SUMMARY

Optimizing Water Retention to Reduce Algal Blooms in Canadian Lakes

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Key Messages

- Water retention projects, such as conserved/restored wetlands or small naturalized dams, are critical for climate change adaptation in the Canadian Prairies as they reduce flood and drought risk while also improving water quality.
- Many water retention projects currently in the pipeline are expected to promote phosphorus reduction benefits, but these benefits are unlikely to be maximized given standard design practices.
- Future water retention projects should be designed more strategically to maximize phosphorus reduction by increasing water retention time and ensuring that runoff capture is targeted from phosphorus hotspots.

Why Water Retention Matters

The loss of natural water storage on Canadian Prairie landscapes over time has resulted in reduced water availability during dry years and greater flooding during wet years. With our changing climate, more frequent and prolonged dry periods and increasingly extreme rainfall events are exacerbating these issues.

Natural infrastructure that provides water retention, such as wetlands or small naturalized dams, is widely recognized for providing a multitude of benefits that can help us adapt to our changing climate on the Canadian Prairies (Simoes et al., 2023).

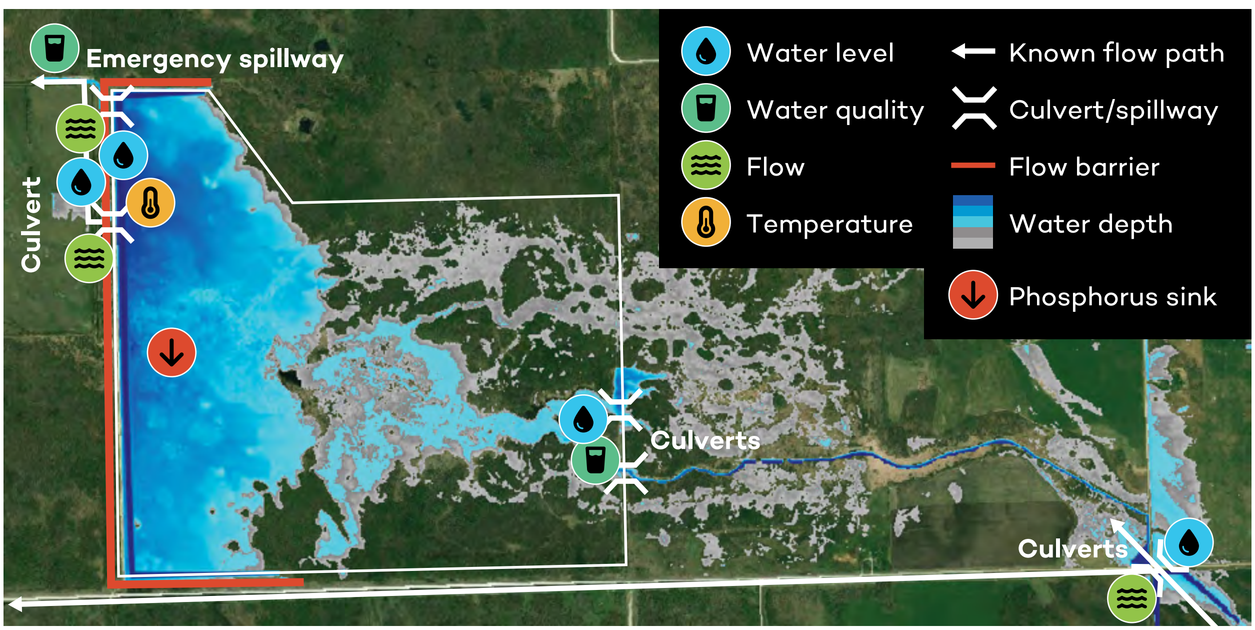
These benefits include reducing the risks of both floods and droughts, improving water quality, creating habitat and improving biodiversity, reducing atmospheric carbon, and a variety of other economic benefits that make water retention an investment with a strong return (estimated to provide CAD 2.45 in benefits for every dollar spent) (Puzyreva et al., 2022).

