Water Quality Monitoring Guidance Manual for the Healthy Lake Huron Initiative

Prepared for: Environment Canada

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Photo: Tom Skinner and Ross Wilson from the Ausable Bayfield Conservation Authority survey a stream cross-section to develop a rating curve for stream discharge. (Photo credit: Daniel Holm Photography, courtesy of the Rural Stormwater Management Model Project of the Healthy Lake Huron: Clean Water, Clean Beaches Initiative)

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1. Introduction

The near-shore area of the Great Lakes provides many residents of Ontario with drinking water and recreational opportunities. However, nutrient, sediment, and bacterial impacts can sometimes limit both the human uses and the ecological integrity of these near-shore waters. Non-point source pollution from landscape runoff during storm events is a significant driver of water quality issues in the Great Lakes. Agricultural activities are recognized as a non-point source contributor of nutrients, sediment, and bacteria to the near-shore waters of the Great Lakes (Smith *et al.* 2015).

To better address near-shore water quality issues in the Great Lakes, collecting data about nutrient and sediment concentrations and loads in local watersheds is essential. Measuring concentrations enables the evaluation of stream conditions against water quality standards that are established to protect the ecological integrity of the system. Estimating loads is required to evaluate land use and management, or issues that are occurring in downstream waterbodies, such as the Great Lakes (Dickinson and Rudra 2015).

Water quality monitoring results often vary both spatially and temporally. Factors that contribute to water quality variability include: climate, soil, geology, topography, land use, and land management practices. When water quality data are interpreted, accounting for these factors may help to remove variability in the data and to identify cause-and-effect relationships.

This manual provides an overview of the equipment and methods that staff from the Ausable Bayfield Conservation Authority, Maitland Valley Conservation Authority, Saugeen Valley Conservation Authority, and St. Clair Region Conservation Authority used for a water quality monitoring program undertaken in five sentinel watersheds for Lake Huron. The resulting data were used to create a Rural Storm Water Management Model (Emmons & Olivier Resources, Inc. *et al.* 2014) and to determine pollutant concentrations and loadings for the five Lake Huron tributaries (Veliz and Upsdell Wright 2015). The methods outlined include the collection of water quantity, water quality, meteorological, and land management data.

2. Water Quantity Data

Stream discharge (volume per unit time) is a key variable used to quantify mass loads of a pollutant moving through a watershed. Stream discharge data are also used to determine when and at what frequency to collect water samples that represent a range of different flow conditions for each precipitation event.

A rating curve is an important tool for developing a continuous stream discharge dataset. A rating curve is a graph that relates water level to discharge for a specific stream location, usually at a gauging station. The development of a rating curve involves two inputs (see schematic in Figure 1). The first input is a continuous dataset of stage (water level) measured at the gauging station. The second input is

