PROJECT UPDATE: JUNE 2022

Adaptive Monitoring on the Winnipeg River

Key Messages

- Adaptive monitoring is a method of delivering the best data for watershed managers, policy-makers, and communities to make meaningful decisions and robust forecasts.
- Satellite telemetry, *in situ* spectral methods, and data-driven modelling (AI) are rapidly changing the way water managers can take a "smart watershed" approach.
- IISD and Aquatic Life® have deployed stations on the Winnipeg River and welcome collaborators in the public, private, and non-governmental organization sectors to explore how high-frequency water data can improve understanding, accelerate action, and build trust in the Winnipeg River basin.
- A major challenge is siting these stations in secure locations on floating buoys, affixed to bridges, or using existing water infrastructure.

Rationale

Much of the world's running fresh water originates in remote uplands, far from urban centres and intensive development. Whether supplying the Indus, the Amazon, the Mississippi, or Winnipeg rivers, these sparsely populated regions are essential for millions of downstream water users. Because of the expansive area and often remote nature of these watersheds, they are challenging to monitor.

While considerable attention is paid to water quantity and availability, the quality of the water is threatened by acute changes to landcover, accidental or intentional discharges of contaminants, urbanization, and agriculture. These changes are exacerbated by changes in climate and precipitation. Further, we do not have reasonable data or knowledge about the state and trends of many watersheds, even in developed countries like Canada (Paquette et al., 2020).

To close the knowledge–action gap, IISD and Aquatic Life® are undertaking a pilot-scale project of adaptive monitoring in the Winnipeg River basin, partially developed based on the lower Winnipeg River basin ecological and socio-economic Discussion Sheet Series.[1] The term "adaptive monitoring" was proposed by Lindenmayer and Likens (2009) to connect knowledge from Long-Term Ecological Research (LTER) to the failures and needs of public sector monitoring systems, which Roberts (1991) noted are designed backwards, as "collect now and think later." In contrast, the adaptive monitoring paradigm acknowledges existing (and likely ongoing) resource constraints, nesting the broad-scale monitoring of a few key parameters with infrequent and intensive sampling based on emerging policy priorities and scientific questions. With an increase in computational power and data telemetry, surrogate modelling and sampling optimization complement conventional and regulatory water quality monitoring with broader sources of data such as satellite/aerial remote sensing, community-based monitoring/surveillance, and academic research.

