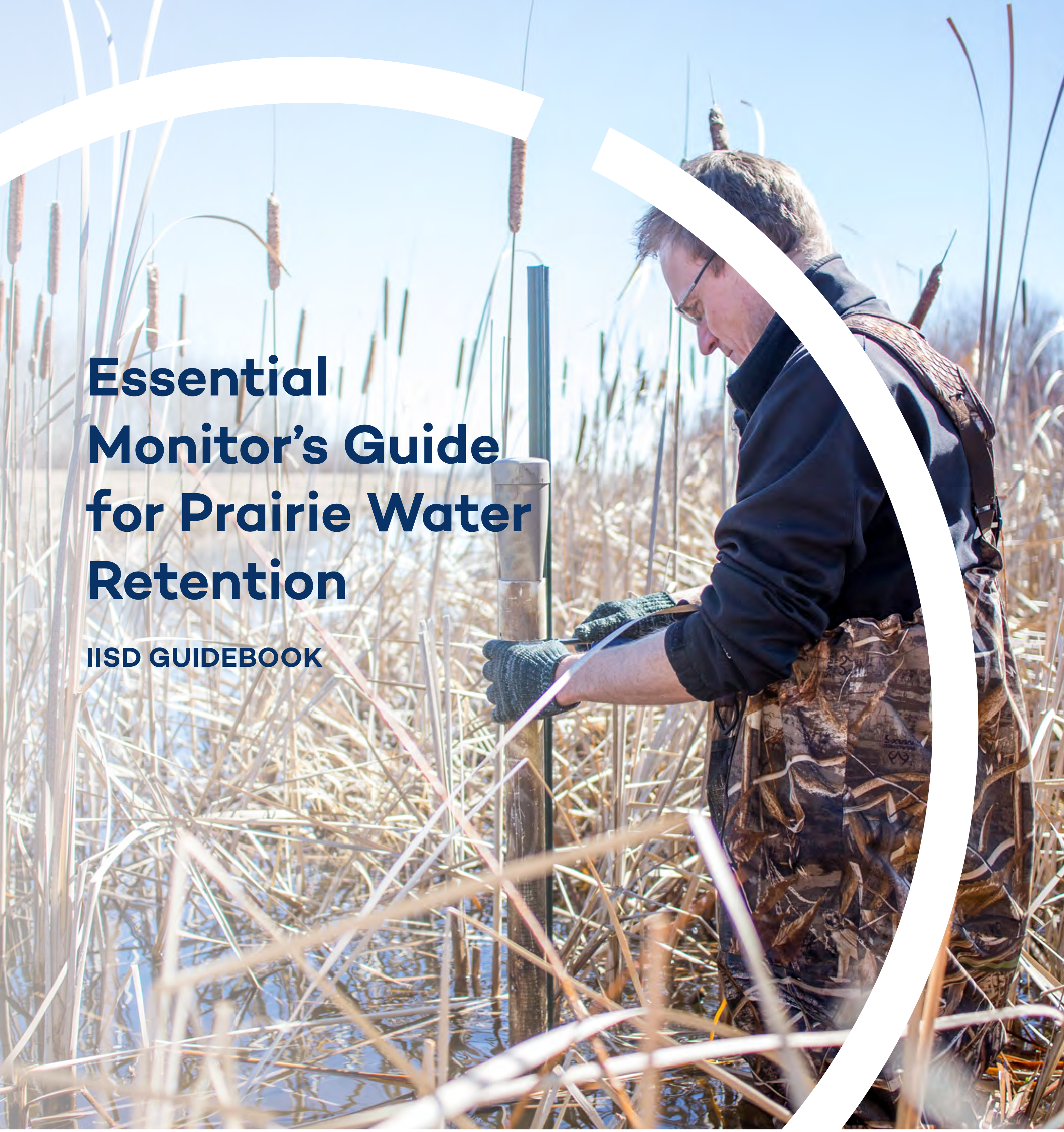

Essential Monitor's Guide for Prairie Water Retention

IISD GUIDEBOOK

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Photo: Joey Simoes/IISD

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1.0 Key Points on Water Retention

A water retention project is natural infrastructure that delivers flood, drought, water quality, and other benefits—such as improved habitat, biodiversity, and carbon storage—as a result of managing water and becoming naturalized.

Monitoring is necessary to ensure that water retention projects across the Prairies are performing to specification and to track that project performance is upheld over time.

Long-term monitoring data for a variety of different water retention projects are needed to advance the design practices and management strategies of future water retention projects.

Biophysical monitoring allows us to understand the additional benefits that water retention projects provide beyond flood and drought mitigation, and the management changes that can be applied to maximize those additional benefits.