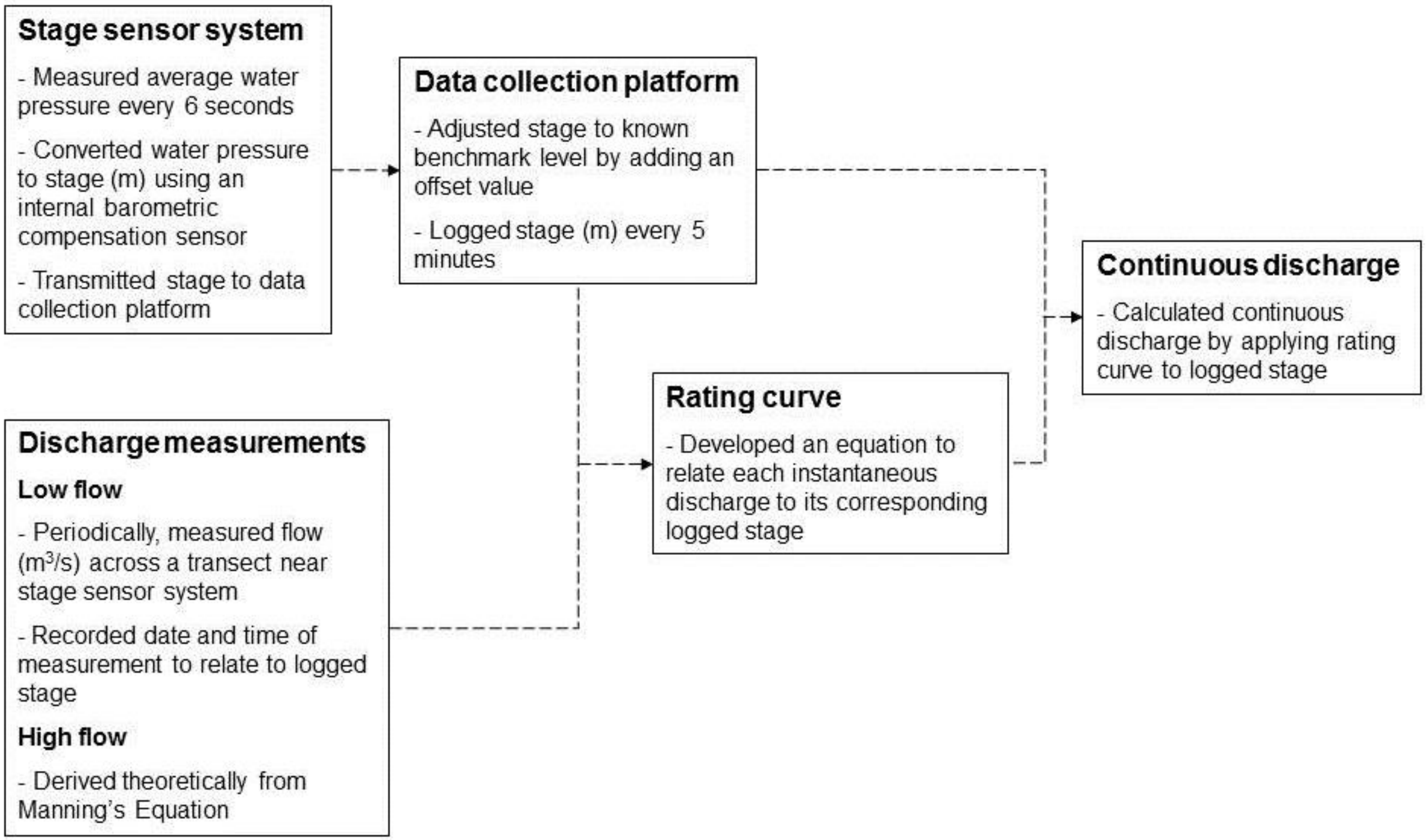

Figure 1: Method for deriving a continuous discharge dataset from a stage sensor system and instantaneous discharge measurements.

instantaneous discharge measurements (as described below), which can be related to stage measurements that are collected at the same time. In high-flow conditions, it is too dangerous to manually measure discharge, so Manning's Equation is used to generate theoretical high-flow values.

2.1 Equipment and Data Collection

2.1.1 Continuous Stage

A hut, with a wood frame and steel walls, was custom-built to house equipment at each gauging station. Considerations for the location of the station included: close to the watershed outlet without the influence of backwater from Lake Huron, traffic and safe parking, and a natural pool with continuous baseflow for measuring water levels. The stations were not co-located with utility availability to avoid monthly costs, and main highways were avoided due to building permit requirements from the Ministry of Transportation. The hut was placed on a poured concrete platform that was braced with supporting stone. A WaterLOG H-3553 Compact Combo Bubbler System was installed in the hut to measure stage (Table 1, Figure 2). A bubbler line was run from the hut to the stream through polyvinyl chloride (PVC) tubing. The bubbler system was powered by a twelve-volt, 100-amp-hour valve-regulated lead acid (VRLA) battery, which was charged by a solar panel installed on the hut roof (Figure 3). It was connected to an FTS Environmental Axiom H2 Datalogger (powered by the same battery), which recorded stage data at five-minute intervals and battery voltage at one-hour intervals. The data were consistently logged in Greenwich Mean Time (GMT), as was required to transmit the data through the Geostationary Operational Environmental Satellite (GOES) system via a transmitter component within the FTS data logger and an antenna installed on the hut roof. An arrangement was made with the Ontario Ministry of Natural Resources and Forestry to upload the data hourly to a database that can be accessed through the Government of Ontario's ONe-*key* website with an account. This allowed for near real-time access to the station's data. Four times a year, the data were downloaded directly from the FTS datalogger to a USB memory stick as a .csv file and copied over to a desktop computer.

Table 1: Continuous stage monitoring equipment installed at each stream gauging station.

Instrument Name	Instrument Type	Manufacturer
H-3553 Compact Combo Bubbler System	stream stage measurement system	WaterLOG
Axiom H2 Datalogger	data collection platform	FTS Environmental
G5 GOES Transmitter	data transmission system to online database	FTS Environmental
Yagi GOES Antenna	data transmission system to online database	FTS Environmental
SPS-20W-F6H2 Solar Panel	power source for bubbler system and datalogger	FTS Environmental
12-V, 100-Ah valve-regulated lead acid battery	power source for bubbler system and datalogger	(various)