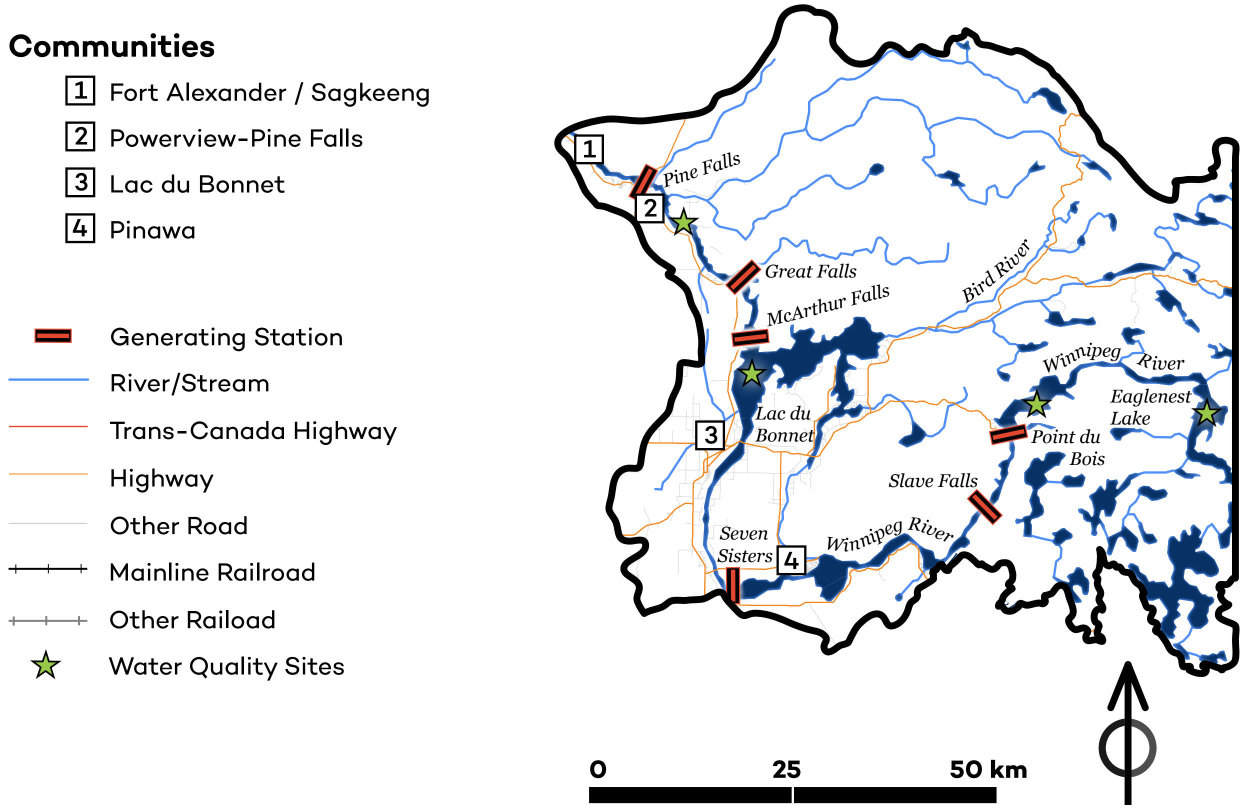
The Winnipeg River Basin

The Winnipeg River is the largest source of water feeding into Lake Winnipeg, accounting for 43% of the water entering the lake annually between 2008 and 2016. While the total phosphorus contributions are less than those of the Red River, the average annual contributions from 1994 to 2016 are still 1,050 tonnes per year (Environment and Climate Change Canada & Manitoba Agriculture and Resource Development, 2020). Additionally, there is evidence that total phosphorus exports increase downstream from the Ontario border to Lake Winnipeg (Environment Canada & Manitoba Water Stewardship, 2011; Stanley et al., 2021), with regular exceedances of the Manitoba Water Quality Standards, Objectives and Guidelines (Manitoba Water Stewardship, 2011). Outputs from the binational Great Lakes basin SPARROW watershed model (Robertson et al., 2019) provide evidence of a hot spot within the Whitemouth River watershed, indicating high incremental phosphorus yield compared to the rest of the Winnipeg River watershed.

Beyond phosphorus, the Winnipeg River basin is the site of historical and present-day water challenges. A history of hydroelectric development and reservoir management dates back to 1893 when the Norman Dam was constructed to hold water on Lake of the Woods (Lovisek et al., 1995). Since then, multiple generating stations have been installed along the runs of the Winnipeg River (Figure 1), which flooded traditional lands and altered the seasonal flows of the river (Sagkeeng Anicinabe, 2014, 2015). Additional industrial development, including forestry, logging mills, and the AECL Whiteshell laboratory, may have influenced the quality of the water—and the perceptions of both local residents and visitors (Canadian Nuclear Laboratories, 2016; CBC News, 2018; Chambers, 1999; Martins et al., 2013; Wilderness Committee., n.d.).

[1] To see an interactive map of the watershed, see: https://www.iisd.org/projects/lower-winnipeg-river-basin-opportunity-improve-health-our-waters

Figure 1. The lower Winnipeg River basin



Source: G. Gunn/IISD with data from Government of Manitoba, n.d.

Pilot Project

The process of characterizing the lower Winnipeg River basin has identified data and information gaps, as well as a need for an improved monitoring system (Stanley et al., 2021). There are currently three formal monitoring programs on the river (CAMP; ECCC Lake Winnipeg Initiative; and the Environment, Climate and Parks Provincial Department), as well as the recent addition of a community-based monitoring program led by the Lake Winnipeg Foundation (the Lake Winnipeg Community-Based Monitoring Network). Each program uses different analytical methods and sampling periods, limiting the ability to conduct site comparisons (Stanley et al., 2021) for effective basin-scale decision making.