With the diversity and affordability of tools available today for monitoring water retention, there has never been a better time to begin monitoring a system in your own watershed.

2.0 Why Do We Need to Monitor Water Retention?

Water retention provides flood, drought, water-quality, and additional benefits, such as improved habitat, biodiversity, and carbon storage, which can be increased through water management and when naturalized. These benefits typically serve as drivers for the implementation of water retention practices within ongoing work to adapt to our changing climate.

Monitoring both water quantity and quality allows us to better understand a site's performance and the various influences that site design, operation, and maintenance have on enhancing its effectiveness and related co-benefits.

Currently, there are limited long-term data available demonstrating water-quality benefits across a variety of different sites, which we know can vary in performance for several reasons.

Critically, the knowledge gained from monitoring water retention can be used to design sites that

- provide better adaption to our changing climate,
- are optimized to deliver multiple benefits, and
- can be better managed to uphold their performance long after they are constructed (Box 1).

Box 1. Water retention design and performance

- The amount of time that water is retained in water retention systems is a key factor in how well sites may improve water quality and is therefore a significant design parameter that can vary between sites.
- The size of the retention area and outlet control structures, such as culverts or spillways, and the specific magnitude and length of hydrologic events that drive their operation greatly impact the time that water is retained within a system, which is needed to reduce nutrient and contaminant runoff.
- Water quality treatment performance can also vary depending on influent concentrations and across seasons. Generally, sites within colder climate regions like the Canadian Prairies perform differently than those of its warmer southern neighbours.

3.0 What Do We Need to Monitor for Water Retention?

Water Balance

To be successful in monitoring a water retention project, it is important to have a good understanding of the site's water balance.

A water balance accounts for the quantity of water flowing in and out of the retention area, including surface runoff, groundwater interactions, and losses from evapotranspiration. These foundational components of a water balance can always be estimated using models, but they can only ever be validated using monitoring data.

Knowledge of the most significant components of a site's water balance can help prioritize the monitoring resources available and determine what needs to be monitored, at a minimum, to understand the site's performance. For example, when analyzing high-volume but short-term hydrologic events individually, it is important to know that groundwater interactions and evapotranspiration for a water retention site may not contribute as significantly to water balance.

Contaminant Mass Balance

Another key to understanding water-quality treatment performance is understanding the site's contaminant mass balance.

Like a water balance, a contaminant mass balance accounts for the mass of water quality constituents flowing in and out of the water retention site. A contaminant mass balance builds on a water balance by integrating concentration data of water quality constituents, such as nutrients like phosphorus and nitrogen, sediments, carbon, and others.