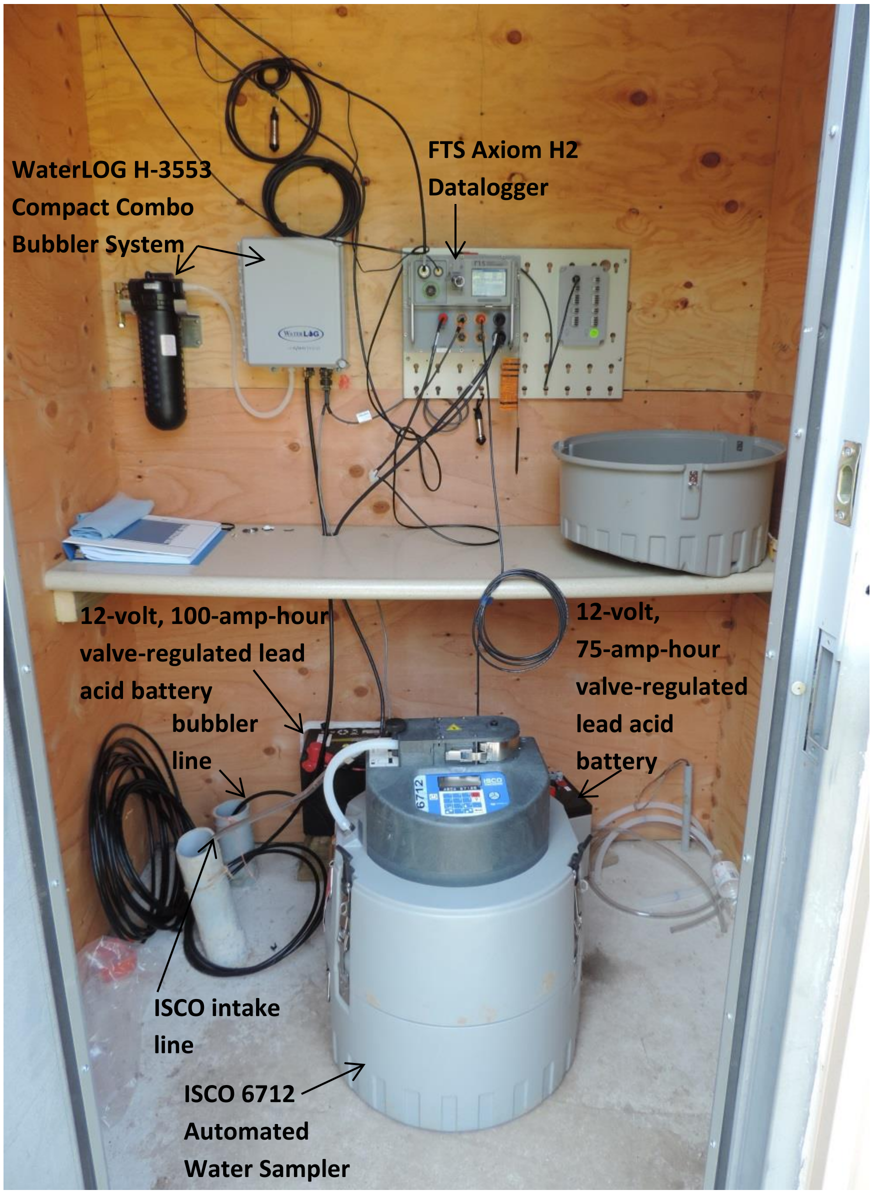

Figure 2: Stream gauging station hut with equipment for measuring stage, logging data, and collecting water samples.

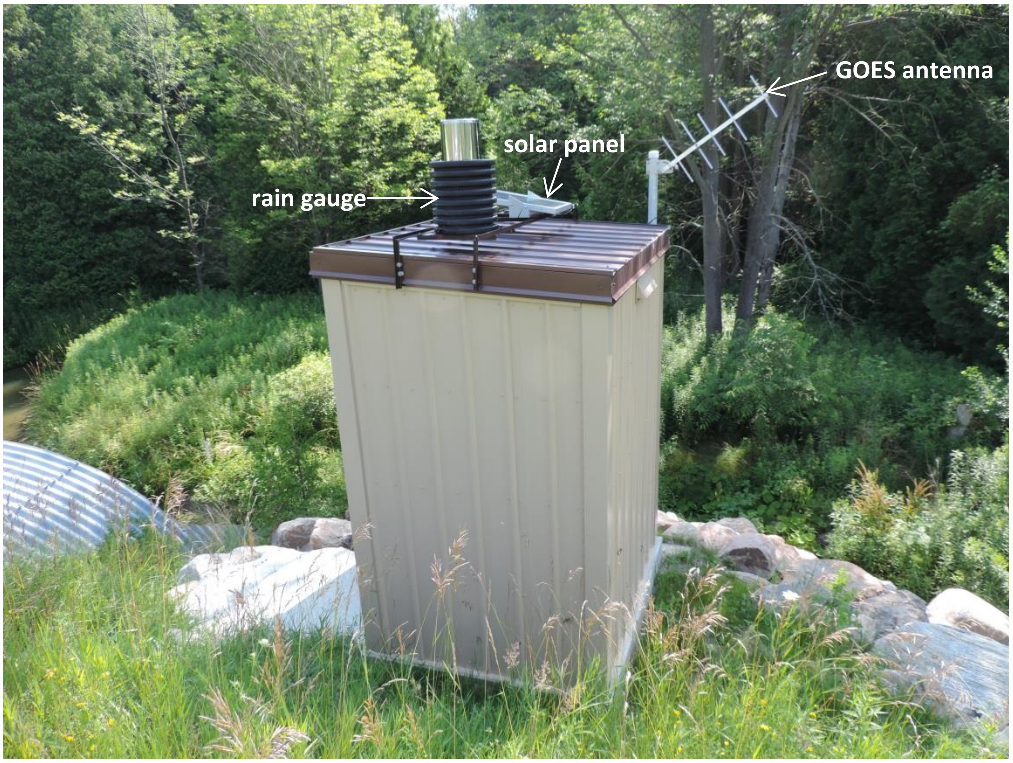

Figure 3: A stream gauging station with a tipping bucket rain gauge, solar panel, and Geostationary Operational Environmental Satellite (GOES) antenna.