Even so, the wealth of benefits that water retention provides may only be achieved together with careful site design, maintenance, and operation. Analytical practices that quantify flood mitigation for water retention site designs are common, but benefits like phosphorus reduction are often only qualitatively assessed. Long-term research from the IISD Experimental Lakes Area established that phosphorus is the key limiting nutrient responsible for these blooms, and therefore, its reduction to waterways is of critical importance for improving water quality (Schindler et al., 1971).

Phosphorus reduction analyses and site selection for new water retention projects need to consider both the spatial variability of water quality across the landscape and the performance of potential sites in treating that water. These considerations allow us to better assess and maximize the water quality benefits at a given cost. Treatment models can be used to optimize water quality outcomes for new sites, but methods simple enough to be integrated into current site design practices are needed.

How Water Retention Sites Reduce Phosphorus

Figure 1. Integrated hydraulic and treatment wetland model and monitoring locations for the De Salaberry water retention site

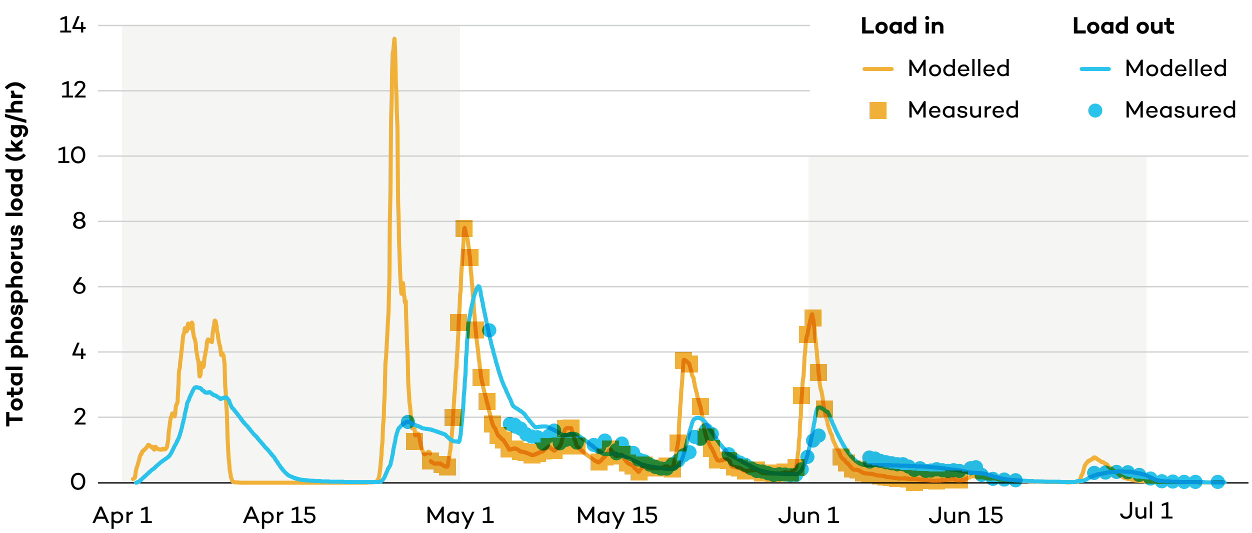


Source: Authors' diagram.

IISD monitored the De Salaberry water retention project for 5 years between 2019 and 2023 to better understand how water retention systems perform under a range of hydrologic conditions. The resulting data set supported the development of an integrated prototype hydraulic and phosphorus reduction model designed specifically for small, naturalized dams that are common across the Canadian Prairies (Figure 1). By combining field monitoring with modelling, the project evaluated how runoff conditions and site design influence phosphorus reduction outcomes.

Unlike more simplified annual loading estimates, the developed model evaluates site performance dynamically under changing weather and inflow water quality patterns. This allows the model to better represent (and enables) the disaggregation of shorter-duration spring runoff and rainfall events that dominate phosphorus transport in Canadian Prairie watersheds (Figure 2). The model also allows alternative site designs to be tested virtually, which could provide essential information before construction or retrofit decisions are made. Design changes to outlet structures and reservoir storage can therefore be evaluated to better understand how water retention time and phosphorus reduction outcomes may change under different conditions.

