	$50,826	$616	$61,964	$1,377
MU	Large	In-channel	Passive	35.00	$87,050	$111	$89,054	$2,544
CH2	Large	Overland flow	Manual-stop logs	20.00	$19,800	$897	$36,024	$1,801
GR	Large	In-channel	Passive	17.00	$15,627	$180	$18,882	$1,111
CL	Small[c]	In-channel	Passive	9.00	$15,812	$789	$30,079	$3,342

	Technical specifications				Costs, in 2020 CAD			
Site ID	**Licence class**	**Storage type**	**Control**	**Storage capacity[a], acre-feet[b] of water**	**Upfront costs**	**Maintenance cost and opportunity costs per year**	**Present value of total costs from 2021 to 2040, 3% discount rate**	**Present value of total costs per acre-foot of storage, 3% discount rate**
CH1	Large	In-channel	Manual gate	3.00	$20,481	$997	$38,513	$12,838
KE	Small[c]	Overland flow	Passive	2.50	$7,025	$0	$7,025	$2,810

[a] Sorted by storage capacity

[b] An acre-foot equals 1,233 cubic metres. An acre-foot of water covers the area of a football field 1 foot (30 centimetres) deep.

[c] Small project= less than 1 metre from culvert invert, must have “permanent” flow and be less than 25 decametre cube storage.

[d] Passive control structure means there is no active intervention to manipulate water levels and retention relies upon hydraulic restrictions to raise water level in the storage area.

Appendix B. Water Quality Benefits and Performance Summary for 10 Projects

Water quality benefits for the 10 water retention sites in the SRRWD have been assessed based on total average annual phosphorus (TP), nitrogen (TN), and sediment (TSS) reductions. This analysis uses a modified version of the PTMApp methodology, a modelling approach that was developed by Houston Engineering Inc. (2016). This modelling approach considers upstream hydrology and other physical parameters such as topography, land use, and soils within the watershed. As none of these 10 sites except for Wiens De Salaberry site have been historically monitored, the provided evaluations are based on estimated incoming nutrients, sediments, and removal rate efficiencies, not measured data. However, water quality benefits determined for the Wiens De Salaberry site have been cross-referenced against existing IISD research for validation (Simoes & Grosshans, 2020; Swanson et al., 2021), which provides more confidence in the results provided for the other sites.

There were three components to the analysis performed to determine nutrient and sediment reductions for each of the water retention sites:

1. **Determine the incoming nutrient loads at each site from their upstream catchment.** Nutrient loads have been estimated based on the default average annual nutrient export coefficients (mass generated per unit area) provided by PTMApp but scaled to match long-term average annual phosphorus and nitrogen loading rates, to be more representative of nutrient loading observed in the Manitoban Prairies. USGS (2016) National Land Cover Database values were interpreted from AAFC (2018) annual crop inventory data to associate export coefficients to land use in each watershed. The default total phosphorus and nitrogen nutrient export coefficients were multiplied by 0.865 and 0.346 respectively to improve this representation and fit to the South Tobacco Creek Steppler Dam data set (J. Elliot, personal communication, February 10, 2021; Tiessen et al., 2011). That is, the default average annual nutrient export coefficients used in PTMApp would overestimate the phosphorus and nitrogen loading rates (and therefore the benefits) observed at the South Tobacco Creek Steppler Dam and thus have been scaled down. The nutrient export summation was taken for the entire area of the upstream watershed for each site (with an exception for the Wiens De Salaberry site, which by design splits half of its inflow between the inlet and a neighbouring drain).
2. **Determine incoming sediment loads.** The incoming sediment loads have been estimated using the Revised Universal Soil Loss Equation (AAFC, 2002), which provides average annual soil loss based on rainfall–runoff, soil erodibility, watershed slope and length, crop management, and support practice factors. Rainfall–runoff factors were interpreted from the Revised Universal Soil Loss Equation Handbook (AAFC, 2002). Erodibility factors were obtained using an adaptation of the Soil Landscapes of Canada (SLC) 3.2 dataset (Government of Canada, 2011) using the methodology outlined by