2.1.2 Instantaneous Discharge

Instantaneous discharge was measured under a range of flow conditions at each gauging station so that a rating curve could be developed for the site. In order to produce instantaneous discharge data, stream velocity measurements were taken with a Marsh-McBirney Flo-Mate Model 2000 Portable Flowmeter and a top-setting wading rod. The mean-section method was used to measure stream velocity and calculate discharge (Rantz 1982). This method involved dividing a stream cross-section near the gauging station into a number of panels (Figure 4). The width of each panel was measured along the water's surface with a tape measure affixed to each stream bank. At the edge of each panel, water depth was measured with the wading rod and water velocity was measured with the flowmeter. Velocity measurements were taken at 60 per cent of the depth from the water surface (see red dots in Figure 4). All data collected were recorded immediately in Microsoft Excel (Microsoft Corporation 2010) on a Panasonic Toughbook H2 tablet, in a file that was set up to calculate the instantaneous discharge for the stream cross-section. The instantaneous discharge for each panel along the stream cross-section was calculated by multiplying the panel width by the average depth and the average velocity of the two panel edges. Equation 1 uses the first panel as an example. The total stream instantaneous discharge was determined by adding the discharges for the individual panels.

$$Q_1 = W_2 - W_1 \times \frac{D_1 + D_2}{2} \times \frac{V_1 + V_2}{2} \qquad \textbf{Equation 1}$$

where Q_1 is the water discharge of the first panel ($m^3 \cdot s^{-1}$)
W_1 is the distance between the left stream bank and the first vertical (m)
W_2 is the distance between the left stream bank and second vertical (m)
D_1 is the water depth at the first vertical (m)
D_2 is the water depth at the second vertical (m)
V_1 is the water velocity at the first vertical ($m \cdot s^{-1}$)
V_2 is the water velocity at the second vertical ($m \cdot s^{-1}$)

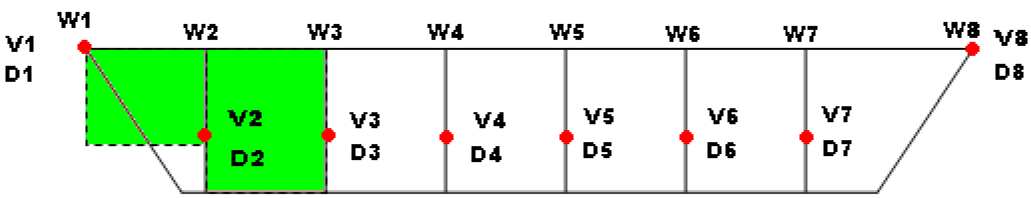

Figure 4: Stream cross-section panels for measuring instantaneous discharge with the mean-section method (D – water depth, V – water velocity, W – panel width).

2.1.3 Stream Profile and Slope

In order to generate theoretical discharges for high-flow conditions with Manning's Equation, a cross-section of the stream was surveyed near the gauging station to obtain a dataset of horizontal distance and elevation measurements that describe the shape of the stream channel (Figure 5). The slope of the streambed was also measured by surveying from a point upstream of the cross-section to a point downstream. Stream profile and slope data were entered into and stored in a Microsoft Excel file. Guidance on surveying methods can be found in Moffitt and Bossler (1998) and Ritchie (1988).

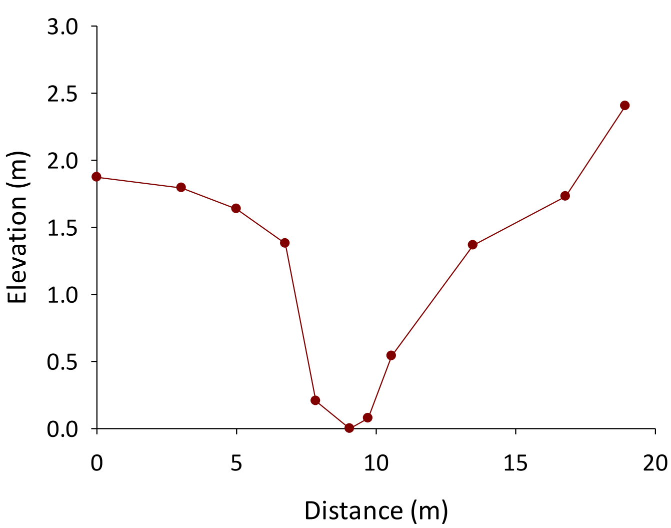

Figure 5: A stream profile example from Gully Creek, one of the five Lake Huron sentinel watersheds.

2.1.4 Equipment Maintenance

The stream gauging stations were inspected visually whenever the sites were visited (at least once per month). During each site visit, the stage reading was checked to make sure it was within a reasonable range for the current site conditions, and the bubbler line was purged to clear out any sediment build-up that can artificially increase stage readings. A desiccant cartridge on the bubbler system air intake was changed whenever the desiccant changed colour. In the winter, ice and snow were removed periodically from the solar panel in order to maintain power for the equipment.

Four times a year, manual measurements were taken to confirm the consistent position of the bubbler system's sensor point in the stream relative to a fixed measuring point, such as the edge of a culvert. This involved two measurements: 1) the distance between the fixed measuring point and the water level; and 2) the distance between the water level and the bubbler sensor point. The two measurements were added to obtain the distance between the fixed measuring point and the bubbler sensor point. A change in this value over time indicated that the sensor point had moved, and tracking any changes enabled corrections to be made to the stage data.

The flowmeter used for instantaneous discharge measurements was calibrated every few years by Environment Canada's National Calibration Service at the Canada Centre for Inland Waters in Burlington, Ontario.

2.2 Data Storage and Processing

2.2.1 Continuous Stage

Dates and times associated with continuous stage data from the stream gauging station were shifted from GMT to Eastern Standard Time (EST) to maintain consistency between datasets. The stage data were then stored in HEC-DSS, which has a graphical interface program called HEC-DSS Visual Utility Engine (HEC-DSSVue) (USACE 2010). These programs allowed data to be displayed visually as a line graph or in a tabular form.