Figure 2. 2022 De Salaberry phosphorus reduction model results



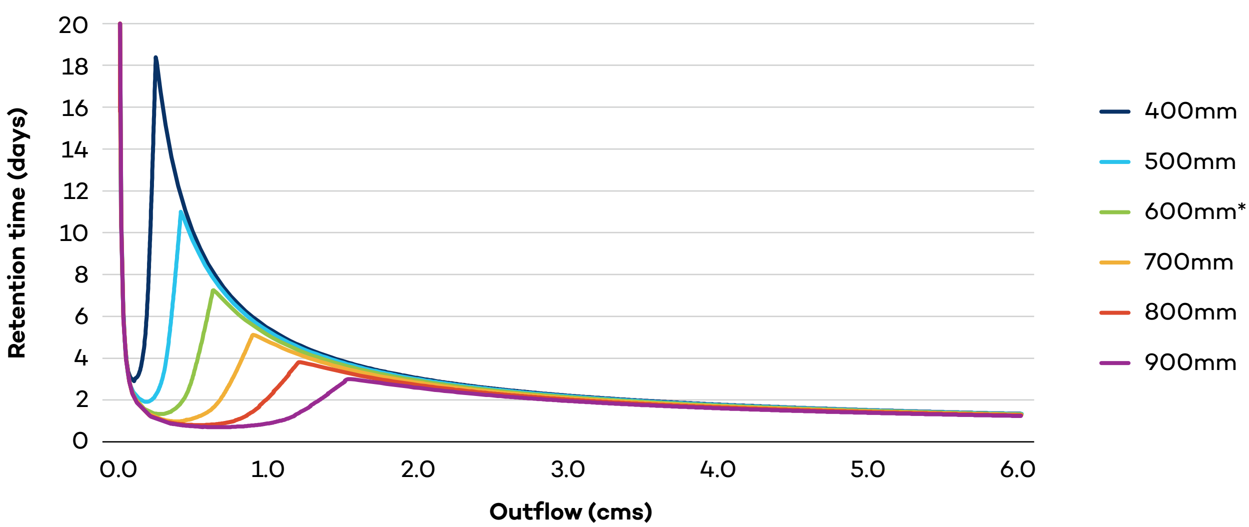
Source: Authors' phosphorus reduction model.

What Should the Water Retention Site of the Future Look Like?

The findings from the De Salaberry project show that future water retention systems could be designed more deliberately to improve phosphorus reduction outcomes. Historically, water retention projects have been designed primarily around flood mitigation and water supply management objectives, with water quality benefits often assumed rather than quantitatively assessed. This project shows that phosphorus reduction performance can vary substantially depending on both how the site is hydraulically designed and the incoming water quality, which can vary with site position and upstream conditions.

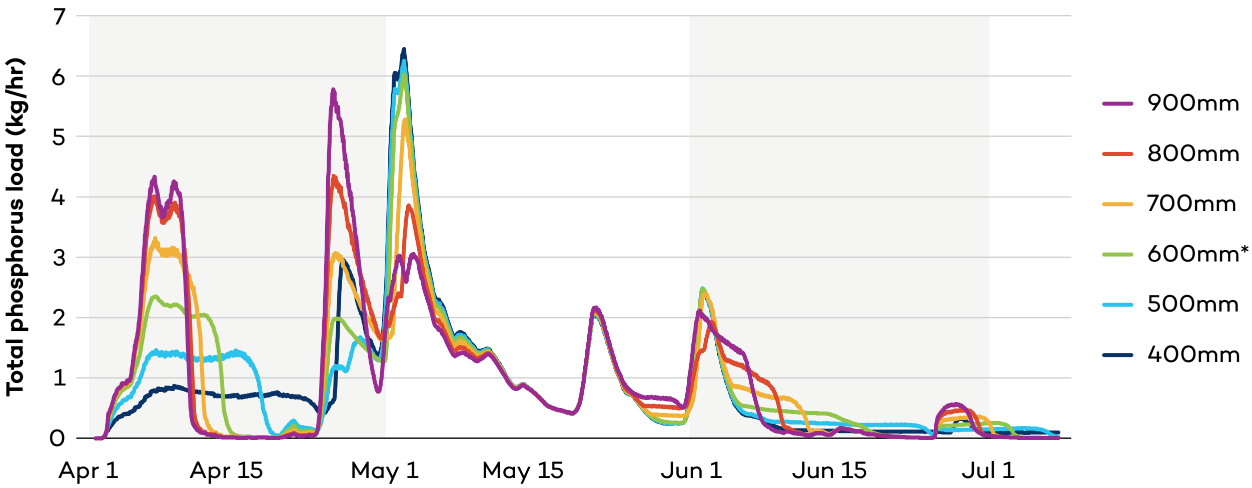
The most important factor influencing phosphorus reduction performance was found to be the hydraulic retention time, i.e., how long water remains stored within the site before being released downstream. Longer retention improves phosphorus reduction by allowing more time for sedimentation and other natural treatment processes to occur. Scenario modelling demonstrated that relatively modest design changes could increase retention time and improve phosphorus reduction outcomes. Examples tested in this study included modifying outlet culvert diameter (e.g., Figures 3 and 4; Table 1), outlet invert elevation, spillway crest elevation, and reservoir storage volume.

