# Comparison of sampling strategies to monitor water quality in Prairie Watersheds

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## Introduction and Background

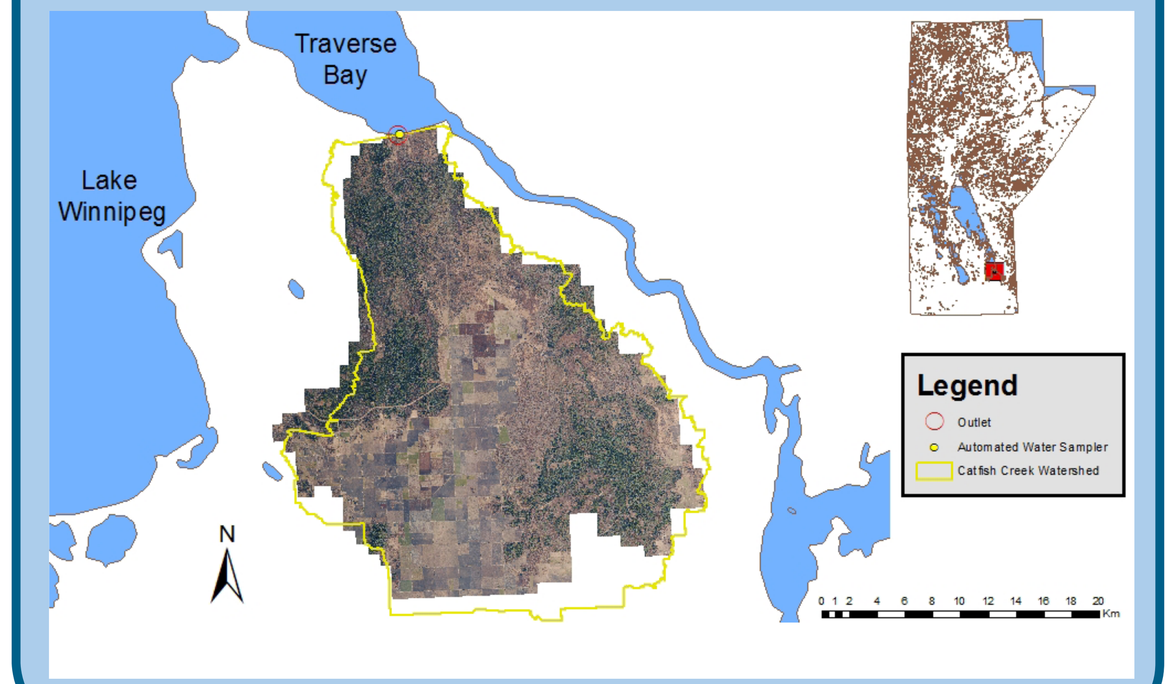
Most water-quality monitoring programs are characterized by low-frequency sampling with variable intervals (Neal et al., 2012). In Manitoba, Conservation and Water Stewardship collects water from streams and creeks approximately four times a year with the intention of capturing seasonal water-quality fluctuations. This type of sampling is however unable to capture changes in water-quality attributes that take place at short timescales. Recent research suggests that significant fluctuations in water-quality occurr across a wide range of timescales (e.g., Kirchner, 2003; Feng et al., 2004; Kirchner et al., 2004; Halliday et al., 2012). Particularly, the diffuse transfer of nutrients in watersheds, particularly phosphorus, has been shown to occur on an hourly scale (Halliday et al., 2012). Additionally, in the Prairies, both snowmelt on frozen ground and intense thunderstorms are short-lived and tend to result in hydrological responses in a matter of hours rather than days or weeks, thus challenging the representativeness of water samples collected outside of these critical hydrological events (Zhao and Gray, 1997).

The general objective of this project was to compare sampling strategies for water-quality monitoring in Prairie watersheds. The comparison was guided by three specific research questions regarding:

1. Water quality parameter sensitivity
   - Do specific water quality parameters range in sensitivity to hydrologic processes typical of Prairie landscapes?
2. Sampling time
   - Does sampling time impact the hydrochemical information obtained from water-quality analysis?
3. Data representativeness
   - Does an increase in sampling interval length necessarily result in the reduction of data representativeness?

## Study Site

- The Catfish Creek Watershed drains an area of 642 km² intro Traverse Bay and Lake Winnipeg.
- Characterized by numerous surface drains, ditches and near level topographic profile across the watershed.
- Spatial distribution of land use and land cover is approximately 50% forest and 50% agricultural.
- Monitoring station located at the outlet of the watershed.




## Methods

- Sample collection between April and October 2013.
- Samples collected every 7-hours on a 7-day schedule resulting in 24 samples per week. The sampling program results in every hour of the day being sampled once a week providing partial diurnal characterization (24/7 solution).
- Sampling is done using a Hach Sigma™ electronically-controlled, battery-powered automated water-sampler .
- Chemical determinands selected for analysis include: phosphate ($PO_4$), electrical conductivity (EC), total dissolved solids (TDS), pH, turbidity and salinity.