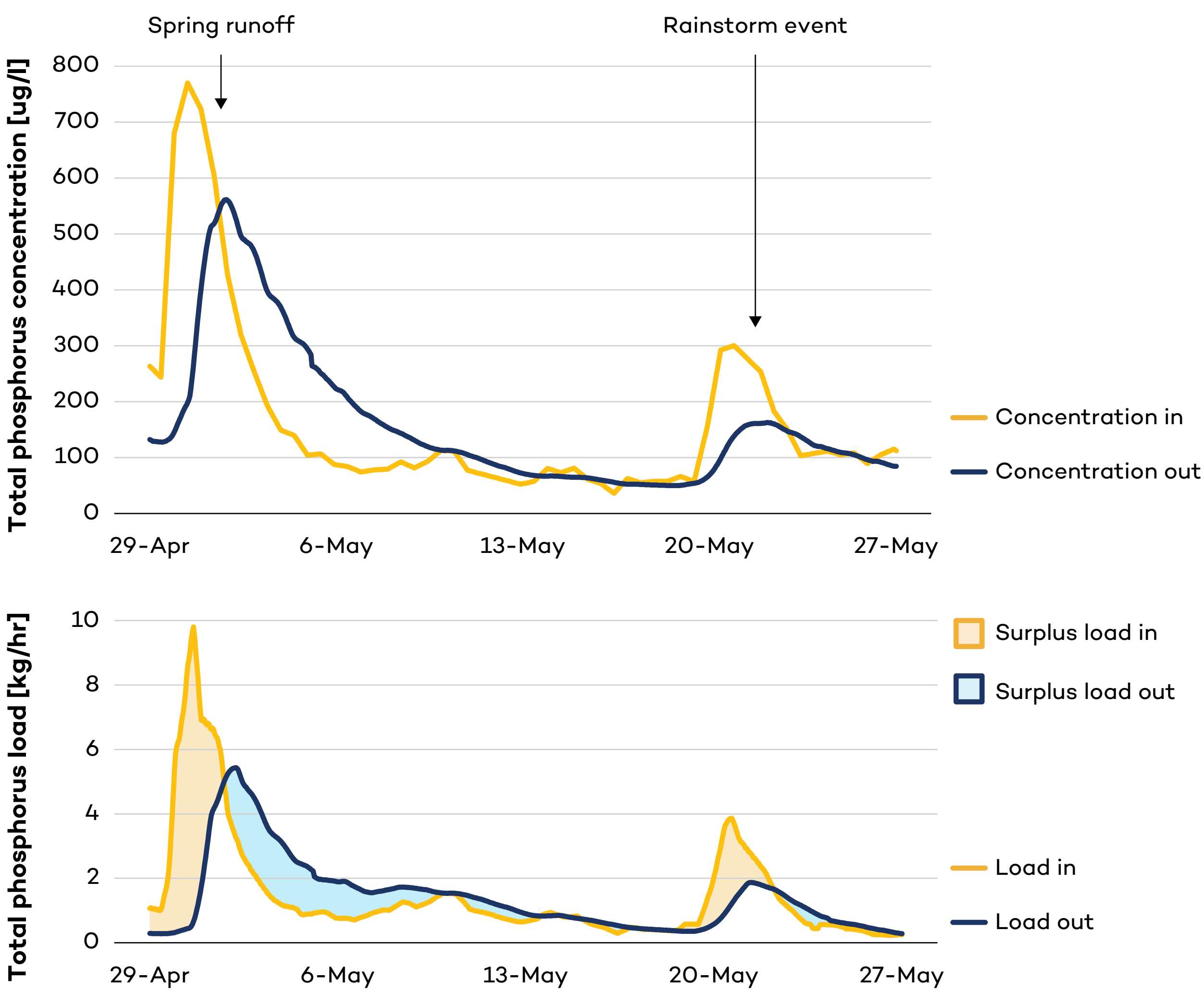
Depending on the specific needs for performance monitoring, more detailed water-quality parameters can be investigated and may include dissolved or particulate forms of nutrients and sediments or nutrient forms that are used for specific purposes. For example, orthophosphate is a form of phosphorus that can be directly taken up by algae and accelerate reproduction, but it is more difficult to monitor. In general, measuring total phosphorus and total nitrogen can provide a good indication of water-quality improvements within a site and meet the requirements of initial monitoring goals.

When we know how much water is flowing in and out of a retention site and the concentration of various water-quality constituents, these values can be multiplied together to determine the loads that are used to understand the contaminant mass balance (Box 2).

Box 2. Concentration and load assessments

- Load assessments are critical to understanding treatment performance for water retention systems in physical quantities, such as the total reduction of nutrient mass in kilograms.
- Figure 1 illustrates how total phosphorus concentration data, when plotted alone, can be mistaken for nutrient export rather than reduction, as outflow concentrations may simply be higher for a longer period than inflow concentrations. However, if we look at the area under each curve, and when using loading rate time-series data, we typically find that the load out of the system through the contaminant mass balance is reduced.

Figure 1. Typical spring runoff and rainstorm event concentration and load data for a prairie water retention site



Source: Authors' diagram.

4.0 What Tools Are Available for Monitoring Water Retention?

The tools available for monitoring water retention sites are diverse and can vary significantly in both their upfront capital cost and the staff time required to use them for data collection.

Understanding the typical magnitude and timing of flow and water-quality characteristics for a water retention site is critical for selecting the right tool for the job.

Finding the right combination of tools to monitor a specific water retention system can therefore reduce equipment and site visit-related expenditures.

What Does the International Institute for Sustainable Development's Team Use?

For water retention projects monitored by the International Institute for Sustainable Development (IISD), we use a combination of high-frequency, seasonally deployed equipment in addition to high-precision handheld equipment and manual sampling.

Automated equipment can be permanently installed, but it requires periodic checkups and maintenance during the course of a field season. Site visits are also necessary to collect manual measurements, which may also be needed to correct automated measurements after the field season has concluded. For example, sensor drift and unforeseen environmental conditions, such as the movement of stilling wells or sediment accumulation on flow sensors, need to be identified and accounted for manually.

On the following pages, we have shared a sampling of the equipment we use in our projects at IISD as well as how we use it.[1]

We have also denoted the approximate cost of these items:

$	$$	$$$	$$$$	$$$$$
< CAD 10	< CAD 100	< CAD 1,000	< CAD 10,000	< CAD 20,000

[1] Note that the provided list of equipment is not exhaustive and that many other options for equipment exist (e.g., dedicated pressure transducers for measuring water levels, which can provide additional flexibility compared to stilling wells but can be more costly). The equipment listed above has enabled IISD to cost-effectively perform monitoring that is sufficient to support complex modelling; however, some due diligence is required to know what is best for any specific monitoring project.