IISD (via IISD-Experimental Lakes Area) and Aquatic Life® have partnered to leverage their expertise in a pilot project to deploy high-frequency (≤1 hour) electronic sensors that deliver data in near real-time via satellite and mobile data networks. Using conventional water quality sensors alongside recent innovations in *in situ* spectroscopy allows robust monitoring of common parameters like temperature, dissolved oxygen, conductivity, and turbidity but also parameters based on spectral (UV-Vis) fingerprints like dissolved organic carbon (DOC), nitrate nitrogen (NO3-N), and total phosphorus (TP). These latter two nutrient parameters are of key importance to the Winnipeg River and Lake Winnipeg and, until recently, were only available by physical sampling. An additional parameter—BTEX[2]—will also be targeted to support innovations in monitoring volatile organic compounds.

Hypothesis and Modelling

The hypothesis of this project is that an adaptive monitoring system, driven by high-frequency *in situ* sensors, is a necessary step in modernizing water management and stewardship. Each site alone can generate more samples in a week than exist in the entire provincial and federal record. Unlike existing water quality systems, the data will be available in near real-time, with delays of minutes rather than years. This means exceedances of certain parameters can trigger alarms or notifications to local officials, and reports on the status of water may be generated. Therefore, the first objective of this project is to generate data for communities and officials along the Winnipeg River to inform their decision making.

This is supported by policy-oriented literature and reviews of water quality management systems. In a review of 34 articles, Behmel et al. (2016) conclude that a key research objective should be

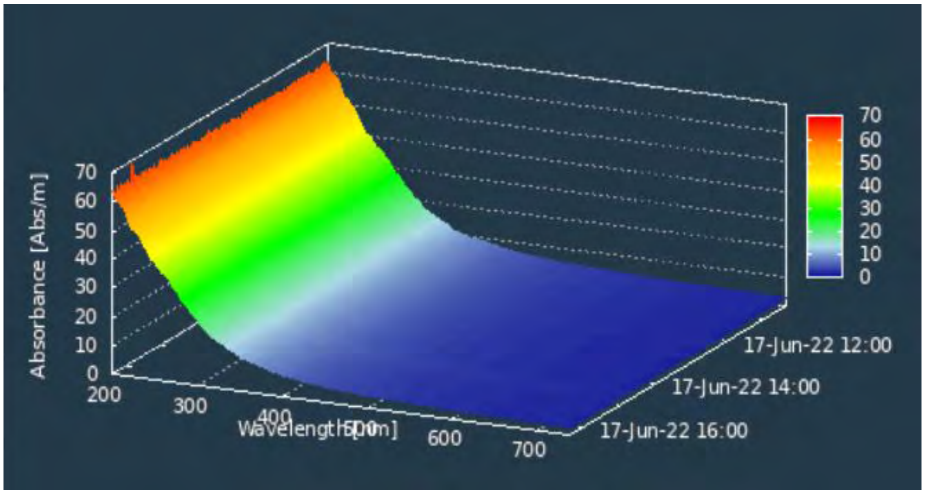
> further investigating the benefits of intelligent decision support systems that can be updated quickly and would make it possible for a watershed manager to obtain a timely, holistic view and support for every aspect of planning and optimizing a [Water Quality Management Plan]. (p. 16)

Tiyasha et al. (2020) report over 200 research articles published in the past two decades on the use of artificial intelligence (AI) to model river water quality. They report the emerging maturity of these systems to classify bulk water masses, estimate parameters given other surrogate parameters, and produce near-term forecasts from upstream variables like precipitation and temperature. The most common parameters modelled include the Water Quality Index (a regionally distinct suite of parameters of interest) including dissolved oxygen, nitrogen, oxygen demand (biological, chemical), water temperature, and dissolved solids. Less frequently modelled parameters include suspended sediments and pH, which are often easier to capture in the field.