## Manual Dataset Generation

Ten datasets **(i)** were created from the deconstruction of the original high-frequency dataset (high-frequency dataset = samples collected in the field every 7 hours). The following assumptions were used:

- Sampling time assumptions for the altered 7-hour datasets
  - Day: 6:00 – 22:00
  - Night: 22:00 – 6:00
- Water-level assumptions for the altered 7-hour datasets
  - Rising: water-level increase ≥ 10% compared to previous
  - Falling: water-level decrease ≥ 10% compared to previous
  - Minimal Change: water-level fluctuation ≤ 10% compared to previous
- Primary assumptions for the lower-frequency datasets
  - 9am – 5pm
  - Monday to Friday

## Results for $PO_4$ Concentrations

- Significant variability at short timescales. **(iii)**
- Low-frequency datasets describe variance and mean concentration of phosphate well. **(ii)**
- Consistent inter-quartile range and mean concentrations between datasets. **(ii)**
- Low-frequency timeseries fail to capture extremes and rapid fluctuations. **(iii)**
- Using the two-sample Kolmogorov-Smirnov test, all dataset and data subset statistical distributions, excluding the one associated with the bi-weekly dataset, were all shown to be from the same origin as the high-frequency dataset.
- Empirical cumulative distribution functions associated with the lower-frequency datasets show less similarity to that of the original high-frequency dataset as sampling interval length increases. **(iv)**

### (i)

Datasets manually generated from the deconstruction of the original 24/7 timeseries.
(HF - high-frequency)

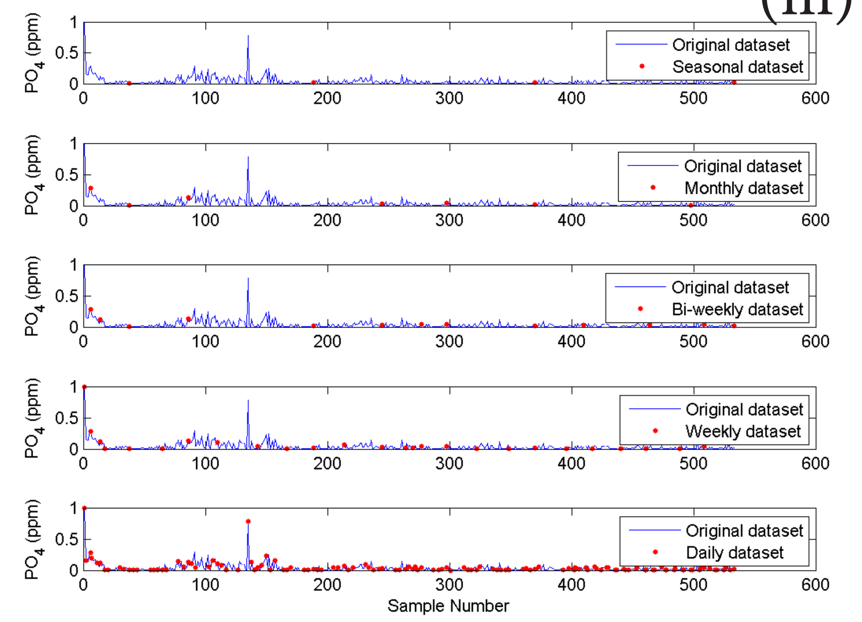
| Dataset | Frequency | Reference Name |
|---|---|---|
| HF dataset from 24/7 solution sampling strategy | 7-hour | Original high-frequency |
| HF dataset from 24/7 solution, including only day-time samples | Altered 7-hour | High-frequency daytime |
| HF dataset from 24/7 solution, including only night-time samples | Altered 7-hour | High-frequency night-time |
| HF dataset from 24/7 solution, including samples with rising water-level | Altered 7-hour | High-frequency rising |
| HF dataset from 24/7 solution, including samples with falling water-level | Altered 7-hour | High-frequency falling |
| HF dataset from 24/7 solution, including samples with minimal change in water-level | Altered 7-hour | High-frequency minimal change |
| **Lower-frequency datasets** | | |
| 24-hour, 'daily' sampling strategy | Daily (24-hr) | Daily |
| Weekly sampling strategy | 7 days | Weekly |
| Bi-Weekly sampling strategy | 14 days | Bi-Weekly |
| Monthly sampling strategy. | 30 days | Monthly |
| Seasonal sampling strategy. | Seasonally | Seasonal |