Equipment

Water level stilling wells

We install capacitive sensors inside custom-made plastic stilling wells to measure stream and reservoir water level at high frequency. The stilling well simply provides a structure to hang the sensor from and stabilizes the water level around the sensor when there are sources of movement like waves from wind. The sensors come in a variety of lengths (we prefer the 2m variety) but need to be installed such that they extend within the expected range of water levels during a field season. These devices are best suited for installation in calmer water, but they can be installed or have their height adjusted easily at any time during a field season.

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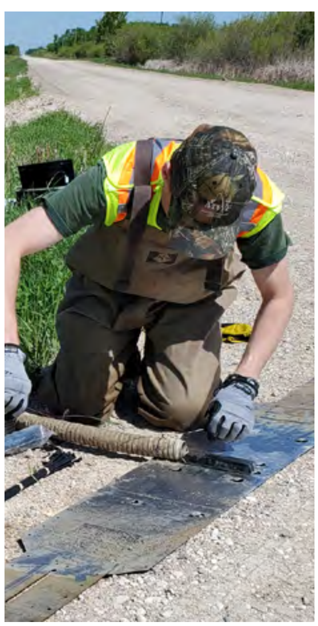


Flow probes and pressure transducers

We install acoustic flow sensors and pressure transducers inside culverts and channels to measure discharge and water levels at high frequencies. The flow module or computer remains elevated and dry, while the sensors themselves are placed inside culverts or at the bottom of channels. Sensor installation is performed using either a scissor ring (culverts only) or an anchor to prevent the sensor from being blown out of the culvert or channel when flow rates become high.

$$$$

Automated water samplers

We install automated water samplers near hydraulic structures and within channels to measure water-quality constituents at high frequency. The water storage system remains elevated and dry while the intakes for the devices are placed within the path of flowing water. These systems can be equipped with different configurations of bottles and programmed in several ways to suit monitoring requirements. Some of the important sampling configurations are described later in this guide.

$$$$

Trail cameras and staff gauges

We install cellular trail cameras to enable real-time monitoring of site conditions and to provide security. Photographs aid in decision making for future field trip timing, provide important context for monitoring data during desk-based analyses, and allow us to track the activity of wildlife. For example, we use trail camera imagery to determine the exact water level at which hydraulic structures begin flowing, physically identify flow obstructions like beaver dams, and characterize points in time when water quality is visibly poor. Water levels can also be manually read from staff gauges in photographs, which can provide data redundancy in the case of water level stilling well failure.

$$–$$$

Handheld flow probes

We collect measurements of discharge manually in culverts and channels using electromagnetic and propellor-based flow probes. Handheld flow probes are far more flexible than fixed-in-place sensors because we can collect multiple measurements of velocity from different positions for a single discharge measurement. This is particularly important for measuring irregular flow cross-sections like naturalized channels or when unusual site conditions like flow obstructions are created and need to be accommodated.

$$$$–$$$$$

Plastic bottles and filters

We collect measurements of water-quality constituents manually in simple plastic bottles. Unlike samples collected by automated water samplers, these samples can be immediately stabilized in the field or transported to a lab for analysis. This is a more practical method of taking measurements of dissolved or particulate forms of nutrients and sediments or nutrient forms, which are used for specific purposes, like orthophosphate.

$

A simple metre stick

We use a metre stick to measure water levels against known elevation benchmarks like culvert inverts and estimate the cross-sectional geometry of naturalized channels without expensive surveying equipment. The metre stick is the Swiss Army Knife of water retention monitoring, and we recommend never visiting a site without one.

$

General hardware

We use a variety of different hardware to serve as the infrastructure for our monitoring equipment. We hammer posts into the ground and install anchors where needed to mount our cameras and sensors. We use plastic bins to keep the computers and batteries of our equipment safe and dry. We protect electronic cabling and intake tubing from destructive entities using metal conduits. This hardware keeps our equipment in place and reliably functional throughout the field season.

$–$$

Box 3. Water retention monitoring safety

- Working around fast-moving water is dangerous, and many precautions are necessary to do so safely. Never work alone and be sure to wear protective equipment like a personal floatation device—it could save your life.
- Take manual samples or measurements only when and where it is safe to do so. Permanent hardware installations are both more convenient and safer to perform during dry periods, when sites are more accessible.