Once the continuous stage data were in HEC-DSS, they were graphed to check for faulty readings or unexpected data gaps. Faulty readings may occur from the bubbler system or datalogger malfunctioning and would be removed from the dataset. Small gaps were filled by interpolating between the stage values on either side of the gap. Large gaps were left blank.

2.2.2 Continuous Discharge

In order to translate the continuous stage dataset into a continuous discharge dataset, a rating curve between stage and discharge had to be developed. A rating curve is specific to an individual stream gauging station, as it depends upon the shape, size, slope, and roughness of the channel at that location.

The development of a rating curve and computation of continuous discharge followed the United States Geological Survey's method for stage-discharge stations (Sauer 2002).

For each measurement of instantaneous discharge, there was a corresponding measurement of stage from the continuous stage dataset. These corresponding discharge and stage measurements helped to develop the lower end of the rating curve, for wadeable stream conditions (Figure 6). For higher stages in the continuous stage dataset, it was not safe to measure discharge in the stream, so theoretical discharges were determined based on Manning's Equation (Equation 2) and Equation 3.

$$\boldsymbol{V = \frac{R^{2/3} \times S^{1/2}}{n}}$$ **Equation 2**

where V is the average velocity of the stream cross-section ($m \cdot s^{-1}$)
R is the hydraulic radius (m), which is the cross-sectional area of flow (m^2) divided by the wetted perimeter (m)
S is the slope of the streambed (-)
n is the Manning roughness coefficient ($s \cdot m^{-1/3}$)

$$\boldsymbol{Q = A \times V}$$ **Equation 3**

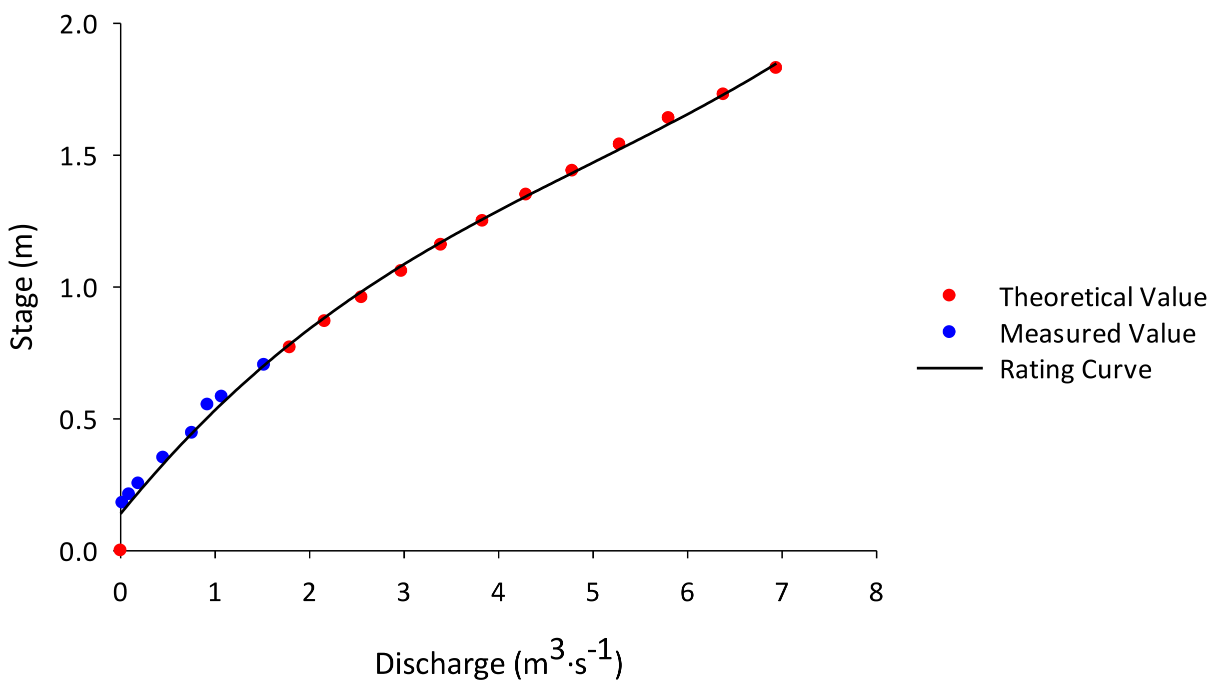

Figure 6: A rating curve example from Gully Creek, one of the five Lake Huron sentinel watersheds.

Curve is a 3rd-order (cubic) polynomial equation

A Visual Basic program called Rating Curve Program, which was developed by a former staff member of the Ausable Bayfield Conservation Authority, was used to automate Manning's Equation. The following data from surveying the stream profile and slope were entered into Rating Curve Program:

- total horizontal distance surveyed for the stream cross-section (metres);
- minimum elevation of the cross-section, standardized to 0 metres;
- maximum elevation of the cross-section, relative to the 0-metre minimum;
- data pairs of horizontal distance from the starting point of the stream cross-section (metres) and elevation (metres); and
- stream slope.

Rating Curve Program also requires the selection of a Manning roughness coefficient. A coefficient of 0.04 was used as a starting point and was refined based on the output from Rating Curve Program.