Cordeiro et al. (2018). Watershed slope and length factors were calculated based on watershed delineations for each site provided by the SRRWD and digital elevation model data collected from the Manitoba Land Initiative (Government of Manitoba, 2022a) and Minnesota Department of Natural Resources (2022). Crop management and support factors were assigned based on the guidance provided by PTMApp documentation (Houston Engineering Inc., 2016). As the upstream watershed for each retention site is generally small (<50km2), nutrient and sediment decay associated with water travel time during flow routing has been omitted from all assessments for simplicity. Like for the nutrient loading estimates, sediment loads were scaled down (multiplied by 0.151) to match long-term average annual observations made for the Tobacco Creek Steppler Dam (Tiessen et al., 2011; J. Elliot, personal communication, February 10, 2021), which suggests that incoming sediment loads would again be overestimated using the Revised Universal Soil Loss Equation method and inputs generated at Manitoban water retention sites without the use of the determined scaling factor.

3. **Estimate the total nutrient and sediment reduction rates "R" for each site.** The total nutrient and sediment reduction rates are calculated using Equation 1 (Houston Engineering Inc., 2016). The volume ratio "r" is based on the ratio of water storage that can be used to treat incoming nutrient and sediment loads to the expected incoming volume from a specified hydrologic event at each site. The volume interpreted from each site to provide treatment is the combination of permanent and extended storage but excludes temporary storage. Permanent and extended storage represents that volume within a water retention site that is expected to retain surface water permanently (losses only through evaporation and groundwater infiltration) or on the order of months with low outflow respectively. Alternatively, temporary storage is that which is expected to only retain water on the order of just days and does not provide enough time to conservatively estimate natural water quality treatment processes.

Equation 1. $R=ar^k$

Incoming flow volume was estimated using the SCS curve number method (United States Department of Agriculture, 1986) with adjustments made to the initial abstraction, as suggested by Woodward et al. (2003) and using estimated 2-year 24-hour storm events from ECCC (2019) intensity duration frequency data. Values for the decay coefficient "k" are equal to 1.878, 2.529, and 0.448 and were previously determined by Swanson et al. (2021) for phosphorus, nitrogen, and sediment removal, respectively, using data from Tiessen et al. (2011; J. Elliot, personal communication, February 10, 2021). The final percent reduction of nutrient or sediment flow through each site was then calculated using the same method as PTMApp (Houston Engineering Inc., 2016), with empirical statistical distribution data to determine median storage BMP performance ("**a**" = to 39%, 57%, and 69% for phosphorus, nitrogen, and sediment removal components, respectively).

Table B1 details the volume ratios and resulting TP, TN, and sediment reduction rates determined for each of the 10 water retention sites and illustrates the significant variability in water retention site performance to reduce nutrient and sediment loads. The low estimated performance exhibited at some sites suggests that many were designed primarily with flood mitigation as the functional priority and thus are composed more significantly of temporary, rather than extended or permanent storage. This observation should not be surprising considering the issues Manitoba commonly faces with respect to flooding and demonstrates an opportunity for water retention sites to be performing better to improve water quality. These improvements could be made by better optimizing water retention site design to maximize both flood mitigation and water quality benefits, or by better targeting their development within nutrient and sediment hotspots. The total reductions to nutrients and sediments expected by each site are further provided in Table B2, with an inclusion of the determined catchment area to help contextualize the magnitude of inflows and loading.

The monetary values of TP, TN, and TSS reductions from each of the sites are presented in Table B3. They are derived by using the following unit costs of TP, TN and TSS removal:

- Cost for TP removal: CAD 60/kg (Berry, 2016; IISD, 2019)
- Cost for N removal: CAD 38/kg (Tetra Tech, 2011; Berry, 2016; IISD, 2019)
- Cost for TSS reduction: CAD 0.025/kg (Yang et al., 2016)

Table B1 presents sums of present values of water quality benefits of TP, TN, and TSS removal over 20 years.