Figure 3. De Salaberry outflow vs retention time—outlet culvert diameter



Source: Authors' hydraulic model (600 mm* is the baseline De Salaberry outlet culvert diameter).

Figure 4. 2022 De Salaberry phosphorus reduction scenarios—outlet culvert diameter



Source: Authors' phosphorus reduction model (600 mm* is the baseline De Salaberry outlet culvert diameter)

Table 1. 2022 De Salaberry phosphorus reduction scenario outputs—outlet culvert diameter

	Outlet culvert diameter (mm)					
	900	**800**	**700**	**600***	**500**	**400**
Average (flow-weighted) retention time [days]	1.77	2.07	2.40	2.76	3.26	4.14
Total phosphorus load reduction [kg]	138.3 (5.68%)	193.5 (7.95%)	240.8 (9.89%)	271.3 (11.15%)	279.9 (11.50%)	309.9 (12.73%)

Source: Authors' phosphorus reduction model (600 mm* is the baseline De Salaberry outlet culvert diameter).

Our findings also demonstrate that design optimization involves trade-offs that must be carefully balanced. Some modifications that improve phosphorus reduction may, at the same time, increase flood risk or increase construction costs. Accordingly, future water retention projects should consider flood mitigation and phosphorus reduction together during planning and design processes, rather than treating water quality benefits as a secondary or assumed outcome.

What Needs to Happen Next

This research identified three key recommendations to improve the planning, design, and evaluation of future water retention projects to reduce phosphorus.

1. Continue Monitoring to Strengthen the Evidence Base

Additional monitoring and modelling at other Prairie water retention sites would continue to improve our understanding of how phosphorus reduction performance changes across different watershed and design conditions. Expanding the evidence base would also improve confidence in future phosphorus reduction estimates from similarly developed models, which would support more reliable future planning and design practices.

2. Position and Design Future Sites Strategically

Future projects should prioritize locations that intercept meaningful phosphorus loads; IISD has previously developed guidance to support the spatial targeting of water retention projects in the Canadian Prairies (Simoes et al., 2025). These projects should also consider flood mitigation and water quality objectives together during project design, planning, upgrades, and retrofits.

3. Develop Practical Tools for Implementation

Simpler planning tools and workflows are needed to help practitioners estimate phosphorus reduction benefits during early-stage planning and design. Practical methods that combine phosphorus loading estimates with flood and retention-time analysis could help watershed planners and engineers compare design options to better optimize water retention projects for both flood mitigation and water quality improvement.

As investment in water retention infrastructure continues across Canada, integrating quantifiable phosphorus reduction estimates into project design and planning will be important for understanding their impact and meeting water quality objectives.

Are you planning new water retention projects in your watershed? IISD can help estimate potential phosphorus reduction benefits and provide guidance on how site positioning and design could be optimized to improve water quality outcomes.

For more information, contact Joey Simoes at jsimoes@iisd.ca.

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