5.0 How Do We Make the Most Out of These Monitoring Tools?

With an understanding of your water retention system and the tools needed to track its water balance and quality constituents over time, decision making around specific deployments and site visitation frequency can begin to be made.

As may be obvious from the cost of various monitoring equipment options, it is unlikely to be cost-effective to place automated high-frequency equipment at every location and for every data type of interest for your water retention system over an entire field season.

Instead, strategies can be employed to simplify your monitoring equipment requirements at the expense of additional analysis after the field season. How you decide to balance this trade-off will depend on your objectives, budget for monitoring, and technical capacity.

Water Quantity

Automated measurements of flow can be extremely valuable, particularly where conditions are dynamic, and the flow for a given location depends on both upstream and downstream water levels.

However, the use of automated flow-measurement equipment across your site could be prohibitively expensive and less flexible than using handheld flow-measurement devices. Automated flow-measurement equipment is best suited for installation within conduits or channels with basic cross-sectional geometry that does not change over time, which cannot be guaranteed within earthen channels.

By contrast, automated water-level monitoring equipment is inexpensive, much easier to deploy, and can even be safely deployed within streams that may erode and change shape over time without much fear of data-quality degradation.

For these reasons, rating curves are often used to estimate discharge using nearby water levels, which can be more affordably monitored at high frequency and replace the need for automated flow measurement. This option to create rating curves can make future monitoring for the site simpler and more affordable while still maintaining an acceptable amount of data collection that can be periodically validated using manual flow measurements.

Hydraulic structures like culverts, weirs, and spillways are ideal locations to deploy water level-monitoring equipment and to develop rating curves. These structures will generally behave in a consistent manner and are designed using specific criteria, such as elevations, which means that they can also be used as common reference points for water-level elevations across the water retention site.

Under most circumstances, a rating curve may be developed by relating the upstream water level to discharge measurements.

For weirs and spillways, under most circumstances, discharge can be estimated based on the upstream water level alone. If it is uncertain whether the weir or spillway may become submerged over time, becoming backwater affected (i.e., influenced by downstream water levels), the safest approach is to also monitor the water level downstream.

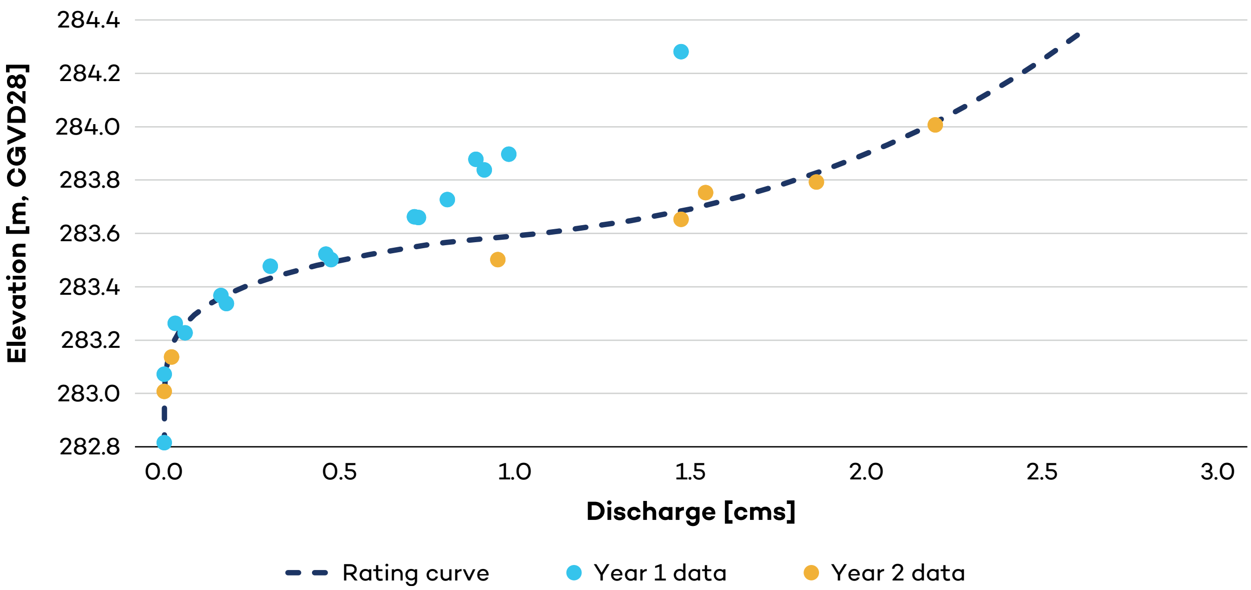
In flat regions like the Canadian Prairies, some hydraulic structures, like culverts, are almost always backwater affected. This being the case, knowing both the upstream and downstream water level of a culvert may be necessary to accurately estimate discharge, and a family of rating curves may need to be developed for the observable range of downstream water levels.