Tiyasha et al. (2020) and many others report a lack of data collected at the appropriate scale to develop these models. The most favoured AI techniques include artificial neural networks and back-propagation neural networks—both are extremely data intensive and essentially require inputs of "big data." Further, the authors report that few of these projects have long life cycles, and many models need continuous inputs of data to remain accurate—particularly as state changes caused by shifts in climate or pollutants can dramatically influence river characteristics. Kämäri et al. (2020) have demonstrated the potential of high-frequency spectral datasets to derive chemical species concentrations (like phosphorus and nitrogen).

[2] Benzene, toluene, ethylbenzene, and three isomers of xylene.

Figure 2. Spectral fingerprint of water in the Winnipeg River



Beyond surrogate modelling, there is a new opportunity to develop spectral libraries for parameters of interest to Manitoba, primarily NO_3-N and TP (see Figure 2). Working with the sensor manufacturer,[3] we are developing high-quality datasets in the Canadian context to improve monitoring of nutrient pollution at minute-scale frequencies—appropriate for understanding the constituents of melt- and stormwater discharges.

This project is answering the following questions:

1. Can high-frequency water quality stations influence water management on the Winnipeg River—including by improving drinking water treatment systems; informing community leaders about the state of the river; and, along with existing programs, contributing to a shared understanding of the state of the river?
2. Does changing the frequency of monitoring from quarterly or monthly to hourly build a useful dataset to develop surrogate models for complex and important chemical or biological parameters?
3. After one season, will there be sufficient data to train a data-driven model to generate near-term forecasts of river water quality?
4. Can we isolate the spectral response of phosphorus and nitrogen in Manitoba's surface waters?

[3] Austria-based s::can, https://www.s-can.at.

Project Progress (2021)

In 2021, IISD-ELA and Aquatic Life® successfully deployed s::can spectro::lyser v2 sensors along the Winnipeg River, at the Pinawa Marina and the Powerview-Pine Falls Drinking Water Treatment Facility, to record ≤ hourly water quality data.

Powerview-Pine Falls Drinking Water Treatment Facility

Equipment: s::can micro::station with spectro::lyser v2 installed on a low-pressure flow line after the pre-filtration system, transmitted with a cellular network.

Measured Parameters: flow, pressure, pH, temperature, and oxidation reduction potential (ORP).

Spectrally-Derived Parameters: turbidity, NO_3-N*, total organic carbon (TOC)*, DOC*, colour, BTEX*, and TP*.

Dates: April 30, 2021–present (May 2022).

* indicates experimental parameters with additional laboratory analytical data collection

Pinawa Marina

Equipment: AquaHive with s::can spectro::lyser v2 installed on the dock at the Pinawa Marina. This instrument uses a 35 mm path length.

Measured Parameters: pH, temperature, ORP, dissolved oxygen, actual conductivity, specific conductivity, turbidity, and total dissolved solids.

Spectrally-Derived Parameters: turbidity, NO_3-N*, TOC*, DOC*, colour, BTEX*, and TP*.

Dates: May 28, 2021–November 15, 2021

During the 2021 deployment, the sensor platform made 4,166 recordings.

* indicates experimental parameters with additional laboratory analytical data collection

Next Steps (2022–2024)

In 2022, IISD and Aquatic Life® plan to continue monitoring the Powerview-Pine Falls Drinking Water Treatment Facility and at the Pinawa Marina and deploy the s::can spectro::lyser v3 along the Whitemouth River pending appropriate site selection and access.

Higher-frequency data collected from the three sites on the Winnipeg River will be explored between 2022 and 2024 for forecasting and prediction potential and used to answer the four questions outlined above.

Results from this project on the Winnipeg River will inform the use of adaptive monitoring practices, including higher-frequency and real-time monitoring, in other watersheds and rivers.

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Head Office

111 Lombard Avenue, Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

Tel: +1 (204) 958-7700
Website: www.iisd.org
Twitter: @IISD_news

Primary Project Contacts

Madeline Stanley, IISD
mstanley@iisd.ca

Jeff Simpson, Aquatic Life®
jsimpson@aquaticlife.ca

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