Table B1. Water retention nutrient and sediment percent reduction rate summaries

Site	Volume ratio	TP reduction rate	TN reduction rate	TSS reduction rate
WS	30.10%	14.60%	19.10%	49.00%
HL	13.60%	6.10%	8.00%	33.70%
HO	50.70%	25.10%	33.90%	60.10%
ST	56.80%	28.00%	38.20%	62.30%
MU	0.30%	0.10%	0.20%	5.40%
CH2	3.10%	1.20%	1.80%	16.10%
GR	4.90%	2.00%	2.80%	20.30%
CL	0.70%	0.30%	0.40%	8.10%
CH1	1.80%	0.70%	1.00%	12.30%
KE	68.10%	32.60%	45.70%	65.50%

Table B2. Water retention total nutrient and sediment mass reduction rate summaries

Site	Catchment area [km²]	TP reduction [kg/yr]	TN reduction [kg/yr]	TSS [tonne/yr]
WS	23.59*	41.61	380.45	3.73
HL	19.37	10.4	119.05	0.48
HO	4.54	12.74	97.2	0.11
ST	1.08	2.23	27.6	0.02
MU	27.78	0.56	4.59	0.79
CH2	5.6	0.87	7.71	0.64
GR	4.78	1.71	10.2	0.13
CL	19.19	0.85	7.86	2.54
CH1	18.69	2.02	18.56	3.84
KE	0.22	1.39	16.71	0.18
Total	**124.85**	**74.37**	**689.93**	**12.46**

*Effective catchment area for Wiens De Salaberry site accounts for 50% flow split upstream of site.

Table B3. Present value of monetized water quality benefits over project's lifespans (discount rate =3%)

	Sum of present value in 2020 CAD (over 20 years)			
Site	**TP reduction [$]**	**TN reduction [$]**	**TSS [$]**	**Total**
WS	$45,142	$261,402	$1,686	$308,230
HL	$11,283	$81,798	$217	$93,297
HO	$13,821	$66,785	$50	$80,656
ST	$2,419	$18,964	$9	$21,392
MU	$608	$3,154	$357	$4,118
CH2	$944	$5,297	$289	$6,531
GR	$1,855	$7,008	$59	$8,922
CL	$922	$5,401	$1,148	$7,471
CH1	$2,191	$12,752	$1,736	$16,680
KE	$1,508	$11,481	$81	$13,071
Total	**$80,682**	**$474,042**	**$5,632**	**$560,356**

Appendix C. Other Co-benefits

In addition to water quality benefits, we monetized other co-benefits that were highlighted by producers in their questionnaire responses. These benefits included:

- **Expanded grazing/crop production** valued in the following ways based on the reported data:
  - Number of additional grazing acres multiplied by average pasture rental rate of CAD 28/acre/year from Government of Manitoba (2021c); Number of additional acres for corn production multiplied by value of net income from corn production of CAD 83/acre (Government of Manitoba, 2021a).
  - Number of cattle supported by the additional grazing land multiplied by the total pastureland costs per head of cattle for improved pasture from Government of Manitoba (2021b)—CAD 1.02/head/day.
  - Cost savings from purchasing additional feed bales for cattle at the total cost reported by the producer.
- **Saved time on hauling water for livestock** (hours/day) multiplied by Manitoba labour rate of CAD 24/hour from Government of Manitoba (2021b) and projected for the entire year.
- **Saved time on livestock and machinery crossing** (hours/trip) enabled by the design of water retention allowing access to different parts of the farm, multiplied by Manitoba labour rate of CAD 24/hour from Government of Manitoba (2021b) and projected for the entire year based on the number of trips per year.
- **Increased land value** because of improved machinery access to another part of the farm and conversion to corn production, which has higher land value than pasture.
- **Saved costs on the purchase of synthetic fertilizer** as the result of the water retention design and improved machinery and cattle access to different parts of the farm: the cattle can overwinter on the corn field, reducing the need for synthetic fertilizer for the corn field. These cost savings are valued at CAD 80/acre, as reported by the producer.
- **Saved costs on removing manure** as the result of the water retention design and improved cattle access to different parts of the farm preventing concentration of manure in one location over winter months. These cost savings were valued at the annual dollar value reported by the producer.
- **Damage prevented** (e.g., fencing) as the result of holding back water with the berm at the annual value reported by the producer.

The annual dollar values of other co-benefits are presented in Table C1 and the sum of present values over the lifespan of the water retention projects in Table C2.