Fortunately, the cumulative backwater effects of prairie landscapes, streams, and culverts sometimes result in flows that can still be accurately estimated with just upstream water levels over a single field season. When this is the case, it can simplify analyses, but downstream water-level monitoring is still recommended to ensure that any assumptions remain accurate over time (Box 4).

Box 4. Rating curves

- A rating curve is used to estimate flow rates from water levels and, in its simplest form, may be developed by tracing a line through available data. Rating curves can reduce the need for automated flow-measurement equipment but does require taking manual measurements or using models to create them.
- It is possible that a single rating curve can successfully estimate flow from upstream water levels during a complete field season but needs to be modified the next. Within Figure 2, note that the single rating curve developed in year 2 does not account for site conditions that resulted in the stronger backwater effect that was observed in year 1, therefore necessitating the need for an updated rating curve (e.g., resulting from the removal of a flow obstruction in year 2).

Figure 2. Demonstration of a simple rating curve fit to measured data and changing conditions between field seasons



Source: Authors' diagram.

Water Quality

Manual sampling is the first type of measurement practice to consider to assess water quality, as it may be the most cost-effective and simple solution for obtaining good enough data to evaluate treatment performance.

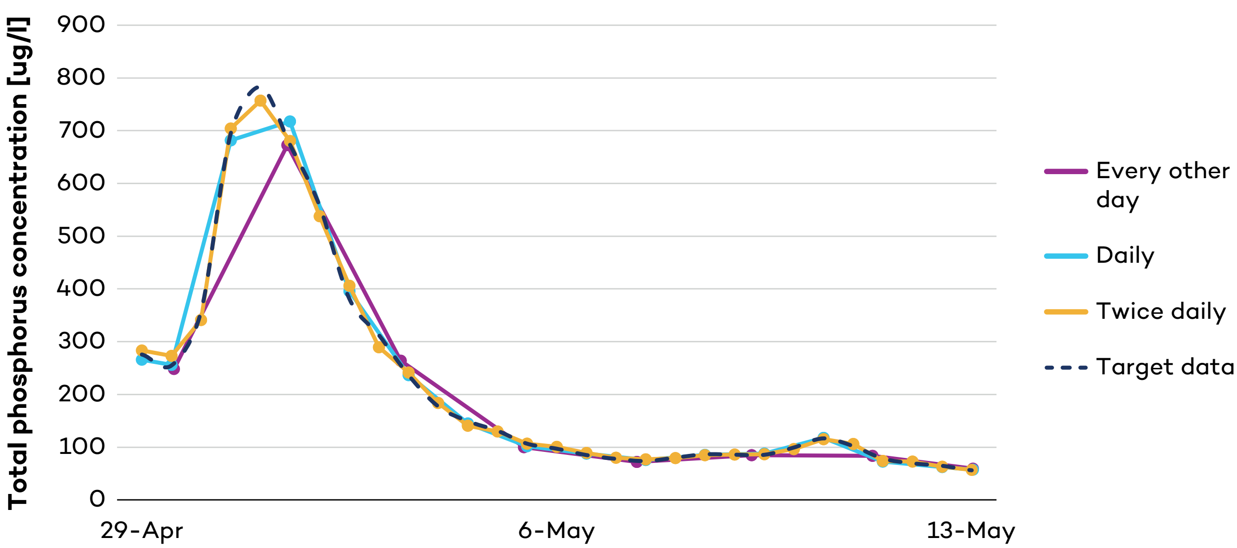
Existing programs like the Lake Winnipeg Foundation's volunteer-led Community-Based Monitoring Network can also provide the equipment needed and guidance for manual sampling methods, providing an easy onramp for most interested people to get started.

However, due diligence leveraging local knowledge is required as part of monitoring plan development to determine an appropriate sampling frequency for a site and whether or not it will be feasible to accurately monitor your site using manual methods (Box 5).

Box 5. Sampling frequency and timing

- The snowmelt and rainfall events that drive streamflow and nutrient/sediment concentration inflows in water retention systems can come and go quickly, and there is nothing preventing these events from reaching their peak while you are fast asleep or otherwise off the clock.
- Figure 3 illustrates how you might fail to collect the critical data needed to evaluate water retention site performance using lower sampling frequencies, despite your best efforts. Note that in this instance, sampling every other day when combined with linear interpolation methods (straight connecting lines between data) would underestimate the measured load.
- While these gaps may be filled using models or more advanced interpolation methods if you have the technical knowledge, these estimates are likely to be more uncertain, as you may not be able to properly validate the data.
- Consider, too, the possibility of missing your opportunity to measure events when timing the deployment of equipment or when taking manual samples, as you never know when life will get in the way.