Rating Curve Program generated an output file that contained a rating table that represented the stage-discharge relationship with Manning's Equation. (A rating table is a tabular representation of the rating curve that matches discharge values with corresponding stage values.) Several iterations of a rating table were generated with Rating Curve Program by adjusting the Manning roughness coefficient until the theoretical stage-discharge dataset created a reasonable extension of the rating curve started with the instantaneous discharge and continuous stage measurements.

When the rating curve was finalized, a hydrologic function in the HEC-DSS program was used to apply the gauging station's rating curve to the continuous stage dataset in order to create a continuous discharge dataset.

3. Water Quality Data

3.1 Equipment and Data Collection

3.1.1 Baseflow Monitoring

To capture baseflow water quality conditions throughout the year, monthly water samples were collected by grab sampling at each stream gauging station. When these grab samples were collected, physicochemical parameters (*i.e.*, water temperature, conductivity, total dissolved solids, dissolved oxygen, and pH) were also measured with a YSI 600 QS probe and recorded by a YSI 650 Multiparameter Display System (MDS). As a back-up to the YSI MDS, data from the YSI probe were also recorded on a field sheet.

The grab samples were submitted to the Ministry of the Environment and Climate Change (MOECC) laboratory in Etobicoke, Ontario, for analysis. They were analyzed for:

- total ammonia (as nitrogen);
- nitrate and nitrite (as nitrogen);
- nitrite (as nitrogen);
- total Kjeldahl nitrogen;
- total nitrogen;
- phosphate (as phosphorus);
- total phosphorus;
- total dissolved solids;
- total suspended solids; and
- total solids.

3.1.2 Event Monitoring

Water samples were also collected during high-flow events that occurred due to rainfall or snowmelt. In order to capture samples throughout the event hydrograph, an ISCO 6712 Automatic Sampler was deployed in the hut at the stream gauging station (Table 2, Figure 2). The ISCO sampler was powered by a twelve-volt, 75-amp-hour VRLA battery, separate from the solar panel and battery that were used to power other equipment at the station because they did not have enough capacity to run all of the equipment. Similar to the bubbler line, the ISCO sampler intake line was run from the hut to the stream through PVC tubing. The intake was positioned in the stream so that it was at least six inches from the streambed to avoid drawing up bed sediment, and near the stream bank to avoid catching floating debris on the intake line. The ISCO sampler clock was set on EST.

The ISCO sampler was connected to the FTS datalogger through an FTS Autosampler Interface Controller (Table 1). The FTS datalogger was then programmed with a script to trigger the ISCO sampler to begin collecting samples when a specified stage, measured by the bubbler, was reached. It was important to develop an understanding of how the stage fluctuated at each gauging station so that a trigger level could be set such that sampling was initiated during events and not due to fluctuations in the stage at baseflow. However, it was also desirable to capture a sample near the onset of an event, when the stage was beginning to rise. A compromise had to be made to minimize triggers that were due to baseflow fluctuations and maximize the portion of the hydrograph rising limb that was sampled during an event.

Table 2: Event water quality monitoring equipment installed at each stream gauging station.

Instrument Name	Instrument Type	Manufacturer
ISCO 6712 Automatic Sampler	stream water sampler	Teledyne ISCO
Autosampler Interface Controller	connection cable for Axiom H2 Datalogger to control ISCO sampler	FTS Environmental
12-V, 75-Ah valve-regulated lead acid battery	power source for ISCO sampler	(various)

The ISCO sampler was set up to collect up to 24 discrete one-litre samples at programmed intervals. The intervals could be consistent (*e.g.*, two-hour intervals between samples for all 24 samples) or variable (*e.g.*, half-hour intervals between samples 1 through 7, one-hour intervals between samples 7 through 13, and two-hour intervals between samples 13 and 24). Selecting the appropriate intervals for a gauging station required an understanding of how event hydrographs typically behaved at that station. At some stations, the stage increased rapidly and descended more slowly. In this case, events were best captured with a shorter sampling interval on the rising limb and a longer sampling interval on the falling limb. The intervals were chosen to provide a good distribution of samples on both the rising and falling limb, and to attempt to capture a sample as close to the peak stage as possible.

The FTS datalogger continuously recorded the last ISCO sample bottle to be filled, at five-minute intervals along with the stage data. (See section 2.1.1 for more information about how these data were logged and collected from the station.)

When the ISCO samples were retrieved from a gauging station, numbered caps (1 through 24) were placed on the bottles to preserve the order in which the samples were collected. The following information was recorded on a field sheet:

1) sample time for bottle 1;
2) intervals between samples;
3) any inconsistencies in the programmed sample intervals;
4) any error messages; and
5) which ISCO sample numbers were collected.

Before leaving the station, the ISCO sampler was refilled with clean and empty ISCO bottles, and was reset either to continue sampling the existing event or to trigger with an increase in stage during the next event.

Resources for sample analysis were limited, so it was not possible to analyse all of the ISCO samples from an event. Instead, a subset of samples was selected for analysis based on their relationship to the stage hydrograph. Stage data for the event were downloaded from the ONe-*key* website. Data accessed through this website are in local time, so if Daylight Savings Time was in effect, the dates and times associated with the stage data were converted to EST. The stage data were graphed with Microsoft Excel software to display the event hydrograph, and the sample dates and times recorded from the ISCO (in EST) were also plotted on the hydrograph. For events with a single peak in the hydrograph, five samples were typically chosen for analysis from different positions on the hydrograph: near the base of the rising limb, mid-way up the rising limb, near the peak, mid-way down the falling limb, and near the base of the falling limb. When events had more than one peak in the hydrograph, more samples were sometimes selected for analysis to represent the hydrograph peaks and troughs.