Table C1. Annual values of monetized additional co-benefits, in 2020 CAD

Site ID	Expanded grazing/crop production, $/year	Saved time on hauling water for livestock, $/year	Saved time on livestock and machinery crossing, $/year	Fertilizer saved, $/year	Saved costs for removing manure, $/year	Damage prevented (e.g., fencing), $/year	Total
WS	$2,066	$1,440				$500	$4,006
HL	$200						$200
HO	$1,000						$1,000
ST							
MU*							
CH2		$7,200					$7,200
GR*							
CL	$1,680						$1,680
CH1	$2,822	$1,800	$3,366	$2,720	$5,500		$16,208
KE							
Total	**$7,768**	**$10,440**	**$3,366**	**$2,720**	**$5,500**	**$500**	**$30,294**

*Crop farmers

Table C2. Present values of monetized additional co-benefits (discount rate = 3%) over 20 years, in 2020 CAD

Site ID	Expanded grazing/ crop production	Saved time on hauling water for livestock	Saved time on livestock and machinery crossing	Fertilizer saved	Saved costs for removing manure	Damage prevented (e.g., fencing)	Land value increased	Total
WS	$37,347	$26,037				$9,041		$72,424
HL	$3,616							$3,616
HO	$18,081							$18,081
ST								
MU*								
CH2		$130,185						$130,185
GR*								
CL	$30,376							$30,376
CH1	$51,025	$32,546	$60,861	$49,181	$99,447		$51,000	$344,061
KE								
Total	**$140,446**	**$188,768**	**$60,861**	**$49,181**	**$99,447**	**$9,041**	**$51,000**	**$598,744**

*Crop farmers

Appendix D. Net Benefits and Benefit-To-Cost Ratios Under Different Discount Rates (Sensitivity Analysis Results)

Table D1. Present value of project costs and benefits from 2021 to 2040, at 3% discount rate, in 2020 CAD

	Costs			Benefits				
Site ID	**Upfront costs**	**Ongoing annual costs**	**Total Present value of costs**	**Water quality benefits**	**On-farm costs savings and co-benefits**	**Total present value of benefits**	**Net present value of a project**	**Benefit-to-cost ratio**
WS	$74,738	$1,850	$108,189	$308,230	$72,424	$380,654	$272,465	3.5
HL	$47,900	$25	$48,352	$93,297	$3,616	$96,913	$48,561	2.0
HO	$26,129		$26,129	$80,656	$18,081	$98,737	$72,608	3.8
ST	$50,826	$616	$61,964	$21,392		$21,392	-$40,572	0.3
MU*	$87,050	$111	$89,054	$4,118		$4,118	-$84,936	0.0
CH2	$19,800	$897	$36,024	$6,531	$130,185	$136,716	$100,692	3.8
GR*	$15,627	$180	$18,882	$8,922		$8,922	-$9,960	0.5
CL	$15,812	$789	$30,079	$7,471	$30,376	$37,847	$7,768	1.3
CH1	$20,481	$997	$38,513	$16,680	$344,061	$360,741	$322,228	9.4
KE	$7,025		$7,025	$13,071		$13,071	$6,046	1.9
Total	**$365,388**	**$5,465**	**$464,211**	**$560,356**	**$598,744**	**$1,159,100**	**$694,900**	**2.5**

*Crop farmers

Table D2. Results of the cost-benefit analysis: Benefit-cost ratio

Site ID	3%	5%	7%	9%
WS	3.5	3.1	2.7	2.4
HL	2.0	1.7	1.4	1.2
HO	3.8	3.1	2.6	2.2
ST	0.3	0.3	0.3	0.2
MU*	0.1	0.0	0.0	0.0
CH2	3.8	3.4	3.1	2.8
GR*	0.5	0.4	0.4	0.3
CL	1.3	1.1	1.0	0.9
CH1	9.4	8.7	8.1	7.5
KE	1.9	1.5	1.3	1.1
Average	**2.5**	**2.1**	**1.9**	**1.6**
Average for livestock producers (excluding MU and GR)	**3.2**	**2.8**	**2.4**	**2.2**

*Crop farmers

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