Figure 3. Simulated comparison of different total phosphorus sampling frequencies for a spring runoff event



Source: Authors' diagram.

Although the equipment needed to automate water-quality sampling does not come cheap, it is very possible that scheduling frequent manual sampling trips around unpredictable hydrologic events may be even more expensive. This is particularly true for rural sites like those monitored by the IISD, which are hours away from Winnipeg, Manitoba, but this could still ring true even if you are monitoring a site on your own property.

As higher-frequency measurements of water quality can, in some cases, be critical for reliable monitoring, it is important to understand the different ways that programmable automated samplers may be configured, if deploying one is appropriate for your site. Each configuration can serve a different purpose, and you need to consider which one is most appropriate for your site.

Some key configurations and reasons for selecting them include

- **sequential sampling:** Individual samples are collected within separate bottles at a specified time interval. This type of sampling is useful when you need to know the water quality at a specific moment in time for a given volume of water. IISD uses this sampling method for measuring the quality of water leaving the reservoir of water retention sites and provides the key time-series dataset for calibrating water-quality treatment models.
- **composite sampling:** Multiple samples are combined within single bottles at a specified time interval. This type of sampling is useful when you know that water quality can vary rapidly over short periods of time and that a single sample may poorly represent the average within that variability. IISD uses this sampling method for measuring the inflows toward water retention sites and provides the key time-series dataset for defining water-quality treatment-model inflow boundary conditions.
- **flow proportional composite sampling:** Multiple samples are combined within a single bottle with sample volumes proportional to the measured flow. This type of sampling requires additional equipment for automated flow measurement but is useful when you want the most accurate value for the total loading of a water-quality constituent. IISD does not currently use this sampling method in the monitoring of water retention sites so that it can obtain higher frequency time-series data to assess site dynamics.

Even when using programmable autosamplers, however, there can still be limitations compared to manual sampling. For example, in order to sample for more complex forms of phosphorus, such as its dissolved or particulate components, or orthophosphates, water samples need to be processed quickly or stabilized to prevent changes from occurring to the sample while in storage.

Some automated samplers are refrigerated, which can give users more time to process samples, but these units are more expensive and may not be practical to use in areas with limited access to power.

For this reason, even if an automated sampler is part of your monitoring, it is still strongly recommended that manual sampling be practised during periodic site checkups and maintenance trips to collect more detailed water-quality samples where needed.

6.0 What Are Some Common Challenges for Monitoring Water Retention?

Mastering Time Management

Timing the deployment of your equipment and scheduling manual sampling trips to capture seasonal events like spring runoff while managing other responsibilities requires a lot of dedication, especially when sites can be far from home. Equipment is also most easily deployed when soils are not frozen, water levels are low, and deployment sites like the insides of culverts are accessible. This means that taking the time to deploy your monitoring infrastructure like posts and other hardware during the fall and your electronics during the early spring may be the best strategy.

Expecting the Unexpected

You developed your understanding of the water balance based on the best available public data and took every reasonable measure to monitor it successfully over your first field season. Yet, when you are back at your desk analyzing the data after a field season has concluded, the water balance cannot be balanced. What gives? The movement of water across natural landscapes is chaotic, and even having access to the best available data may not allow you to perfectly predict future outcomes. You must expect the unexpected when visiting a water retention site and actively seek out and document any oddities that may affect the monitoring of your water balance, including "short-circuits" within expected flow paths; natural flow obstructions, such as build-ups of vegetation, debris, and beaver dams; infrastructure damage that occurs mid-field season, such as eroded roadways and damage to hydraulic structures; and other unforeseen developments.

Everything Fails Eventually

The minute you leave your monitoring site after a hard day's work, you've begun rolling the dice on potential equipment failures that can sully your efforts. Extreme weather conditions, random electronics failures, wild animals, vandalism, and theft can all contribute to discontinuities in your monitoring data. There is not much you can do to avoid these challenges, besides creating redundancy in your monitoring plan wherever possible, securing your equipment from damage and theft, and regularly checking up on your equipment in case it needs repositioning, repairs, or replacing. Being able and ready to respond to these threats during regularly scheduled site visits is therefore critical to ensuring continuity in your data.