Each event sample that was submitted for laboratory analysis was agitated in its ISCO bottle and immediately poured into a laboratory sample bottle. The event samples were submitted primarily to the MOECC laboratory in Etobicoke, Ontario, for analysis. Some samples were submitted to the ALS Environmental laboratory in Waterloo, Ontario, or the SGS laboratory in Lakefield, Ontario. These other laboratories were used for a variety of reasons, including: 1) to avoid exceeding sample holding times by having them analyzed quickly; 2) to avoid exceeding the sample analysis allocation provided by the MOECC; or 3) to cover a portion of the cost for sample analysis in order to match funding contributions for the project from other agencies. The event samples were analyzed for the same water quality indicators as the grab samples (see section 3.1.1).

3.1.3 Maintenance

The conductivity, dissolved oxygen, and pH sensors on the YSI probe were calibrated monthly. The YSI probe and MDS were also sent every year or two to Hoskin Scientific Ltd. in Burlington, Ontario, for more in-depth maintenance, such as the replacement of sensors.

The ISCO sampler intake line was inspected each time the site was visited to maintain a downward slope in the line from the ISCO to the stream, in order to avoid contamination between samples and prevent water from freezing in the line. The ISCO sample volume was recalibrated every three to four months to ensure sufficient volumes were collected for sample analysis. Annual maintenance of the ISCO sampler involved replacing the silicone pump tubing, which wears down with use, and the controller desiccant, which protects the electronic components from damage due to moisture.

3.2 Data Storage and Processing

Water quality data that were measured by the YSI probe were uploaded from the YSI MDS to a desktop computer with EcoWatch Lite software (YSI 2013). Once the data were opened in EcoWatch Lite, they were exported as a .csv file and were transferred to an Excel file for storage. All of the water quality data from a particular sentinel watershed in a particular year were stored in a single Excel file.

After water samples had been analyzed, the laboratory e-mailed water quality data to conservation authority monitoring technicians as Portable Document Format (PDF) and .txt or Excel files. These files were stored on a desktop computer and data were transferred from the laboratory .txt or Excel file to the same Excel file in which the YSI probe data were stored.

4. Meteorological Data

Stream water quality data can vary due to different meteorological conditions. A large rainfall event may cause runoff that transports pollutants into a watercourse, which would not have occurred under dry conditions. Precipitation increases stream flow and that may affect concentrations of pollutants. Forecasted precipitation can sometimes be used as an indicator of an upcoming event for sampling. Checking the forecast and current watershed conditions daily helps to avoid missing an event.

4.1 Equipment and Data Collection

4.1.1 Meteorological Station

A meteorological station was installed within each study watershed to provide precipitation (unfrozen), wind speed, evapotranspiration, and air temperature data (Table 3). New stations were situated as centrally as possible within the watershed to attempt to collect data that were representative of the entire watershed. In some watersheds, previously established meteorological stations were used. A Davis Instruments Vantage Pro2 Integrated Sensor Suite (Table 4) was mounted on an approximately three-metre tall steel pipe that was cemented into the ground (Figure 7). The sensor suite was leveled to allow for correct operation. The station was located at least twenty metres away from any buildings and trees to avoid interference with wind and rainfall measurements. The sensors were powered by an integrated solar panel with a battery back-up (one CR123 three-volt lithium-cell battery). Data were transmitted wirelessly to a nearby Vantage Pro2 Console for logging. The console was located in a home on the property and operated on alternating current (AC) power with a battery back-up (three C-cell batteries). The console was placed away from interfering electronics and large metal surfaces, and within a 120-metre transmitting range of the sensor suite. The data were consistently logged in EST and were downloaded every two weeks by the landowner. Data files in .txt format were e-mailed to conservation authority monitoring technicians, who stored them on a desktop computer.

Table 3: Data logging intervals at meteorological stations.

Parameter	Logging Interval
air temperature	10 minutes
evapotranspiration	60 minutes
precipitation	5 minutes
wind speed	10 minutes

Table 4: Equipment installed at each meteorological station.

Instrument Name	Instrument Type	Manufacturer
Vantage Pro2 Integrated Sensor Suite (ISS)	tipping bucket rain gauge (0.2 mm per tip) temperature sensor ultraviolet light sensor wind speed and direction sensor	Davis Instruments
Vantage Pro2 Console	datalogger for Vantage Pro2 ISS	Davis Instruments
ISS Solar Panel	power source for Vantage Pro2 ISS	Davis Instruments
CR123 3-volt lithium-cell battery	back-up power source for Vantage Pro2 ISS	(various)
3 C-cell batteries	back-up power source for Vantage Pro2 Console	(various)