### (ii)

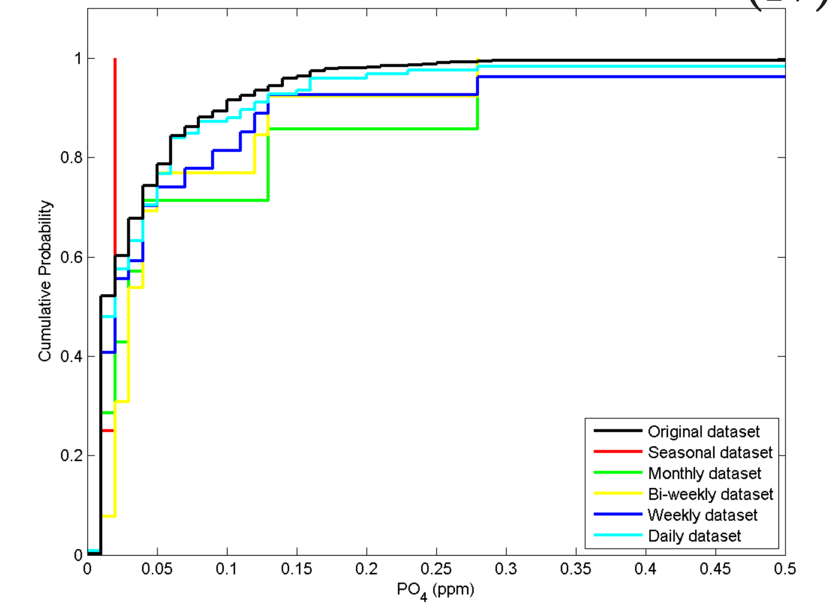
Summary statistics for phosphate ($PO_4$) concentrations, in ppm, for the (original) high-frequency dataset and the manually generated datasets listed in (i). IQR - inter-quartile range; % - percentile; Std - standard deviation; HF – high-frequency; FW mean – Flow-weighted mean.

| | Orig. | HF Day | HF Night | HF Rising | HF Falling | HF Minor | Daily | Weekly | Bi-Weekly | Monthly | Seasonal |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Maximum | 0.99 | 0.99 | 0.29 | 0.16 | 0.09 | 0.78 | 0.99 | 0.99 | 0.28 | 0.28 | 0.02 |
| Range | 0.98 | 0.98 | 0.28 | 0.15 | 0.08 | 0.77 | 0.98 | 0.98 | 0.27 | 0.27 | 0.01 |
| IQR | 0.04 | 0.04 | 0.04 | 0.02 | 0.03 | 0.04 | 0.04 | 0.06 | 0.05 | 0.10 | 0.01 |
| Mean | 0.04 | 0.04 | 0.04 | 0.03 | 0.03 | 0.04 | 0.05 | 0.08 | 0.06 | 0.07 | 0.02 |
| FW Mean | 0.04 | 0.03 | 0.04 | 0.03 | 0.02 | 0.04 | 0.4 | 0.03 | 0.04 | 0.04 | 0.02 |
| Median | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 |
| 1st % | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 99th % | 0.25 | 0.26 | 0.24 | 0.15 | 0.09 | 0.24 | 0.83 | 0.99 | 0.28 | 0.28 | 0.02 |
| Variance | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.04 | 0.01 | 0.01 | 0.00 |
| Std | 0.07 | 0.078 | 0.05 | 0.03 | 0.02 | 0.06 | 0.12 | 0.19 | 0.08 | 0.10 | 0.01 |
| Skewness | 7.96 | 8.16 | 2.36 | 2.68 | 1.41 | 6.28 | 6.11 | 4.24 | 2.08 | 1.46 | -1.15 |
| Kurtosis | 95.55 | 89.70 | 9.47 | 10.36 | 4.00 | 70.44 | 44.79 | 20.52 | 6.44 | 3.62 | 0.02 |

### (iii)




### (iv)




## Revisiting Specific Research Questions

1. Water quality parameter sensitivity
   - Physical water-quality paramaters (e.g., EC, TDS) are more closely coupled to flow than phosphate.
   - Physical water-quality paramaters had larger fluctuations than phosphate.
2. Sampling time
   - Fluctuations were less intense during night-time hours.
   - Overall, day-time samples were highly representative in comparison to the original high-frequency dataset.
3. Data representativeness
   - Certain descriptive statistics (e.g., minimum, maximum) were heavily impacted by sampling interval length, while others were not.

## Outlook: a Weighted Decision Matrix to Support the Choice of a Monitoring Strategy

Criteria considered for selecting a monitoring strategy:
- Program cost
- Execution difficulty
- Ability to capture the mean concentration
- Ability to capture short-term fluctuations
- Ability to capture concentration extremes

Strategies ranked on a five point scale surrounding 0.
- Performance ranked in comparison to reference (24/7 solution)
- (i.e., -2, -1, 0, 1, 2)
- 0: roughly equal
- <0: worse performance
- >0: better performance

Three weighting schemes were developed by prioritizing criteria:
- Scenario 1 weighted all criteria equally
- Scenario 2 prioritized cost and execution difficulty
- Scenario 3 prioritized data completeness

- High-frequency minimal water-level change strategies: best suited for programs concerned with data robustness.
- High-frequency minimal water-level change datasets ranked highest when all evaluation criteria were considered equal, followed by the daily sampling strategy.
- The seasonal sampling strategy is best suited for agencies concerned with cost and execution difficulty.

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