7.0 How Do We Use Water Retention Monitoring Data?

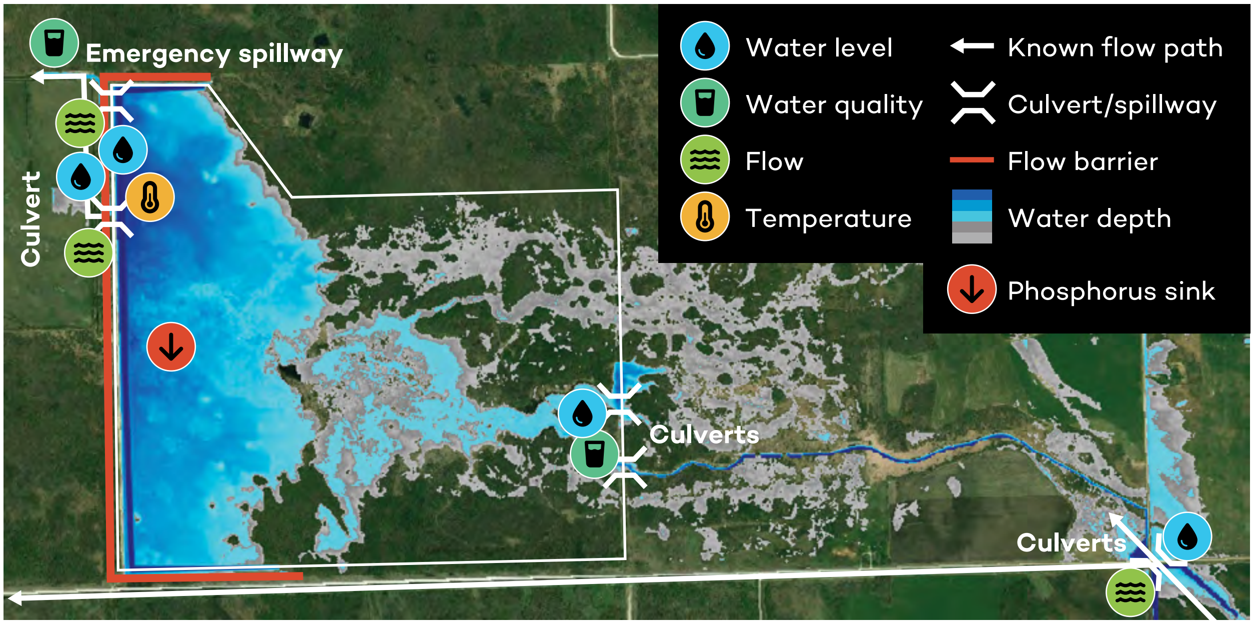
Monitoring data of sufficient quality can be directly processed to determine water-quality treatment performance by taking the difference between your measured loads in and out of the site.

More detailed data collection efforts can also support the development of hydraulic and water-quality treatment models (Box 6). These types of data and models, when evaluated for a multitude of different sites and over long periods of time, can be used to develop guidance on future site designs to maximize site performance.

Box 6. Water retention models

- Treatment models can be used to assess the changes in water quality through water retention sites and how that change is influenced by parameters like water depth and temperature (Figure 4). Monitoring data can also be used to produce additional datasets that are not simple to directly measure. For example, the retention time of water through the site is critical for modelling water-quality treatment and can be nominally estimated using a combination of site water-volume and outflow time-series data.
- We can also go beyond the development of rating curves and create physical models for water retention sites and the hydraulic structures within them. This can allow us to create new hydrologic scenarios from existing data and assess how site performance might change if it was designed or managed differently.

Figure 4. Coupled hydraulic and water-quality treatment model derived from De Salaberry water retention monitoring data



Source: Authors' diagram.

Once we understand, generally, how a water retention site is functioning, this knowledge can also be used to develop recommendations for site management that will enhance and improve site performance, as well as simple management changes that will enhance other additional co-benefits, including habitat, biodiversity, and carbon storage.

8.0 What Is Needed Next for Water Retention Monitoring in the Prairies?

There continues to be a significant need for water retention performance data, but there is a lack of different long-term monitoring sites to draw this information from.

As we scale up the implementation of natural infrastructure on the Canadian Prairies, like water retention, long-term biophysical monitoring data will be needed to improve site design and management and to ensure that implemented projects are performing as they should in theory.

This guidance document aims to make water retention monitoring a more accessible practice from a technical standpoint by demystifying some of the considerations required to get started.

Monitoring equipment is also becoming more accessible in terms of both cost and ease of use, which should continue to encourage new monitoring efforts.

IISD pledges to continue supporting future efforts by providing guidance to organizations that are curious about monitoring water retention. Please contact us if you have any questions or if you need any assistance in setting up monitoring equipment at your own water retention sites in the future.

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