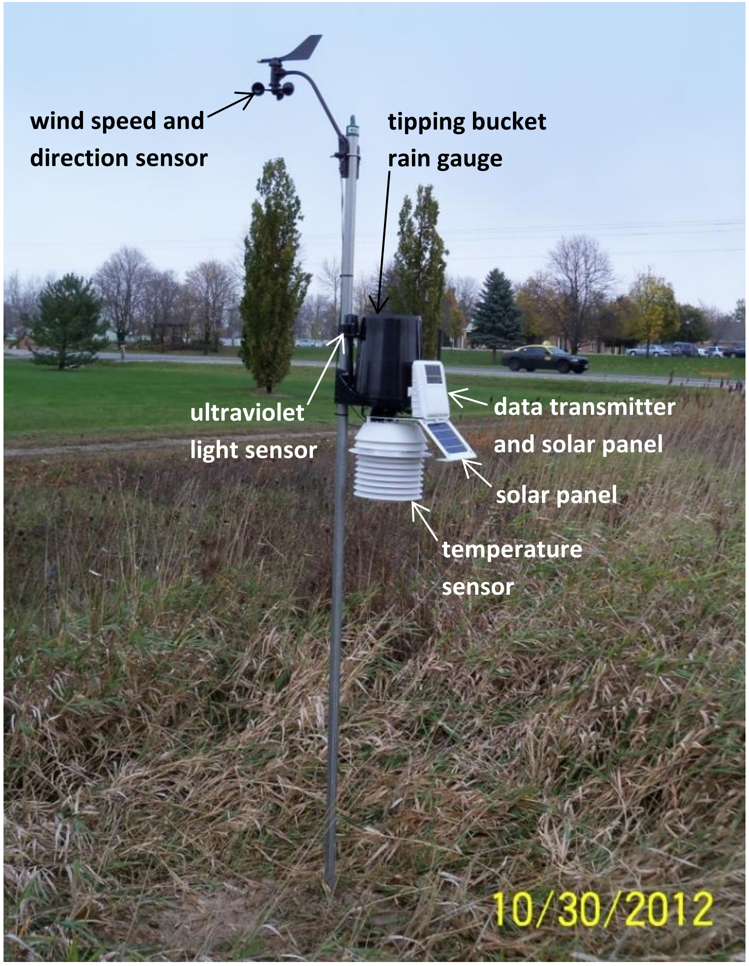

Figure 7: A meteorological station with a Davis Instruments Vantage Pro2 Integrated Sensor Suite.

4.1.2 Precipitation Station

At a stream gauging station in each study watershed, a Hydrological Services Pty Ltd TB3 tipping bucket rain gauge (0.2 mm per tip) was installed to provide unfrozen precipitation data (Figure 3). These data were logged at five-minute intervals with the FTS datalogger that was located inside the station hut. (See section 2.1.1 for more information about how the precipitation data were logged and collected from the station along with stage data.)

4.1.3 Equipment Maintenance

The meteorological and precipitation stations were inspected visually at least twice per year, typically in the spring and fall seasons. Precipitation collection buckets were removed and emptied of debris. At other times, if precipitation data were unexpectedly low, the collection buckets were checked for a blockage. Inside a collection bucket, precipitation is funneled through a small hole and deposited on a tipping mechanism. If this hole becomes blocked, precipitation pools instead of flowing through the collection system and causing a tip, which results in missed measurements. Back-up batteries inside the solar-powered Vantage Pro2 Integrated Sensor Suite and inside the AC-powered Vantage Pro2 Console were changed yearly.

4.2 Data Storage and Processing

Dates and times associated with precipitation data from the stream gauging station were shifted from GMT to EST to maintain consistency between datasets. All of the meteorological data were then stored in HEC-DSS.

Once the data were in HEC-DSS, they were graphed to identify faulty readings or unexpected data gaps. Faulty readings occurred occasionally due to a sensor or logger malfunction and were removed from the dataset. Data gaps were left blank.

5. Land Management Data

Land management data can be useful for several different reasons. For instance, the proportion of a watershed that has been planted in a particular crop can be calculated. This can provide a general understanding of the types and amounts of nutrients that might be applied to the land, if typical nutrient application practices are known for the watershed. It is also helpful to have a broad understanding of the types of tillage that are practised in a watershed, as they can influence erosion during storm events.

5.1 Equipment and Data Collection

Detailed information on land management practices for each sentinel watershed was collected through windshield surveys of agricultural land. Conservation authority monitoring technicians drove to the edge of each field and, from visual inspection, collected data on crop type, tillage type, crop row direction, crop row width, and crop residue type and percentage. As data were collected at the field edge, they were entered directly into a geodatabase using ArcGIS software (Esri 2012) on a tablet or laptop. Livestock information (*e.g.*, livestock type, manure storage type, feed storage type) was also collected, if applicable to the property, and added to the database.

Agricultural land was surveyed three times each year. An initial survey was completed in late spring to record crop, tillage, and crop residue information. The watersheds were surveyed again in late summer to note any cover crops that were planted after early harvest. A final survey was completed in the fall to collect fall tillage and crop residue data.

5.2 Data Storage and Processing

Aerial photography from the year 2010 was overlaid with the Agricultural Resource Inventory (AgRI) field layer (OMAFRA 2011) in ArcGIS to delineate individual fields throughout each watershed. Data collected from the windshield surveys were assigned to each individual field. Occasionally, the surveys revealed that portions of an individual field from the AgRI layer were planted with different crops. In this case, the field was split in the AgRI layer and a letter representing each portion of the field was added onto the AgRI field identification code (*e.g.*, E for the east portion of the field and W for the west portion).

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